EUROPA LEHRMITTEL




# Mechanical and Metal Trades Handbook




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for the Metalworking Trades

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# Mechanical and Metal Trades Handbook

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The content of the chapter "Program structure of CNC machines according to PAL" (page 386 to 400) complies with the publications of the PAL Prüfungs- und Lehrmittelentwicklungsstelle (Institute for the development of training and testing material) of the IHK Region Stuttgart (Chamber of Commerce and Industry of the Stuttgart region).

English edition: Mechanical and Metal Trades Handbook
2nd edition, 2010

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All printings of this edition may be used concurrently in the classroom since they are unchanged, except for some corrections to typographical errors and slight changes in standards.

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# Preface

The Mechanical and Metal Trades Handbook is well-suited for shop reference, tooling, machine building, maintenance and as a general book of knowledge. It is also useful for educational purposes, especially in practical work or curricula and continuing education programs.

**Target Groups**

- Industrial and trade mechanics
- Tool & Die makers
- Machinists
- Millwrights
- Draftspersons
- Technical Instructors
- Apprentices in above trade areas
- Practitioners in trades and industry
- Mechanical Engineering students

**Notes for the user**

The contents of this book include tables and formulae in eight chapters, including Tables of Contents, Subject Index and Standards Index.

The **tables** contain the most important guidelines, designs, types, dimensions and standard values for their subject areas.

Units are not specified in the legends for the **formulae** if several units are possible. However, the calculation examples for each formula use those units normally applied in practice.

**Designation examples**, which are included for all standard parts, materials and drawing designations, are highlighted by a red arrow (⇒).

The **Table of Contents** in the front of the book is expanded further at the beginning of each chapter in form of a partial Table of Contents.

The **Subject Index** at the end of the book (pages 417–428) is extensive.

The **Standards Index** (pages 407–416) lists all the current standards and regulations cited in the book. In many cases previous standards are also listed to ease the transition from older, more familiar standards to new ones.

We have thoroughly revised the **2nd edition** of the "Mechanical and Metal Trades Handbook" in line with the 44th edition of the German version "Tabellenbuch Metall". The section dealing with PAL programming of CNC machine tools was updated (to the state of 2008) and considerably enhanced.

Special thanks to the **Magna Technical Training Centre** for their input into the English translation of this book. Their assistance has been extremely valuable.

The authors and the publisher will be grateful for any suggestions and constructive comments.

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# Standards and other Regulations

## Standardization and Standards terms

Standardization is the systematic achievement of uniformity of material and non-material objects, such as components, calculation methods, process flows and services for the benefit of the general public.

| Standards term | Example | Explanation |
|---|---|---|
| Standard | DIN 7157 | A standard is the published result of standardization, e.g. the selection of certain fits in DIN 7157. |
| Part | DIN 30910-2 | The part of a standard associated with other parts with the same main number. DIN 30910-2 for example describes sintered materials for filters, while Part 3 and 4 describe sintered materials for bearings and formed parts. |
| Supplement | DIN 743 Suppl. 1 | A supplement contains information for a standard, however no additional specifications. The supplement DIN 743 Suppl. 1, for example, contains application examples of load capacity calculations for shafts and axles described in DIN 743. |
| Draft | E DIN 6316 (2007-02) | A draft standard contains the preliminary finished results of a standardization; this version of the intended standard is made available to the public for comments. For example, the planned new version of DIN 6316 for goose-neck clamps has been available to the public since February 2007 as Draft E DIN 6316. |
| Preliminary standard | DIN V 66304 (1991-12) | A preliminary standard contains the results of standardization which are not released by DIN as a standard, because of certain provisos. DIN V 66304, for example, discusses a format for exchange of standard part data for computer-aided design. |
| Issue date | DIN 76-1 (2004-06) | Date of publication which is made public in the DIN publication guide; this is the date at which time the standard becomes valid. DIN 76-1, which sets undercuts for metric ISO threads has been valid since June 2004 for example. |

## Types of Standards and Regulations (selection)

| Type | Abbreviation | Explanation | Purpose and contents |
|---|---|---|---|
| International Standards (ISO standards) | ISO | International Organization for Standardization, Geneva (O and S are reversed in the abbreviation) | Simplifies the international exchange of goods and services, as well as cooperation in scientific, technical and economic areas. |
| European Standards (EN standards) | EN | European Committee for Standardization (Comité Européen de Normalisation), Brussels | Technical harmonization and the associated reduction of trade barriers for the advancement of the European market and the coalescence of Europe. |
| German Standards (DIN standards) | DIN | Deutsches Institut für Normung e.V., Berlin (German Institute for Standardization) | National standardization facilitates rationalization, quality assurance, environmental protection and common understanding in economics, technology, science, management and public relations. |
| | DIN EN | European standard for which the German version has attained the status of a German standard. | |
| | DIN ISO | German standard for which an international standard has been adopted without change. | |
| | DIN EN ISO | European standard for which an international standard has been adopted unchanged and the German version has the status of a German standard. | |
| | DIN VDE | Printed publication of the VDE, which has the status of a German standard. | |
| VDI Guidelines | VDI | Verein Deutscher Ingenieure e.V., Düsseldorf (Society of German Engineers) | These guidelines give an account of the current state of the art in specific subject areas and contain, for example, concrete procedural guidelines for the performing calculations or designing processes in mechanical or electrical engineering. |
| VDE printed publications | VDE | Verband Deutscher Elektrotechniker e.V., Frankfurt (Organization of German Electrical Engineers) | |
| DGQ publications | DGQ | Deutsche Gesellschaft für Qualität e.V., Frankfurt (German Association for Quality) | Recommendations in the area of quality technology. |
| REFA sheets | REFA | Association for Work Design/Work Structure, Industrial Organization and Corporate Development REFA e.V., Darmstadt | Recommendations in the area of production and work planning. |

# 1 Mathematics

| $d$ | $\sqrt{d}$ | $A = \frac{\pi \cdot d^2}{4}$ |
|---|---|---|
| 1 | 1.0000 | 0.7854 |
| 2 | 1.4142 | 3.1416 |
| 3 | 1.7321 | 7.0686 |


**1.1 Numerical tables**
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| | | |
|---|---|---|
| sine | = | opposite side / hypotenuse |
| cosine | = | adjacent side / hypotenuse |
| tangent | = | opposite side / adjacent side |
| cotangent | = | adjacent side / opposite side |


**1.2 Trigonometric Functions**
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$$\frac{3}{x} + \frac{5}{x} = \frac{1}{x} \cdot (3+5)$$


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$$1\ \text{kW} \cdot \text{h} = 3.6 \cdot 10^6\ \text{W} \cdot \text{s}$$


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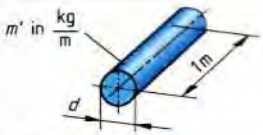


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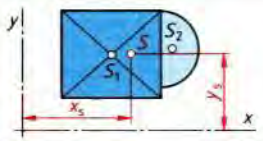


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# Square root, Area of a circle

| $d$ | $\sqrt{d}$ | $A=\frac{\pi \cdot d^2}{4}$ | $d$ | $\sqrt{d}$ | $A=\frac{\pi \cdot d^2}{4}$ | $d$ | $\sqrt{d}$ | $A=\frac{\pi \cdot d^2}{4}$ | $d$ | $\sqrt{d}$ | $A=\frac{\pi \cdot d^2}{4}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1.0000 | 0.7854 | 51 | 7.1414 | 2042.82 | 101 | 10.049 9 | 8011.85 | 151 | 12.2882 | 17907.9 |
| 2 | 1.4142 | 3.1416 | 52 | 7.2111 | 2123.72 | 102 | 10.0995 | 8171.28 | 152 | 12.3288 | 18145.8 |
| 3 | 1.7321 | 7.0686 | 53 | 7.2801 | 2206.18 | 103 | 10.1489 | 8332.29 | 153 | 12.3693 | 18385.4 |
| 4 | 2.0000 | 12.5664 | 54 | 7.3485 | 2290.22 | 104 | 10.1980 | 8494.87 | 154 | 12.4097 | 18626.5 |
| 5 | 2.236 1 | 19.6350 | 55 | 7.4162 | 2375.83 | 105 | 10.2470 | 8659.01 | 155 | 12.4499 | 18869.2 |
| 6 | 2.4495 | 28.2743 | 56 | 7.4833 | 2463.01 | 106 | 10.2956 | 8824.73 | 156 | 12.4900 | 19113.4 |
| 7 | 2.6458 | 38.4845 | 57 | 7.5498 | 2551.76 | 107 | 10.3441 | 8992.02 | 157 | 12.5300 | 19359.3 |
| 8 | 2.8284 | 50.2655 | 58 | 7.6158 | 2642.08 | 108 | 10.3923 | 9160.88 | 158 | 12.5698 | 19606.7 |
| 9 | 3.0000 | 63.6173 | 59 | 7.6811 | 2733.97 | 109 | 10.4403 | 9331.32 | 159 | 12.6095 | 19855.7 |
| **10** | 3.1623 | 78.5398 | **60** | 7.7460 | 2827.43 | **110** | 10.4881 | 9503.32 | **160** | 12.6491 | 20106.2 |
| 11 | 3.3166 | 95.0332 | 61 | 7.8102 | 2922.47 | 111 | 10.5357 | 9676.89 | 161 | 12.6886 | 20358.3 |
| 12 | 3.4641 | 113.097 | 62 | 7.8740 | 3019.07 | 112 | 10.5830 | 9852.03 | 162 | 12.7279 | 20612.0 |
| 13 | 3.6056 | 132.732 | 63 | 7.9373 | 3117.25 | 113 | 10.6301 | 10028.7 | 163 | 12.7671 | 20867.2 |
| 14 | 3.7417 | 153.938 | 64 | 8.0000 | 3216.99 | 114 | 10.6771 | 10207.0 | 164 | 12.8062 | 21124.1 |
| 15 | 3.8730 | 176.715 | 65 | 8.0623 | 3318.31 | 115 | 10.7238 | 10386.9 | 165 | 12.8452 | 21382.5 |
| 16 | 4.0000 | 201.062 | 66 | 8.1240 | 3421.19 | 116 | 10.7703 | 10568.3 | 166 | 12.8841 | 21642.4 |
| 17 | 4.1231 | 226.980 | 67 | 8.1854 | 3525.65 | 117 | 10.8167 | 10751.3 | 167 | 12.9228 | 21904.0 |
| 18 | 4.2426 | 254.469 | 68 | 8.2462 | 3631.68 | 118 | 10.8628 | 10935.9 | 168 | 12.9615 | 22167.1 |
| 19 | 4.3589 | 283.529 | 69 | 8.3066 | 3739.28 | 119 | 10.9087 | 11122.0 | 169 | 13.0000 | 22431.8 |
| **20** | 4.4721 | 314.159 | **70** | 8.3666 | 3848.45 | **120** | 10.9545 | 11309.7 | **170** | 13.0384 | 22698.0 |
| 21 | 4.5826 | 346.361 | 71 | 8.4261 | 3959.19 | 121 | 11.0000 | 11499.0 | 171 | 13.0767 | 22965.8 |
| 22 | 4.6904 | 380.133 | 72 | 8.4853 | 4071.50 | 122 | 11.0454 | 11689.9 | 172 | 13.1149 | 23235.2 |
| 23 | 4.7958 | 415.476 | 73 | 8.5440 | 4185.39 | 123 | 11.0905 | 11882.3 | 173 | 13.1529 | 23506.2 |
| 24 | 4.8990 | 452.389 | 74 | 8.6023 | 4300.84 | 124 | 11.1355 | 12076.3 | 174 | 13.1909 | 23778.7 |
| 25 | 5.0000 | 490.874 | 75 | 8.6603 | 4417.86 | 125 | 11.1803 | 12271.8 | 175 | 13.2288 | 24052.8 |
| 26 | 5.0990 | 530.929 | 76 | 8.7178 | 4536.46 | 126 | 11.2250 | 12469.0 | 176 | 13.2665 | 24328.5 |
| 27 | 5.1962 | 572.555 | 77 | 8.7750 | 4656.63 | 127 | 11.2694 | 12667.7 | 177 | 13.3041 | 24605.7 |
| 28 | 5.2915 | 615.752 | 78 | 8.8318 | 4778.36 | 128 | 11.3137 | 12868.0 | 178 | 13.3417 | 24884.6 |
| 29 | 5.3852 | 660.520 | 79 | 8.8882 | 4901.67 | 129 | 11.3578 | 13069.8 | 179 | 13.3791 | 25164.9 |
| **30** | 5.4772 | 706.858 | **80** | 8.9443 | 5026.55 | **130** | 11.4018 | 13273.2 | **180** | 13.4164 | 25446.9 |
| 31 | 5.5678 | 754.768 | 81 | 9.0000 | 5153.00 | 131 | 11.4455 | 13478.2 | 181 | 13.4536 | 25730.4 |
| 32 | 5.6569 | 804.248 | 82 | 9.0554 | 5281.02 | 132 | 11.4891 | 13684.8 | 182 | 13.4907 | 26015.5 |
| 33 | 5.7446 | 855.299 | 83 | 9.1104 | 5410.61 | 133 | 11.5326 | 13892.9 | 183 | 13.5277 | 26302.2 |
| 34 | 5.8310 | 907.920 | 84 | 9.1652 | 5541.77 | 134 | 11.5758 | 14102.6 | 184 | 13.5647 | 26590.4 |
| 35 | 5.9161 | 962.113 | 85 | 9.2195 | 5674.50 | 135 | 11.6190 | 14313.9 | 185 | 13.6015 | 26880.3 |
| 36 | 6.0000 | 1017.88 | 86 | 9.2736 | 5808.80 | 136 | 11.6619 | 14526.7 | 186 | 13.6382 | 27171.6 |
| 37 | 6.0828 | 1075.21 | 87 | 9.3274 | 5944.68 | 137 | 11.7047 | 14741.1 | 187 | 13.6748 | 27464.6 |
| 38 | 6.1644 | 1134.11 | 88 | 9.3808 | 6082.12 | 138 | 11.7473 | 14957.1 | 188 | 13.7113 | 27759.1 |
| 39 | 6.2450 | 1194.59 | 89 | 9.4340 | 6221.14 | 139 | 11.7898 | 15174.7 | 189 | 13.7477 | 28055.2 |
| **40** | 6.3246 | 1256.64 | **90** | 9.4868 | 6361.73 | **140** | 11.8322 | 15393.8 | **190** | 13.7840 | 28352.9 |
| 41 | 6.4031 | 1320.25 | 91 | 9.5394 | 6503.88 | 141 | 11.8743 | 15614.5 | 191 | 13.8203 | 28652.1 |
| 42 | 6.4807 | 1385.44 | 92 | 9.5917 | 6647.61 | 142 | 11.9164 | 15836.8 | 192 | 13.8564 | 28952.9 |
| 43 | 6.5574 | 1452.20 | 93 | 9.6437 | 6792.91 | 143 | 11.9583 | 16060.6 | 193 | 13.8924 | 29255.3 |
| 44 | 6.6332 | 1520.53 | 94 | 9.6954 | 6939.78 | 144 | 12.0000 | 16286.0 | 194 | 13.9284 | 29559.2 |
| 45 | 6.7082 | 1590.43 | 95 | 9.7468 | 7088.22 | 145 | 12.0416 | 16513.0 | 195 | 13.9642 | 29864.8 |
| 46 | 6.7823 | 1661.90 | 96 | 9.7980 | 7238.23 | 146 | 12.0830 | 16741.5 | 196 | 14.0000 | 30171.9 |
| 47 | 6.8557 | 1734.94 | 97 | 9.8489 | 7389.81 | 147 | 12.1244 | 16971.7 | 197 | 14.0357 | 30480.5 |
| 48 | 6.9282 | 1809.56 | 98 | 9.8995 | 7542.96 | 148 | 12.1655 | 17203.4 | 198 | 14.0712 | 30790.7 |
| 49 | 7.0000 | 1885.74 | 99 | 9.9499 | 7697.69 | 149 | 12.2066 | 17436.6 | 199 | 14.1067 | 31102.6 |
| **50** | 7.0711 | 1963.50 | **100** | 10.0000 | 7853.98 | **150** | 12.2474 | 17671.5 | **200** | 14.1421 | 31415.9 |

Table values of $\sqrt{d}$ and A are rounded off.

# Values of Sine and Cosine Trigonometric Functions

| degrees | sine 0° to 45° — minutes 0′ | 15′ | 30′ | 45′ | 60′ | | degrees | sine 45° to 90° — minutes 0′ | 15′ | 30′ | 45′ | 60′ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **0°** | 0.0000 | 0.0044 | 0.0087 | 0.0131 | 0.0175 | 89° | 45° | 0.7071 | 0.7102 | 0.7133 | 0.7163 | 0.7193 | 44° |
| 1° | 0.0175 | 0.0218 | 0.0262 | 0.0305 | 0.0349 | 88° | 46° | 0.7193 | 0.7224 | 0.7254 | 0.7284 | 0.7314 | 43° |
| 2° | 0.0349 | 0.0393 | 0.0436 | 0.0480 | 0.0523 | 87° | 47° | 0.7314 | 0.7343 | 0.7373 | 0.7402 | 0.7431 | 42° |
| 3° | 0.0523 | 0.0567 | 0.0610 | 0.0654 | 0.0698 | 86° | 48° | 0.7431 | 0.7461 | 0.7490 | 0.7518 | 0.7547 | 41° |
| 4° | 0.0698 | 0.0741 | 0.0785 | 0.0828 | 0.0872 | 85° | 49° | 0.7547 | 0.7576 | 0.7604 | 0.7632 | 0.7660 | **40°** |
| 5° | 0.0872 | 0.0915 | 0.0958 | 0.1002 | 0.1045 | 84° | **50°** | 0.7660 | 0.7688 | 0.7716 | 0.7744 | 0.7771 | 39° |
| 6° | 0.1045 | 0.1089 | 0.1132 | 0.1175 | 0.1219 | 83° | 51° | 0.7771 | 0.7799 | 0.7826 | 0.7853 | 0.7880 | 38° |
| 7° | 0.1219 | 0.1262 | 0.1305 | 0.1349 | 0.1392 | 82° | 52° | 0.7880 | 0.7907 | 0.7934 | 0.7960 | 0.7986 | 37° |
| 8° | 0.1392 | 0.1435 | 0.1478 | 0.1521 | 0.1564 | 81° | 53° | 0.7986 | 0.8013 | 0.8039 | 0.8064 | 0.8090 | 36° |
| 9° | 0.1564 | 0.1607 | 0.1650 | 0.1693 | 0.1736 | **80°** | 54° | 0.8090 | 0.8116 | 0.8141 | 0.8166 | 0.8192 | 35° |
| **10°** | 0.1736 | 0.1779 | 0.1822 | 0.1865 | 0.1908 | 79° | 55° | 0.8192 | 0.8216 | 0.8241 | 0.8266 | 0.8290 | 34° |
| 11° | 0.1908 | 0.1951 | 0.1994 | 0.2036 | 0.2079 | 78° | 56° | 0.8290 | 0.8315 | 0.8339 | 0.8363 | 0.8387 | 33° |
| 12° | 0.2079 | 0.2122 | 0.2164 | 0.2207 | 0.2250 | 77° | 57° | 0.8387 | 0.8410 | 0.8434 | 0.8457 | 0.8480 | 32° |
| 13° | 0.2250 | 0.2292 | 0.2334 | 0.2377 | 0.2419 | 76° | 58° | 0.8480 | 0.8504 | 0.8526 | 0.8549 | 0.8572 | 31° |
| 14° | 0.2419 | 0.2462 | 0.2504 | 0.2546 | 0.2588 | 75° | 59° | 0.8572 | 0.8594 | 0.8616 | 0.8638 | 0.8660 | **30°** |
| 15° | 0.2588 | 0.2630 | 0.2672 | 0.2714 | 0.2756 | 74° | **60°** | 0.8660 | 0.8682 | 0.8704 | 0.8725 | 0.8746 | 29° |
| 16° | 0.2756 | 0.2798 | 0.2840 | 0.2882 | 0.2924 | 73° | 61° | 0.8746 | 0.8767 | 0.8788 | 0.8809 | 0.8829 | 28° |
| 17° | 0.2924 | 0.2965 | 0.3007 | 0.3049 | 0.3090 | 72° | 62° | 0.8829 | 0.8850 | 0.8870 | 0.8890 | 0.8910 | 27° |
| 18° | 0.3090 | 0.3132 | 0.3173 | 0.3214 | 0.3256 | 71° | 63° | 0.8910 | 0.8930 | 0.8949 | 0.8969 | 0.8988 | 26° |
| 19° | 0.3256 | 0.3297 | 0.3338 | 0.3379 | 0.3420 | **70°** | 64° | 0.8988 | 0.9007 | 0.9026 | 0.9045 | 0.9063 | 25° |
| **20°** | 0.3420 | 0.3461 | 0.3502 | 0.3543 | 0.3584 | 69° | 65° | 0.9063 | 0.9081 | 0.9100 | 0.9118 | 0.9135 | 24° |
| 21° | 0.3584 | 0.3624 | 0.3665 | 0.3706 | 0.3746 | 68° | 66° | 0.9135 | 0.9153 | 0.9171 | 0.9188 | 0.9205 | 23° |
| 22° | 0.3746 | 0.3786 | 0.3827 | 0.3867 | 0.3907 | 67° | 67° | 0.9205 | 0.9222 | 0.9239 | 0.9255 | 0.9272 | 22° |
| 23° | 0.3907 | 0.3947 | 0.3987 | 0.4027 | 0.4067 | 66° | 68° | 0.9272 | 0.9288 | 0.9304 | 0.9320 | 0.9336 | 21° |
| 24° | 0.4067 | 0.4107 | 0.4147 | 0.4187 | 0.4226 | 65° | 69° | 0.9336 | 0.9351 | 0.9367 | 0.9382 | 0.9397 | **20°** |
| 25° | 0.4226 | 0.4266 | 0.4305 | 0.4344 | 0.4384 | 64° | **70°** | 0.9397 | 0.9412 | 0.9426 | 0.9441 | 0.9455 | 19° |
| 26° | 0.4384 | 0.4423 | 0.4462 | 0.4501 | 0.4540 | 63° | 71° | 0.9455 | 0.9469 | 0.9483 | 0.9497 | 0.9511 | 18° |
| 27° | 0.4540 | 0.4579 | 0.4617 | 0.4656 | 0.4695 | 62° | 72° | 0.9511 | 0.9524 | 0.9537 | 0.9550 | 0.9563 | 17° |
| 28° | 0.4695 | 0.4733 | 0.4772 | 0.4810 | 0.4848 | 61° | 73° | 0.9563 | 0.9576 | 0.9588 | 0.9600 | 0.9613 | 16° |
| 29° | 0.4848 | 0.4886 | 0.4924 | 0.4962 | 0.5000 | **60°** | 74° | 0.9613 | 0.9625 | 0.9636 | 0.9648 | 0.9659 | 15° |
| **30°** | 0.5000 | 0.5038 | 0.5075 | 0.5113 | 0.5150 | 59° | 75° | 0.9659 | 0.9670 | 0.9681 | 0.9692 | 0.9703 | 14° |
| 31° | 0.5150 | 0.5188 | 0.5225 | 0.5262 | 0.5299 | 58° | 76° | 0.9703 | 0.9713 | 0.9724 | 0.9734 | 0.9744 | 13° |
| 32° | 0.5299 | 0.5336 | 0.5373 | 0.5410 | 0.5446 | 57° | 77° | 0.9744 | 0.9753 | 0.9763 | 0.9772 | 0.9781 | 12° |
| 33° | 0.5446 | 0.5483 | 0.5519 | 0.5556 | 0.5592 | 56° | 78° | 0.9781 | 0.9790 | 0.9799 | 0.9808 | 0.9816 | 11° |
| 34° | 0.5592 | 0.5628 | 0.5664 | 0.5700 | 0.5736 | 55° | 79° | 0.9816 | 0.9825 | 0.9833 | 0.9840 | 0.9848 | **10°** |
| 35° | 0.5736 | 0.5771 | 0.5807 | 0.5842 | 0.5878 | 54° | **80°** | 0.9848 | 0.9856 | 0.9863 | 0.9870 | 0.9877 | 9° |
| 36° | 0.5878 | 0.5913 | 0.5948 | 0.5983 | 0.6018 | 53° | 81° | 0.9877 | 0.9884 | 0.9890 | 0.9897 | 0.9903 | 8° |
| 37° | 0.6018 | 0.6053 | 0.6088 | 0.6122 | 0.6157 | 52° | 82° | 0.9903 | 0.9909 | 0.9914 | 0.9920 | 0.9925 | 7° |
| 38° | 0.6157 | 0.6191 | 0.6225 | 0.6259 | 0.6293 | 51° | 83° | 0.9925 | 0.9931 | 0.9936 | 0.9941 | 0.9945 | 6° |
| 39° | 0.6293 | 0.6327 | 0.6361 | 0.6394 | 0.6428 | **50°** | 84° | 0.9945 | 0.9950 | 0.9954 | 0.9958 | 0.9962 | 5° |
| **40°** | 0.6428 | 0.6461 | 0.6494 | 0.6528 | 0.6561 | 49° | 85° | 0.9962 | 0.9966 | 0.9969 | 0.9973 | 0.9976 | 4° |
| 41° | 0.6561 | 0.6593 | 0.6626 | 0.6659 | 0.6691 | 48° | 86° | 0.9976 | 0.9979 | 0.9981 | 0.9984 | 0.9986 | 3° |
| 42° | 0.6691 | 0.6724 | 0.6756 | 0.6788 | 0.6820 | 47° | 87° | 0.9986 | 0.9988 | 0.9990 | 0.9992 | 0.9994 | 2° |
| 43° | 0.6820 | 0.6852 | 0.6884 | 0.6915 | 0.6947 | 46° | 88° | 0.9994 | 0.9995 | 0.9997 | 0.9998 | 0.99985 | 1° |
| 44° | 0.6947 | 0.6978 | 0.7009 | 0.7040 | 0.7071 | 45° | 89° | 0.99985 | 0.99991 | 0.99996 | 0.99999 | 1.0000 | **0°** |
| | 60′ | 45′ | 30′ | 15′ | 0′ | ↑ degrees | | 60′ | 45′ | 30′ | 15′ | 0′ | ↑ degrees |
| | minutes — **cosine 45° to 90°** | | | | | | | minutes — **cosine 0° to 45°** | | | | | |

Table values of the trigonometric functions are rounded off to four decimal places.

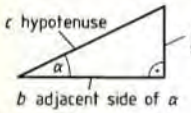
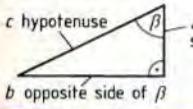
# Values of Tangent and Cotangent Trigonometric Functions

| degrees | tangent 0° to 45° — minutes | | | | | | degrees | tangent 45° to 90° — minutes | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ↓ | 0′ | 15′ | 30′ | 45′ | 60′ | | ↓ | 0′ | 15′ | 30′ | 45′ | 60′ | |
| **0°** | 0.0000 | 0.0044 | 0.0087 | 0.0131 | 0.0175 | 89° | 45° | 1.0000 | 1.0088 | 1.0176 | 1.0265 | 1.0355 | 44° |
| 1° | 0.0175 | 0.0218 | 0.0262 | 0.0306 | 0.0349 | 88° | 46° | 1.0355 | 1.0446 | 1.0538 | 1.0630 | 1.0724 | 43° |
| 2° | 0.0349 | 0.0393 | 0.0437 | 0.0480 | 0.0524 | 87° | 47° | 1.0724 | 1.0818 | 1.0913 | 1.1009 | 1.1106 | 42° |
| 3° | 0.0524 | 0.0568 | 0.0612 | 0.0655 | 0.0699 | 86° | 48° | 1.1106 | 1.1204 | 1.1303 | 1.1403 | 1.1504 | 41° |
| 4° | 0.0699 | 0.0743 | 0.0787 | 0.0831 | 0.0875 | 85° | 49° | 1.1504 | 1.1606 | 1.1708 | 1.1812 | 1.1918 | **40°** |
| 5° | 0.0875 | 0.0919 | 0.0963 | 0.1007 | 0.1051 | 84° | **50°** | 1.1918 | 1.2024 | 1.2131 | 1.2239 | 1.2349 | 39° |
| 6° | 0.1051 | 0.1095 | 0.1139 | 0.1184 | 0.1228 | 83° | 51° | 1.2349 | 1.2460 | 1.2572 | 1.2685 | 1.2799 | 38° |
| 7° | 0.1228 | 0.1272 | 0.1317 | 0.1361 | 0.1405 | 82° | 52° | 1.2799 | 1.2915 | 1.3032 | 1.3151 | 1.3270 | 37° |
| 8° | 0.1405 | 0.1450 | 0.1495 | 0.1539 | 0.1584 | 81° | 53° | 1.3270 | 1.3392 | 1.3514 | 1.3638 | 1.3764 | 36° |
| 9° | 0.1584 | 0.1629 | 0.1673 | 0.1718 | 0.1763 | **80°** | 54° | 1.3764 | 1.3891 | 1.4019 | 1.4150 | 1.4281 | 35° |
| **10°** | 0.1763 | 0.1808 | 0.1853 | 0.1899 | 0.1944 | 79° | 55° | 1.4281 | 1.4415 | 1.4550 | 1.4687 | 1.4826 | 34° |
| 11° | 0.1944 | 0.1989 | 0.2035 | 0.2080 | 0.2126 | 78° | 56° | 1.4826 | 1.4966 | 1.5108 | 1.5253 | 1.5399 | 33° |
| 12° | 0.2126 | 0.2171 | 0.2217 | 0.2263 | 0.2309 | 77° | 57° | 1.5399 | 1.5547 | 1.5697 | 1.5849 | 1.6003 | 32° |
| 13° | 0.2309 | 0.2355 | 0.2401 | 0.2447 | 0.2493 | 76° | 58° | 1.6003 | 1.6160 | 1.6319 | 1.6479 | 1.6643 | 31° |
| 14° | 0.2493 | 0.2540 | 0.2586 | 0.2633 | 0.2679 | 75° | 59° | 1.6643 | 1.6808 | 1.6977 | 1.7147 | 1.7321 | **30°** |
| 15° | 0.2679 | 0.2726 | 0.2773 | 0.2820 | 0.2867 | 74° | **60°** | 1.7321 | 1.7496 | 1.7675 | 1.7856 | 1.8040 | 29° |
| 16° | 0.2867 | 0.2915 | 0.2962 | 0.3010 | 0.3057 | 73° | 61° | 1.8040 | 1.8228 | 1.8418 | 1.8611 | 1.8807 | 28° |
| 17° | 0.3057 | 0.3105 | 0.3153 | 0.3201 | 0.3249 | 72° | 62° | 1.8807 | 1.9007 | 1.9210 | 1.9416 | 1.9626 | 27° |
| 18° | 0.3249 | 0.3298 | 0.3346 | 0.3395 | 0.3443 | 71° | 63° | 1.9626 | 1.9840 | 2.0057 | 2.0278 | 2.0503 | 26° |
| 19° | 0.3443 | 0.3492 | 0.3541 | 0.3590 | 0.3640 | **70°** | 64° | 2.0503 | 2.0732 | 2.0965 | 2.1203 | 2.1445 | 25° |
| **20°** | 0.3640 | 0.3689 | 0.3739 | 0.3789 | 0.3839 | 69° | 65° | 2.1445 | 2.1692 | 2.1943 | 2.2199 | 2.2460 | 24° |
| 21° | 0.3839 | 0.3889 | 0.3939 | 0.3990 | 0.4040 | 68° | 66° | 2.2460 | 2.2727 | 2.2998 | 2.3276 | 2.3559 | 23° |
| 22° | 0.4040 | 0.4091 | 0.4142 | 0.4193 | 0.4245 | 67° | 67° | 2.3559 | 2.3847 | 2.4142 | 2.4443 | 2.4751 | 22° |
| 23° | 0.4245 | 0.4296 | 0.4348 | 0.4400 | 0.4452 | 66° | 68° | 2.4751 | 2.5065 | 2.5386 | 2.5715 | 2.6051 | 21° |
| 24° | 0.4452 | 0.4505 | 0.4557 | 0.4610 | 0.4663 | 65° | 69° | 2.6051 | 2.6395 | 2.6746 | 2.7106 | 2.7475 | **20°** |
| 25° | 0.4663 | 0.4716 | 0.4770 | 0.4823 | 0.4877 | 64° | **70°** | 2.7475 | 2.7852 | 2.8239 | 2.8636 | 2.9042 | 19° |
| 26° | 0.4877 | 0.4931 | 0.4986 | 0.5040 | 0.5095 | 63° | 71° | 2.9042 | 2.9459 | 2.9887 | 3.0326 | 3.0777 | 18° |
| 27° | 0.5095 | 0.5150 | 0.5206 | 0.5261 | 0.5317 | 62° | 72° | 3.0777 | 3.1240 | 3.1716 | 3.2205 | 3.2709 | 17° |
| 28° | 0.5317 | 0.5373 | 0.5430 | 0.5486 | 0.5543 | 61° | 73° | 3.2709 | 3.3226 | 3.3759 | 3.4308 | 3.4874 | 16° |
| 29° | 0.5543 | 0.5600 | 0.5658 | 0.5715 | 0.5774 | **60°** | 74° | 3.4874 | 3.5457 | 3.6059 | 3.6680 | 3.7321 | 15° |
| **30°** | 0.5774 | 0.5832 | 0.5890 | 0.5949 | 0.6009 | 59° | 75° | 3.7321 | 3.7983 | 3.8667 | 3.9375 | 4.0108 | 14° |
| 31° | 0.6009 | 0.6068 | 0.6128 | 0.6188 | 0.6249 | 58° | 76° | 4.0108 | 4.0876 | 4.1653 | 4.2468 | 4.3315 | 13° |
| 32° | 0.6249 | 0.6310 | 0.6371 | 0.6432 | 0.6494 | 57° | 77° | 4.3315 | 4.4194 | 4.5107 | 4.6057 | 4.7046 | 12° |
| 33° | 0.6494 | 0.6556 | 0.6619 | 0.6682 | 0.6745 | 56° | 78° | 4.7046 | 4.8077 | 4.9152 | 5.0273 | 5.1446 | 11° |
| 34° | 0.6745 | 0.6809 | 0.6873 | 0.6937 | 0.7002 | 55° | 79° | 5.1446 | 5.2672 | 5.3955 | 5.5301 | 5.6713 | **10°** |
| 35° | 0.7002 | 0.7067 | 0.7133 | 0.7199 | 0.7265 | 54° | **80°** | 5.6713 | 5.8197 | 5.9758 | 6.1402 | 6.3138 | 9° |
| 36° | 0.7265 | 0.7332 | 0.7400 | 0.7467 | 0.7536 | 53° | 81° | 6.3138 | 6.4971 | 6.6912 | 6.8969 | 7.1154 | 8° |
| 37° | 0.7536 | 0.7604 | 0.7673 | 0.7743 | 0.7813 | 52° | 82° | 7.1154 | 7.3479 | 7.5958 | 7.8606 | 8.1443 | 7° |
| 38° | 0.7813 | 0.7883 | 0.7954 | 0.8026 | 0.8098 | 51° | 83° | 8.1443 | 8.4490 | 8.7769 | 9.1309 | 9.5144 | 6° |
| 39° | 0.8098 | 0.8170 | 0.8243 | 0.8317 | 0.8391 | **50°** | 84° | 9.5144 | 9.9310 | 10.3854 | 10.8829 | 11.4301 | 5° |
| **40°** | 0.8391 | 0.8466 | 0.8541 | 0.8617 | 0.8693 | 49° | 85° | 11.4301 | 12.0346 | 12.7062 | 13.4566 | 14.3007 | 4° |
| 41° | 0.8693 | 0.8770 | 0.8847 | 0.8925 | 0.9004 | 48° | 86° | 14.3007 | 15.2571 | 16.3499 | 17.6106 | 19.0811 | 3° |
| 42° | 0.9004 | 0.9083 | 0.9163 | 0.9244 | 0.9325 | 47° | 87° | 19.0811 | 20.8188 | 22.9038 | 25.4517 | 28.6363 | 2° |
| 43° | 0.9325 | 0.9407 | 0.9490 | 0.9573 | 0.9657 | 46° | 88° | 28.6363 | 32.7303 | 38.1885 | 45.8294 | 57.2900 | 1° |
| 44° | 0.9657 | 0.9742 | 0.9827 | 0.9913 | 1.0000 | 45° | 89° | 57.2900 | 76.3900 | 114.5887 | 229.1817 | ∞ | **0°** |
| | 60′ | 45′ | 30′ | 15′ | 0′ | ↑ | | 60′ | 45′ | 30′ | 15′ | 0′ | ↑ |
| | ← minutes — **cotangent 45° to 90°** | | | | | degrees | | ← minutes — **cotangent 0° to 45°** | | | | | degrees |

Table values of the trigonometric functions are rounded off to four decimal places.

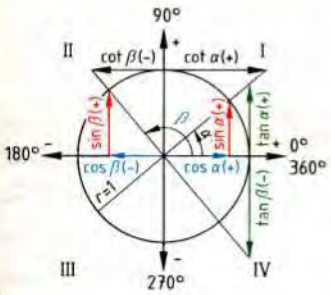
# Trigonometric functions of right triangles

## Definitions

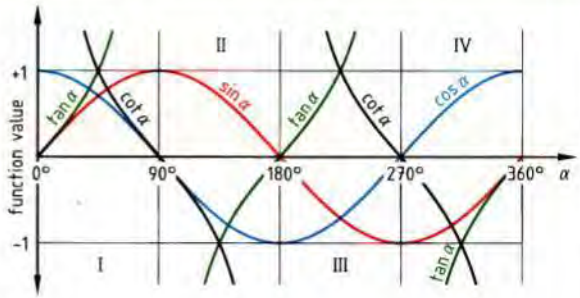
| Designations in a right triangle | Definitions of the ratios of the sides | Application for $\sphericalangle \alpha$ | Application for $\sphericalangle \beta$ |
|---|---|---|---|
|  | sine = opposite side / hypotenuse | $\sin\alpha = \frac{a}{c}$ | $\sin\beta = \frac{b}{c}$ |
| | cosine = adjacent side / hypotenuse | $\cos\alpha = \frac{b}{c}$ | $\cos\beta = \frac{a}{c}$ |
|  | tangent = opposite side / adjacent side | $\tan\alpha = \frac{a}{b}$ | $\tan\beta = \frac{b}{a}$ |
| | cotangent = adjacent side / opposite side | $\cot\alpha = \frac{b}{a}$ | $\cot\beta = \frac{a}{b}$ |

## Graph of the trigonometric functions between 0° and 360°

Representation on a unit circle




Graph of the trigonometric functions




The values of the trigonometric functions of angles > 90° can be derived from the values of the angles between 0° and 90° and then read from the tables (pages 11 and 12). Refer to the graphed curves of the trigonometric functions for the correct sign. Calculators with trigonometric functions display both the value and sign for the desired angle.

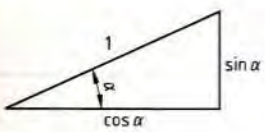
**Example:** Relationships for Quadrant II

| Relationships | Example: Function values for the angle 120° ($\alpha$ = 30° in the formulae) | |
|---|---|---|
| $\sin(90° + \alpha) = +\cos\alpha$ | $\sin(90° + 30°) = \sin 120° = +0.8660$ | $\cos 30° = +0.8660$ |
| $\cos(90° + \alpha) = -\sin\alpha$ | $\cos(90° + 30°) = \cos 120° = -0.5000$ | $-\sin 30° = -0.5000$ |
| $\tan(90° + \alpha) = -\cot\alpha$ | $\tan(90° + 30°) = \tan 120° = -1.7321$ | $-\cot 30° = -1.7321$ |

Function values for selected angles

| Function | 0° | 90° | 180° | 270° | 360° | Function | 0° | 90° | 180° | 270° | 360° |
|---|---|---|---|---|---|---|---|---|---|---|---|
| sin | 0 | +1 | 0 | −1 | 0 | tan | 0 | ∞ | 0 | ∞ | 0 |
| cos | +1 | 0 | −1 | 0 | +1 | cot | ∞ | 0 | ∞ | 0 | ∞ |

## Relationships between the functions of an angle

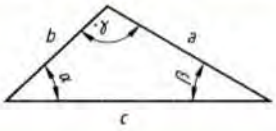



| | |
|---|---|
| $\sin^2\alpha + \cos^2\alpha = 1$ | $\tan\alpha \cdot \cot\alpha = 1$ |
| $\tan\alpha = \frac{\sin\alpha}{\cos\alpha}$ | $\cot\alpha = \frac{\cos\alpha}{\sin\alpha}$ |

Example: Calculation of $\tan\alpha$ from $\sin\alpha$ and $\cos\alpha$ for $\alpha = 30°$:
$\tan\alpha = \sin\alpha/\cos\alpha = 0.5000/0.8660 = 0.5774$

# Trigonometric functions of oblique triangles, Angles, Theorem of intersecting lines

## Law of sines and Law of cosines

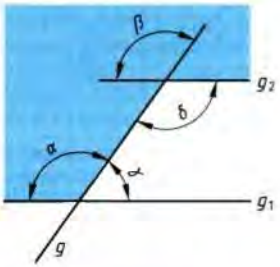



| Law of sines | Law of cosines |
|---|---|
| $a : b : c = \sin\alpha : \sin\beta : \sin\gamma$ | $a^2 = b^2 + c^2 - 2 \cdot b \cdot c \cdot \cos\alpha$ |
| $\frac{a}{\sin\alpha} = \frac{b}{\sin\beta} = \frac{c}{\sin\gamma}$ | $b^2 = a^2 + c^2 - 2 \cdot a \cdot c \cdot \cos\beta$ |
| | $c^2 = a^2 + b^2 - 2 \cdot a \cdot b \cdot \cos\gamma$ |

## Application in calculating sides and angles

| Calculation of sides | | Calculation of angles | |
|---|---|---|---|
| using the Law of sines | using the Law of cosines | using the Law of sines | using the Law of cosines |
| $a = \frac{b \cdot \sin\alpha}{\sin\beta} = \frac{c \cdot \sin\alpha}{\sin\gamma}$ | $a = \sqrt{b^2 + c^2 - 2 \cdot b \cdot c \cdot \cos\alpha}$ | $\sin\alpha = \frac{a \cdot \sin\beta}{b} = \frac{a \cdot \sin\gamma}{c}$ | $\cos\alpha = \frac{b^2 + c^2 - a^2}{2 \cdot b \cdot c}$ |
| $b = \frac{a \cdot \sin\beta}{\sin\alpha} = \frac{c \cdot \sin\beta}{\sin\gamma}$ | $b = \sqrt{a^2 + c^2 - 2 \cdot a \cdot c \cdot \cos\beta}$ | $\sin\beta = \frac{b \cdot \sin\alpha}{a} = \frac{b \cdot \sin\gamma}{c}$ | $\cos\beta = \frac{a^2 + c^2 - b^2}{2 \cdot a \cdot c}$ |
| $c = \frac{a \cdot \sin\gamma}{\sin\alpha} = \frac{b \cdot \sin\gamma}{\sin\beta}$ | $c = \sqrt{a^2 + b^2 - 2 \cdot a \cdot b \cdot \cos\gamma}$ | $\sin\gamma = \frac{c \cdot \sin\alpha}{a} = \frac{c \cdot \sin\beta}{b}$ | $\cos\gamma = \frac{a^2 + b^2 - c^2}{2 \cdot a \cdot b}$ |

## Types of angles




If two parallels $g_1$ and $g_2$ are intersected by a straight line $g$, there are geometrical interrelationships between the corresponding, opposite, alternate and adjacent angles.

**Corresponding angles**

$\alpha = \beta$

**Opposite angles**

$\beta = \delta$

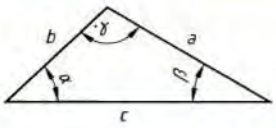
**Alternate angles**

$\alpha = \delta$

**Adjacent angles**

$\alpha + \gamma = 180°$

## Sum of angles in a triangle

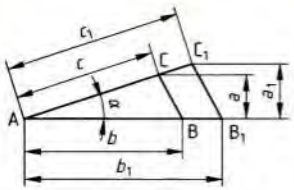



In every triangle the sum of the interior angles equals 180°.

**Sum of angles in a triangle**

$\alpha + \beta + \gamma = 180°$

## Theorem of intersecting lines




If two lines extending from Point A are intersected by two parallel lines BC and $B_1C_1$, the segments of the parallel lines and the corresponding ray segments of the lines extending from A form equal ratios.

**Theorem of intersecting lines**

$$\frac{a}{a_1} = \frac{b}{b_1} = \frac{c}{c_1}$$

$$\frac{a}{b} = \frac{a_1}{b_1} \qquad \frac{b}{c} = \frac{b_1}{c_1}$$

# Using brackets, powers and roots

## Calculations with brackets

| Type | Explanation | Example |
|---|---|---|
| **Factoring out** | Common factors (divisors) in addition and subtraction are placed before a bracket. | $3 \cdot x + 5 \cdot x = x \cdot (3+5) = 8 \cdot x$<br>$\frac{3}{x} + \frac{5}{x} = \frac{1}{x} \cdot (3+5)$ |
| | A fraction bar combines terms in the same manner as brackets. | $\frac{a+b}{2} \cdot h = (a+b) \cdot \frac{h}{2}$ |
| **Expanding bracketed terms** | A bracketed term is multiplied by a value (number, variable, another bracketed term), by multiplying each term inside the brackets by this value. | $5 \cdot (b+c) = 5b + 5c$<br>$(a+b) \cdot (c-d) = ac - ad + bc - bd$ |
| | A bracketed term is divided by a value (number, variable, another bracketed term), by dividing each term inside the bracket by this value. | $(a+b) : c = a : c + b : c$<br>$\frac{a-b}{5} = \frac{a}{5} - \frac{b}{5}$ |
| **Binomial formulae** | A binomial formula is a formula in which the term $(a + b)$ or $(a - b)$ is multiplied by itself. | $(a+b)^2 = a^2 + 2ab + b^2$<br>$(a-b)^2 = a^2 - 2ab + b^2$<br>$(a+b) \cdot (a-b) = a^2 - b^2$ |
| **Multiplication/division and addition/subtraction calculations** | In mixed equations, the bracketed terms must be solved first. Then multiplication and division calculations are performed, and finally addition and subtraction. | $a \cdot (3x - 5x) - b \cdot (12y - 2y)$<br>$= a \cdot (-2x) - b \cdot 10y$<br>$= -2ax - 10by$ |

## Powers

| | | |
|---|---|---|
| **Definitions** | a base; $x$ exponent; $y$ exponential value<br>Product of identical factors | $a^x = y$<br>$a \cdot a \cdot a \cdot a = a^4$<br>$4 \cdot 4 \cdot 4 \cdot 4 = 4^4 = 256$ |
| **Addition Subtraction** | Powers with the same base and the same exponents are treated like equal numbers. | $3a^3 + 5a^3 - 4a^3$<br>$= a^3 \cdot (3 + 5 - 4) = 4a^3$ |
| **Multiplication Division** | Powers with the same base are multiplied (divided) by adding (subtracting) the exponents and keeping the base. | $a^4 \cdot a^2 = a \cdot a \cdot a \cdot a \cdot a \cdot a = a^6$<br>$2^4 \cdot 2^2 = 2^{(4+2)} = 2^6 = 64$<br>$3^2 \div 3^3 = 3^{(2-3)} = 3^{-1} = 1/3$ |
| **Negative exponent** | Numbers with negative exponents can also be written as fractions. The base is then given a positive exponent and is placed in the denominator. | $m^{-1} = \frac{1}{m^1} = \frac{1}{m}$<br>$a^{-3} = \frac{1}{a^3}$ |
| **Fractions in exponents** | Powers with fractional exponents can also be written as roots. | $a^{\frac{4}{3}} = \sqrt[3]{a^4}$ |
| **Zero in exponents** | Every power with a zero exponent has the value of one. | $(m+n)^0 = 1$<br>$a^4 \div a^4 = a^{(4-4)} = a^0 = 1$<br>$2^0 = 1$ |

## Roots

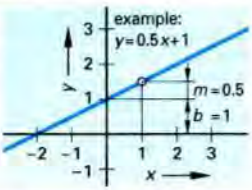
| | | |
|---|---|---|
| **Definitions** | x root's exponent; $a$ radicand; $y$ root value | $\sqrt[x]{a} = y$ or $a^{1/x} = y$ |
| **Signs** | Even number exponents of the root give positive and negative values, if the radicand is positive. A negative radicand results in an imaginary number. | $\sqrt[2]{9} = \pm 3$<br>$\sqrt[2]{-9} = +3i$ |
| | Odd number exponents of the root give positive values if the radicand is positive and negative values if the radicand is negative. | $\sqrt[3]{8} = 2$<br>$\sqrt[3]{-8} = -2$ |
| **Addition Subtraction** | Identical root expressions can be added and subtracted. | $\sqrt{a} + 3\sqrt{a} - 2\sqrt{a} = 2\sqrt{a}$ |
| **Multiplication Division** | Roots with the same exponents are multiplied (divided) by taking the root of the product (quotient) of the radicands. | $\sqrt[n]{a} \cdot \sqrt[n]{b} = \sqrt[n]{ab}$<br>$\frac{\sqrt[3]{a}}{\sqrt[3]{n}} = \sqrt[3]{\frac{a}{n}}$ |

# Types of equations, Rules of transformation

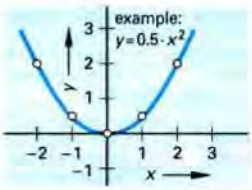
## Equations

| Type | Explanation | Example |
|---|---|---|
| **Variable equation** | Equivalent terms (formula terms of equal value ) form relationships between variables (see also, Rules of transformation). | $v = \pi \cdot d \cdot n$<br>$(a+b)^2 = a^2 + 2ab + b^2$ |
| **Compatible units equation** | Immediate conversion of units and constants to an SI unit in the result.<br>Only used in special cases, e.g. if engineering parameters are specified or for simplification. | $P = \frac{M \cdot n}{9550}$; $P$ in kW, if<br>$n$ in 1/min and $M$ in Nm |
| **Single variable equation** | Calculation of the value of a variable. | $x + 3 = 8$<br>$x = 8 - 3 = 5$ |
| **Function equation** | Assigned function equation: $y$ is a function of $x$ with $x$ as the independent variable; $y$ as the dependent variable.<br>The number pair $(x,y)$ of a value table form the graph of the function in the $(x,y)$ coordinate system. | $y = f(x)$<br>$\mathbb{R} \rightarrow$ real numbers |
| | **Constant function**<br>The graph is a line parallel to the $x$-axis. | $y = f(x) = b$ |
| | **Proportional function**<br>The graph is a straight line through the origin. | $y = f(x) = mx$<br>$y = 2x$ |
| | **Linear function**<br>The graph is a straight line with slope $m$ and $y$ intercept $b$ (example below). | $y = f(x) = mx + b$<br>$y = 0.5x + 1$ |
| | **Quadratic function**<br>Every quadratic function graphs as a parabola (example below). | $y = f(x) = x^2$<br>$y = a_2x^2 + a_1x + a_0$ |

**linear function** $y = mx + b$




**quadratic function** $y = x^2$




## Rules of transformation

Equations are usually transformed to obtain an equation in which the unknown variable stands alone on the left side of the equation.

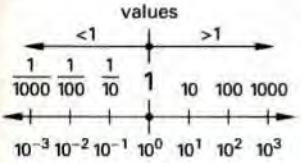
| | | |
|---|---|---|
| **Addition Subtraction** | The same number can be added or subtracted from both sides.<br>In the equations $x + 5 = 15$ and $x + 5 - 5 = 15 - 5$, x has the same value, i.e. the equations are equivalent. | $x + 5 = 15 \quad \vert -5$<br>$x + 5 - 5 = 15 - 5$<br>$x = 10$<br>$y - c = d \quad \vert +c$<br>$y - c + c = d + c$<br>$y = d + c$ |
| **Multiplication Division** | It is possible to multiply or divide each side of the equation by the same number. | $a \cdot x = b \quad \vert \div a$<br>$\frac{a \cdot x}{a} = \frac{b}{a}$<br>$x = \frac{b}{a}$ |
| **Powers** | The expressions on both sides of the equations can be raised to the same exponential power. | $\sqrt{x} = a + b \quad \vert ()^2$<br>$(\sqrt{x})^2 = (a+b)^2$<br>$x = a^2 + 2ab + b^2$ |
| **Roots** | The root of the expressions on both sides of the equation can be taken using the same root exponent. | $x^2 = a + b \quad \vert \sqrt{}$<br>$(\sqrt{x})^2 = \sqrt{a+b}$<br>$x = \pm\sqrt{a+b}$ |

# Decimal multiples and factors of units, Interest calculation

## Decimal multiples and factors of units

cf. DIN 1301-1 (2002-10)

| Mathematics | | | SI units | | | |
|---|---|---|---|---|---|---|
| Power of ten | Name | Multiplication factor | Prefix Name | Prefix Character | Examples Unit | Examples Meaning |
| $10^{18}$ | quintillion | 1 000 000 000 000 000 000 | exa | E | Em | $10^{18}$ meters |
| $10^{15}$ | quadrillion | 1 000 000 000 000 000 | peta | P | Pm | $10^{15}$ meters |
| $10^{12}$ | trillion | 1 000 000 000 000 | tera | T | TV | $10^{12}$ volts |
| $10^{9}$ | billion | 1 000 000 000 | giga | G | GW | $10^{9}$ watts |
| $10^{6}$ | million | 1 000 000 | mega | M | MW | $10^{6}$ watts |
| $10^{3}$ | thousand | 1 000 | kilo | k | kN | $10^{3}$ newtons |
| $10^{2}$ | hundred | 100 | hecto | h | hl | $10^{2}$ liters |
| $10^{1}$ | ten | 10 | deca | da | dam | $10^{1}$ meters |
| $10^{0}$ | one | 1 | – | – | m | $10^{0}$ meter |
| $10^{-1}$ | tenth | 0.1 | deci | d | dm | $10^{-1}$ meters |
| $10^{-2}$ | hundredth | 0.01 | centi | c | cm | $10^{-2}$ meters |
| $10^{-3}$ | thousandth | 0.001 | milli | m | mV | $10^{-3}$ volts |
| $10^{-6}$ | millionth | 0.000 001 | micro | µ | µA | $10^{-6}$ ampere |
| $10^{-9}$ | billionth | 0.000 000 001 | nano | n | nm | $10^{-9}$ meters |
| $10^{-12}$ | trillionth | 0.000 000 000 001 | pico | p | pF | $10^{-12}$ farad |
| $10^{-15}$ | quadrillionth | 0.000 000 000 000 001 | femto | f | fF | $10^{-15}$ farads |
| $10^{-18}$ | quintillionth | 0.000 000 000 000 000 001 | atto | a | am | $10^{-18}$ meters |




Numbers greater than 1 are expressed with **positive exponents** and numbers less than 1 are expressed with **negative exponents.**

**Examples:** $4300 = 4.3 \cdot 1000 = 4.3 \cdot 10^3$

$14638 = 1.4638 \cdot 10^4$

$0.07 = \frac{7}{100} = 7 \cdot 10^{-2}$

## Simple interest

$P$ principle; $A$ amount accumulated; $I$ interest; $r$ interest rate per year; $t$ time in days, interest period

**Interest**

$$I = \frac{P \cdot r \cdot t}{100\,\% \cdot 360}$$

1 interest year (1 a) = 360 days (360 d)

360 d = 12 months

1 interest month = 30 days

**1st example:**

$P = \$\,2800.00;\ r = 6\,\frac{\%}{a};\ t = {}^1/_2\,a;\ I = ?$

$$I = \frac{\$\,2800.00 \cdot 6\,\frac{\%}{a} \cdot 0.5\,a}{100\,\%} = \mathbf{\$\,84.00}$$

**2nd example:**

$P = \$\,4800.00;\ r = 5.1\,\frac{\%}{a};\ t = 50\,d;\ I = ?$

$$I = \frac{\$\,4800.00 \cdot 5.1\,\frac{\%}{a} \cdot 50\,d}{100\,\% \cdot 360\,\frac{d}{a}} = \mathbf{\$\,34.00}$$

## Compound interest calculation for one-time payment

$P$ principle; $A$ amount accumulated; $I$ interest; $r$ interest rate per year; $n$ time; $q$ compounding factor

**Amount accumulated**

$$A = P \cdot q^n$$

**Compounding factor**

$$q = 1 + \frac{r}{100\,\%}$$

**Example:**

$P = \$\,8000.00;\ n = 7$ years; $r = 6.5\,\%;\ A = ?$

$$q = 1 + \frac{6.5\,\%}{100\,\%} = 1.065$$

$$A = P \cdot q^n = \$\,8000.00 \cdot 1.065^7 = \$\,8000.00 \cdot 1.553986$$

$$= \mathbf{\$\,12431.89}$$

# Percentage calculation, Proportion calculations

## Percentage calculation

The **percentage rate** gives the fraction of the base value in hundredths.
The **base value** is the value from which the percentage is to be calculated.
The **percent value** is the amount representing the percentage of the base value.

$P_r$ percentage rate, in percent  $P_v$ percent value  $B_v$ base value.

**Percent value**

$$P_v = \frac{B_v \cdot P_r}{100\%}$$

**Percentage rate**

$$P_r = \frac{P_v}{B_v} \cdot 100\%$$

**1st example:**

Workpiece rough part weight 250 kg (base value); material loss 2% (percentage rate); material loss in kg = ? (percent value)

$$P_v = \frac{B_v \cdot P_r}{100\%} = \frac{250\ \text{kg} \cdot 2\%}{100\%} = \mathbf{5\ kg}$$

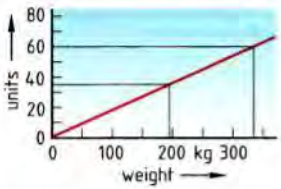
**2nd example:**

Rough weight of a casting 150 kg; weight after machining 126 kg; weight percent rate (%) of material loss?

$$P_r = \frac{P_v}{B_v} \cdot 100\% = \frac{150\ \text{kg} - 126\ \text{kg}}{150\ \text{kg}} \cdot 100\% = \mathbf{16\%}$$

## Proportion calculations

### Three steps for calculating direct proportional ratios




Example:

60 elbow pipes weigh 330 kg. What is the weight of 35 elbow pipes?

1st step: Known data — 60 elbow pipes weigh 330 kg.

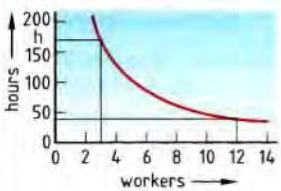
2nd step: Calculate the unit weight by dividing

1 elbow pipe weighs $\frac{330\ \text{kg}}{60}$

3rd step: Calculate the total by multiplying

35 elbow pipes weigh $\frac{330\ \text{kg} \cdot 35}{60} = \mathbf{192.5\ kg}$

### Three steps for calculating inverse proportional ratios




Example:

It takes 3 workers 170 hours to process one order. How many hours do 12 workers need to process the same order?

Known data — It takes 3 workers 170 hours

2nd step: Calculate the unit time by multiplying

It takes 1 worker 3 · 170 hrs

3rd step: Calculate the total by dividing

It takes12 workers $\frac{3 \cdot 170\ \text{hrs}}{12} = \mathbf{42.5\ hrs}$

### Using the three steps for calculating direct and inverse proportions

**Example:**

660 workpieces are manufactured by 5 machines in 24 days.

How much time does it take for 9 machines to produce 312 workpieces of the same type?

**1st application of 3 steps:**

5 machines produce 660 workpieces in 24 days
1 machine produces 660 workpieces in 24 · 5 days
9 machines produce 660 workpieces in $\frac{24 \cdot 5}{9}$ days

**2nd application of 3 steps:**

9 machines produce 660 workpieces in $\frac{24 \cdot 5}{9}$ days
9 machines produce 1 workpiece in $\frac{24 \cdot 5}{9 \cdot 660}$ days
9 machines produce 312 workpieces in $\frac{24 \cdot 5 \cdot 312}{9 \cdot 660} = \mathbf{6.3\ days}$

# Formula symbols, Mathematical symbols

## Formula symbols

cf. DIN 1304-1 (1994-03)

| Formula symbol | Meaning | Formula symbol | Meaning | Formula symbol | Meaning |
|---|---|---|---|---|---|
| **Length, Area, Volume, Angle** | | | | | |
| $l$ | Length | $r, R$ | Radius | $\alpha, \beta, \gamma$ | Planar angle |
| $w$ | Width | $d, D$ | Diameter | $\Omega$ | Solid angle |
| $h$ | Height | $A, S$ | Area, Cross-sectional area | $\lambda$ | Wave length |
| $s$ | Linear distance | $V$ | Volume | | |
| **Mechanics** | | | | | |
| $m$ | Mass | $F$ | Force | $G$ | Shear modulus |
| $m'$ | Linear mass density | $F_W, W$ | Gravitational force, Weight | $\mu, f$ | Coefficient of friction |
| $m''$ | Area mass density | $M$ | Torque | $W$ | Section modulus |
| $\varrho$ | Density | $T$ | Torsional moment | $I$ | Second moment of an area |
| $J$ | Moment of inertia | $M_b$ | Bending moment | $W, E$ | Work, Energy |
| $p$ | Pressure | $\sigma$ | Normal stress | $W_p, E_p$ | Potential energy |
| $p_{abs}$ | Absolute pressure | $\tau$ | Shear stress | $W_k, E_k$ | Kinetic energy |
| $p_{amb}$ | Ambient pressure | $\varepsilon$ | Normal strain | $P$ | Power |
| $p_g$ | Gage pressure | $E$ | Modulus of elasticity | $\eta$ | Efficiency |
| **Time** | | | | | |
| $t$ | Time, Duration | $f, \nu$ | Frequency | $a$ | Acceleration |
| $T$ | Cycle duration | $v, u$ | Velocity | $g$ | Gravitational acceleration |
| $n$ | Revolution frequency, Speed | $\omega$ | Angular velocity | $\alpha$ | Angular acceleration |
| | | | | $Q, \dot{V}, q_v$ | Volumetric flow rate |
| **Electricity** | | | | | |
| $Q$ | Electric charge, Quantity of electricity | $L$ | Inductance | $X$ | Reactance |
| $E$ | Electromotive force | $R$ | Resistance | $Z$ | Impedance |
| $C$ | Capacitance | $\varrho$ | Specific resistance | $\varphi$ | Phase difference |
| $I$ | Electric current | $\gamma, \varkappa$ | Electrical conductivity | $N$ | Number of turns |
| **Heat** | | | | | |
| $T, \Theta$ | Thermodynamic temperature | $Q$ | Heat, Quantity of heat | $\Phi, \dot{Q}$ | Heat flow |
| $\Delta T, \Delta t, \Delta\vartheta$ | Temperature difference | $\lambda$ | Thermal conductivity | $a$ | Thermal diffusivity |
| $t, \vartheta$ | Celsius temperature | $\alpha$ | Heat transition coefficient | $c$ | Specific heat |
| $\alpha_l, \alpha$ | Coefficient of linear expansion | $k$ | Heat transmission coefficient | $H_{net}$ | Net calorific value |
| **Light, Electromagnetic radiation** | | | | | |
| $E$ | Illuminance | $f$ | Focal length | $I$ | Luminous intensity |
| | | $n$ | Refractive index | $Q, W$ | Radiant energy |
| **Acoustics** | | | | | |
| $p$ | Acoustic pressure | $L_P$ | Acoustic pressure level | $N$ | Loudness |
| $c$ | Acoustic velocity | $I$ | Sound intensity | $L_N$ | Loudness level |

## Mathematical symbols

cf. DIN 1302 (1999-12)

| Math. symbol | Spoken | Math. symbol | Spoken | Math. symbol | Spoken |
|---|---|---|---|---|---|
| $\approx$ | approx. equals, around, about | $\sim$ | proportional | log | logarithm (general) |
| $\triangleq$ | equivalent to | $a^n$ | a to the n-th power, the n-th power of a | lg | common logarithm |
| ... | and so on, etc. | $\sqrt{}$ | square root of | ln | natural logarithm |
| $\infty$ | infinity | $\sqrt[n]{}$ | n-th root of | e | Euler number (e = 2.718281...) |
| $=$ | equal to | $\lvert x \rvert$ | absolute value of x | sin | sine |
| $\neq$ | not equal to | $\perp$ | perpendicular to | cos | cosine |
| $\stackrel{\text{def}}{=}$ | is equal to by definition | $\parallel$ | is parallel to | tan | tangent |
| $<$ | less than | $\uparrow\uparrow$ | parallel in the same direction | cot | cotangent |
| $\leq$ | less than or equal to | $\uparrow\downarrow$ | parallel in the opposite direction | (), [], {} | parentheses, brackets |
| $>$ | greater than | $\sphericalangle$ | angle | | open and closed |
| $\geq$ | greater than or equal to | $\triangle$ | triangle | $\pi$ | pi (circle constant = 3.14159...) |
| $+$ | plus | $\cong$ | congruent to | | |
| $-$ | minus | $\Delta x$ | delta x (difference between two values) | $\overline{AB}$ | line segment AB |
| $\cdot$ | times, multiplied by | | | $\overset{\frown}{AB}$ | arc AB |
| $-, /, :, \div$ | over, divided by, per, to | % | percent, of a hundred | a', a" | a prime, a double prime |
| $\Sigma$ | sigma (summation) | ‰ | per mil, of a thousand | $a_1, a_2$ | a sub 1, a sub 2 |

# SI quantities and units of measurement

## SI[1] Base quantities and base units

cf. DIN 1301-1 (2002-10), -2 (1978-02), -3 (1979-10)

| Base quantity | Length | Mass | Time | Electric current | Thermodynamic temperature | Amount of substance | Luminous intensity |
|---|---|---|---|---|---|---|---|
| Base units | meter | kilogram | second | ampere | kelvin | mole | candela |
| Unit symbol | m | kg | s | A | K | mol | cd |

[1] The units for measurement are defined in the International System of Units SI (**S**ystème International d'Unités). It is based on the seven basic units (SI units), from which other units are derived.

## Base quantities, derived quantities and their units

| Quantity | Symbol | Unit Name | Unit Symbol | Relationship | Remarks Examples of application |
|---|---|---|---|---|---|
| **Length, Area, Volume, Angle** | | | | | |
| **Length** | $l$ | meter | m | 1 m = 10 dm = 100 cm = 1000 mm<br>1 mm = 1000 µm<br>1 km = 1000 m | 1 inch = 25.4 mm<br>In aviation and nautical applications the following applies:<br>1 international nautical mile = 1852 m |
| Area | $A$, $S$ | square meter<br>are<br>hectare | $m^2$<br>a<br>ha | $1\ m^2 = 10000\ cm^2 = 1000000\ mm^2$<br>$1\ a = 100\ m^2$<br>$1\ ha = 100\ a = 10000\ m^2$<br>$100\ ha = 1\ km^2$ | Symbol $S$ only for cross-sectional areas<br>Are and hectare only for land |
| Volume | $V$ | cubic meter<br>liter | $m^3$<br>l, L | $1\ m^3 = 1000\ dm^3 = 1000000\ cm^3$<br>$1\ l = 1\ L = 1\ dm^3 = 10\ dl = 0.001\ m^3$<br>$1\ ml = 1\ cm^3$ | Mostly for fluids and gases |
| Plane angle (angle) | $\alpha, \beta, \gamma \ldots$ | radian<br>degrees<br>minutes<br>seconds | rad<br>°<br>'<br>" | $1\ rad = 1\ m/m = 57.2957\ldots° = 180°/\pi$<br>$1° = \frac{\pi}{180}\ rad = 60'$<br>$1' = 1°/60 = 60"$<br>$1" = 1'/60 = 1°/3600$ | 1 rad is the angle formed by the intersection of a circle around the center of 1 m radius with an arc of 1 m length.<br>In technical calculations instead of $\alpha = 33° 17' 27.6"$, better use is $\alpha = 33.291°$. |
| Solid angle | $\Omega$ | steradian | sr | $1\ sr = 1\ m^2/m^2$ | An object whose extension measures 1 rad in one direction and perpendicularly to this also 1 rad, covers a solid angle of 1 sr. |
| **Mechanics** | | | | | |
| **Mass** | $m$ | kilogram<br>gram<br>megagram<br>metric ton | kg<br>g<br>Mg<br>t | 1 kg = 1000 g<br>1 g = 1000 mg<br>1 metric t = 1000 kg = 1 Mg<br>0.2 g = 1 ct | Mass in the sense of a scale result or a weight is a quantity of the type of mass (unit kg).<br>Mass for precious stones in carat (ct). |
| Linear mass density | $m'$ | kilogram per meter | kg/m | 1 kg/m = 1 g/mm | For calculating the mass of bars, profiles, pipes. |
| Area mass density | $m''$ | kilogram per square meter | $kg/m^2$ | $1\ kg/m^2 = 0.1\ g/cm^2$ | To calculate the mass of sheet metal. |
| Density | $\varrho$ | kilogram per cubic meter | $kg/m^3$ | $1000\ kg/m^3 = 1$ metric $t/m^3 = 1\ kg/dm^3 = 1\ g/cm^3 = 1\ g/ml = 1\ mg/mm^3$ | The density is a quantity independent of location. |

# SI quantities and units of measurement

## Quantities and Units (continued)

| Quantity | Symbol | Unit Name | Unit Symbol | Relationship | Remarks Examples of application |
|---|---|---|---|---|---|
| **Mechanics** | | | | | |
| Moment of inertia, 2nd Moment of mass | $J$ | kilogram x square meter | $kg \cdot m^2$ | The following applies for a homogenous body: $J = \varrho \cdot r^2 \cdot V$ | The moment of inertia (2nd moment of mass) is dependent upon the total mass of the body as well as its form and the position of the axis of rotation. |
| Force<br><br>Weight | $F$<br><br>$F_G$, $G$ | newton | N | $1\ N = 1\ \frac{kg \cdot m}{s^2} = 1\ \frac{J}{m}$<br>$1\ MN = 10^3\ kN = 1000000\ N$ | The force 1 N effects a change in velocity of 1 m/s in 1 s in a 1 kg mass. |
| Torque<br>Bending mom.<br>Torsional | $M$<br>$M_b$<br>$T$ | newton x meter | N · m | $1\ N \cdot m = 1\ \frac{kg \cdot m^2}{s^2}$ | 1 N · m is the moment that a force of 1 N effects with a lever arm of 1 m. |
| Momentum | $p$ | kilogram x meter per second | kg · m/s | $1\ kg \cdot m/s = 1\ N \cdot s$ | The momentum is the product of the mass times velocity. It has the direction of the velocity. |
| Pressure<br><br>Mechanical stress | $p$<br><br>$\sigma, \tau$ | pascal<br><br>newton per square millimeter | Pa<br><br>$N/mm^2$ | $1\ Pa = 1\ N/m^2 = 0.01\ mbar$<br>$1\ bar = 100000\ N/m^2 = 10\ N/cm^2 = 10^5\ Pa$<br>$1\ mbar = 1\ hPa$<br>$1\ N/mm^2 = 10\ bar = 1\ MN/m^2 = 1\ MPa$<br>$1\ daN/cm^2 = 0.1\ N/mm^2$ | Pressure refers to the force per unit area. For gage pressure the symbol $p_g$ is used (DIN 1314).<br>1 bar = 14.5 psi (pounds per square inch ) |
| Second moment of area | $I$ | meter to the fourth power<br>centimeter to the fourth power | $m^4$<br><br>$cm^4$ | $1\ m^4 = 100000000\ cm^4$ | Previously: Geometrical moment of inertia |
| Energy, Work, Quantity of heat | $E, W$ | joule | J | $1\ J = 1\ N \cdot m = 1\ W \cdot s = 1\ kg \cdot m^2/s^2$ | Joule for all forms of energy, kW · h preferred for electrical energy. |
| Power<br>Heat flux | $P$<br>$\Phi$ | watt | W | $1\ W = 1\ J/s = 1\ N \cdot m/s = 1\ V \cdot A = 1\ m^2 \cdot kg/s^3$ | Power describes the work which is achieved within a specific time. |
| **Time** | | | | | |
| **Time,**<br>Time span,<br>Duration | $t$ | seconds<br>minutes<br>hours<br>day<br>year | s<br>min<br>h<br>d<br>a | $1\ min = 60\ s$<br>$1\ h = 60\ min = 3600\ s$<br>$1\ d = 24\ h = 86400\ s$ | 3 h means a time span (3 hrs.), $3^h$ means a point in time (3 o'clock). If points in time are written in mixed form, e.g. $3^h24^m10^s$, the symbol min can be shortened to m. |
| Frequency | $f, \nu$ | hertz | Hz | $1\ Hz = 1/s$ | 1 Hz ≙ 1 cycle in 1 second. |
| Rotational speed,<br>Rotational frequency | $n$ | 1 per second<br><br>1 per minute | 1/s<br><br>1/min | $1/s = 60/min = 60\ min^{-1}$<br>$1/min = 1\ min^{-1} = \frac{1}{60\ s}$ | The number of revolutions per unit of time gives the revolution frequency, also called rpm. |
| Velocity | $v$ | meters per second<br>meters per minute<br>kilometers per hour | m/s<br><br>m/min<br><br>km/h | $1\ m/s = 60\ m/min = 3.6\ km/h$<br>$1\ m/min = \frac{1\ m}{60\ s}$<br>$1\ km/h = \frac{1\ m}{3.6\ s}$ | Nautical velocity in knots (kn):<br>1 kn = 1.852 km/h<br>miles per hour = 1 mile/h = 1 mph<br>1 mph = 1.60934 km/h |
| Angular-velocity | $\omega$ | 1 per second<br>radians per second | 1/s<br>rad/s | $\omega = 2\pi \cdot n$ | For a rpm of $n = 2$/s the angular velocity $\omega = 4\pi$/s. |
| Acceleration | $a, g$ | meters per second squared | $m/s^2$ | $1\ m/s^2 = \frac{1\ m/s}{1\ s}$ | Symbol g only for acceleration due to gravity.<br>$g = 9.81\ m/s^2 \approx 10\ m/s^2$ |

# SI quantities and units of measurement

## Quantities and units (continued)

| Quantity | Symbol | Unit Name | Symbol | Relationship | Remarks Examples of application |
|---|---|---|---|---|---|
| **Electricity and Magnetism** | | | | | |
| **Electric current** | $I$ | ampere | A | | The movement of an electrical charge is called current. The electromotive force is equal to the potential difference between two points in an electric field. The reciprocal of the electrical resistance is called the electrical conductivity. |
| Electromotive force | $E$ | volt | V | 1 V = 1 W/1 A = 1 J/C | |
| Electrical resistance | $R$ | ohm | Ω | 1 Ω = 1 V/1 A | |
| Electrical conductance | $G$ | siemens | S | 1 S = 1 A/1 V = 1/Ω | |
| Specific resistance | $\varrho$ | ohm x meter | Ω · m | $10^{-6}$ Ω · m = 1 Ω · mm²/m | $\varrho = \frac{1}{\varkappa}$ in $\frac{\Omega \cdot mm^2}{m}$ |
| Conductivity | $\gamma, \varkappa$ | siemens per meter | S/m | | $\varkappa = \frac{1}{\varrho}$ in $\frac{m}{\Omega \cdot mm^2}$ |
| Frequency | $f$ | hertz | Hz | 1 Hz = 1/s<br>1000 Hz = 1 kHz | Frequency of public electric utility: EU 50 Hz, USA/Canada 60 Hz |
| Electrical energy | $W$ | joule | J | 1 J = 1 W · s = 1 N · m<br>1 kW · h = 3.6 MJ<br>1 W · h = 3.6 kJ | In atomic and nuclear physics the unit eV (electron volt) is used. |
| Phase difference | $\varphi$ | – | – | for alternating current: $\cos\varphi = \frac{P}{U \cdot I}$ | The angle between current and voltage in inductive or capacitive load. |
| Elect. field strength | $E$ | volts per meter | V/m | | $E = \frac{F}{Q}$, $C = \frac{Q}{U}$, $Q = I \cdot t$ |
| Elect. charge | $Q$ | coulomb | C | 1 C = 1 A · 1 s; 1 A · h = 3.6 kC | |
| Elect. capacitance | $C$ | farad | F | 1 F = 1 C/V | |
| inductance | $L$ | henry | H | 1 H = 1 V · s/A | |
| Power<br>Effective power | $P$ | watt | W | 1 W = 1 J/s = 1 N · m/s<br>= 1 V · A | In electrical power engineering: Apparent power $S$ in V · A |
| **Thermodynamics and Heat transfer** | | | | | |
| **Thermodynamic temperature** | $T, \Theta$ | kelvin | K | 0 K = –273.15 °C | Kelvin (K) and degrees Celsius (°C) are used for temperatures and temperature differences.<br>$t = T - T_0$; $T_0$ = 273.15 K<br>degrees Fahrenheit (°F): 1.8 °F = 1 °C |
| Celsius temperature | $t, \vartheta$ | degrees Celsius | °C | 0 °C = 273.15 K<br>0 °C = 32 °F<br>0 °F = –17.77 °C | |
| Quantity of heat | $Q$ | joule | J | 1 J = 1 W · s = 1 N · m<br>1 kW · h = 3600000 J = 3.6 MJ | 1 kcal = 4.1868 kJ |
| Net calorific value | $H_{net}$ | joule per kilogram | J/kg | 1 MJ/kg = 1000000 J/kg | Thermal energy released per kg fuel minus the heat of vaporization of the water vapor contained in the exhaust gases. |
| | | Joule per cubic meter | J/m³ | 1 MJ/m³ = 1000000 J/m³ | |

## Non-SI units

| Length | Area | Volume | Mass | Energy, Power |
|---|---|---|---|---|
| 1 inch = 25.4 mm | 1 sq.in = 6.452 cm² | 1 cu.in = 16.39 cm³ | 1 oz = 28.35 g | 1 PSh = 0.735 kWh |
| 1 foot = 0.3048 m | 1 sq.ft = 9.29 dm² | 1 cu.ft = 28.32 dm³ | 1 lb = 453.6 g | 1 PS = 735 W |
| 1 yard = 0.9144 m | 1 sq.yd = 0.8361 m² | 1 cu.yd = 764.6 dm³ | 1 metric t = 1000 kg | 1 kcal = 4186.8 Ws |
| 1 nautical mile = 1.852 km | **Pressure** | 1 US gallon = 3.785 dm³ | 1 short ton = 907.2 kg | 1 kcal = 1.166 Wh |
| 1 mile = 1.609 km | 1 bar = 14.5 psi | 1 Imp. gallon = 4.536 dm³ | 1 carat = 0.2 g | 1 kpm/s = 9.807 W |
| | | 1 barrel = 158.8 dm³ | | 1 Btu = 1055 Ws |
| | | | | 1 hp = 745.7 W |

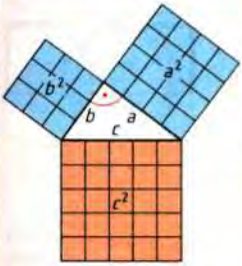
**Prefixes of decimal factors and multiples**

| Prefix | pico | nano | micro | milli | centi | deci | deca | hecto | kilo | mega | giga | tera |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Prefix symbol | p | n | μ | m | c | d | da | h | k | M | G | T |
| Power of ten | $10^{-12}$ | $10^{-9}$ | $10^{-6}$ | $10^{-3}$ | $10^{-2}$ | $10^{-1}$ | $10^{1}$ | $10^{2}$ | $10^{3}$ | $10^{6}$ | $10^{9}$ | $10^{12}$ |
| | ← Factor | | | | | | Multiple → | | | | | |

1 mm = $10^{-3}$ m = 1/1000 m, 1 km = 1000 m, 1 kg = 1000 g, 1 GB (Gigabyte) = 1000000000 bytes

# Calculations in a right triangle

## The Pythagorean Theorem




In a **right triangle** the square of the hypotenuse is equal to the sum of the squares of the two sides.

*a* side
*b* side
*c* hypotenuse

**1st example:**

$c = 35$ mm; $a = 21$ mm; $b = ?$

$b = \sqrt{c^2 - a^2} = \sqrt{(35\text{ mm})^2 - (21\text{ mm})^2} = \mathbf{28\text{ mm}}$

**2nd example:**

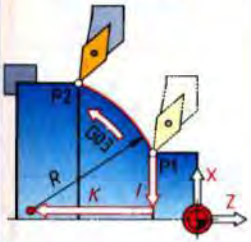
CNC program with $R = 50$ mm and $I = 25$ mm.
$K = ?$

$c^2 = a^2 + b^2$

$R^2 = I^2 + K^2$

$K = \sqrt{R^2 - I^2} = \sqrt{50^2\text{ mm}^2 - 25^2\text{ mm}^2}$

$\mathbf{K = 43.3\text{ mm}}$




**Square of the hypotenuse**

$$c^2 = a^2 + b^2$$

**Length of the hypotenuse**

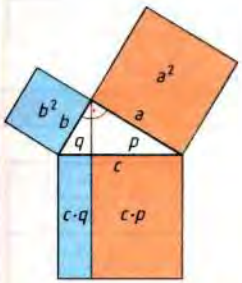
$$c = \sqrt{a^2 + b^2}$$

**Length of the sides**

$$a = \sqrt{c^2 - b^2}$$

$$b = \sqrt{c^2 - a^2}$$

## Euclidean Theorem (Theorem of sides)




The square over one side is equal in area to a rectangle formed by the hypotenuse and the adjacent hypotenuse segment.

*a, b* sides
*c* hypotenuse
*p, q* hypotenuse segments

**Example:**

A rectangle with $c = 6$ cm and $p = 3$ cm should be changed into a square with the same area.
How long is the side of the square *a*?

$a^2 = c \cdot p$

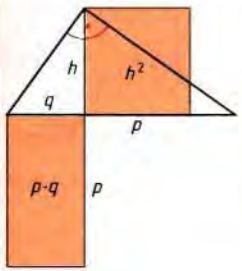
$\mathbf{a} = \sqrt{c \cdot p} = \sqrt{6\text{ cm} \cdot 3\text{ cm}} = \mathbf{4.24\text{ cm}}$

**Square over the side**

$$b^2 = c \cdot q$$

$$a^2 = c \cdot p$$

## Pythagorean theorem of height




The square of height *h* is equal in area to the rectangle of the hypotenuse sections *p* and *q*.

*h* height
*p, q* hypotenuse sections

**Example:**

Right triangle
$p = 6$ cm; $q = 2$ cm; $h = ?$

$h^2 = p \cdot q$

$\mathbf{h} = \sqrt{p \cdot q} = \sqrt{6\text{ cm} \cdot 2\text{ cm}} = \sqrt{12\text{ cm}^2} = \mathbf{3.46\text{ cm}}$

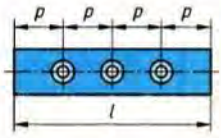
**Square of the height**

$$h^2 = p \cdot q$$

# Division of lengths, Arc length, Composite length

## Sub-dividing lengths

**Edge distance = spacing**




$l$ total length $n$ number of holes
$p$ spacing

**Example:**

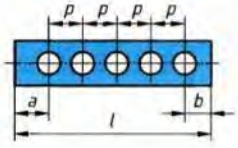
$l = 2$ m; $n = 24$ holes; $p = ?$

$$p = \frac{l}{n+1} = \frac{2000\ \text{mm}}{24+1} = \mathbf{80\ mm}$$

**Spacing**

$$p = \frac{l}{n+1}$$

**Edge distance ≠ spacing**




$l$ total length $n$ number of holes
$p$ spacing $a, b$ edge distances

**Example:**

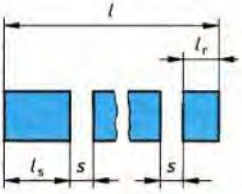
$l = 1950$ mm; $a = 100$ mm; $b = 50$ mm;
$n = 25$ holes; $p = ?$

$$p = \frac{l-(a+b)}{n-1} = \frac{1950\ \text{mm} - 150\ \text{mm}}{25-1} = \mathbf{75\ mm}$$

**Spacing**

$$p = \frac{l-(a+b)}{n-1}$$

**Subdividing into pieces**




$l$ bar length $s$ saw cutting width
$z$ number of pieces $l_r$ remaining length
$l_s$ piece length

**Example:**

$l = 6000$ mm; $l_s = 230$ mm; $s = 1.2$ mm; $z = ?$; $l_r = ?$

$$z = \frac{l}{l_s + s} = \frac{6000\ \text{mm}}{230\ \text{mm} + 1.2\ \text{mm}} = \mathbf{25.95 = 25\ pieces}$$

$$l_r = l - z \cdot (l_s + s) = 6000\ \text{mm} - 25 \cdot (230\ \text{mm} + 1.2\ \text{mm}) = \mathbf{220\ mm}$$

**Number of pieces**

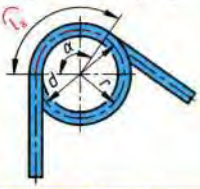
$$z = \frac{l}{l_s + s}$$

**Remaining length**

$$l_r = l - z \cdot (l_s + s)$$

## Arc length

**Example: Torsion spring**




$l_a$ arc length $\alpha$ angle at center
$r$ radius $d$ diameter

**Example:**

$r = 36$ mm; $\alpha = 120°$; $l_a = ?$

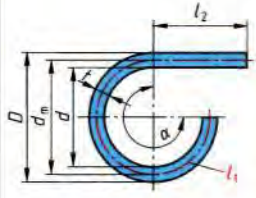
$$l_a = \frac{\pi \cdot r \cdot \alpha}{180°} = \frac{\pi \cdot 36\ \text{mm} \cdot 120°}{180°} = \mathbf{75.36\ mm}$$

**Arc length**

$$l_a = \frac{\pi \cdot r \cdot \alpha}{180°}$$

$$l_a = \frac{\pi \cdot d \cdot \alpha}{360°}$$

## Composite length




$D$ outside diameter $d$ inside diameter
$d_m$ mean diameter $t$ thickness
$l_1, l_2$ section lengths $L$ composite length
$\alpha$ angle at center

**Example** (composite length, picture left):

$D = 360$ mm; $t = 5$ mm; $\alpha = 270°$; $l_2 = 70$ mm;
$d_m = ?$; $L = ?$

$$d_m = D - t = 360\ \text{mm} - 5\ \text{mm} = \mathbf{355\ mm}$$

$$L = l_1 + l_2 = \frac{\pi \cdot d_m \cdot \alpha}{360} + l_2$$

$$= \frac{\pi \cdot 355\ \text{mm} \cdot 270°}{360°} + 70\ \text{mm} = \mathbf{906.45\ mm}$$

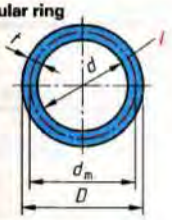
**Composite length**

$$L = l_1 + l_2 + \ldots$$

# Effective length, Spring wire length, Rough length

## Effective lengths

**Circular ring**




$D$ outside diameter
$d$ inside diameter
$d_m$ mean diameter
$t$ thickness
$l$ effective length
$\alpha$ angle at center

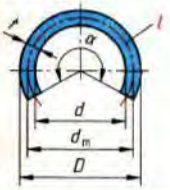
**Effective length of a circular ring**

$$l = \pi \cdot d_m$$

**Effective length of a circular ring sector**

$$l = \frac{\pi \cdot d_m \cdot \alpha}{360°}$$

**Circular ring sector**




**Example** (circular ring sector):

$D = 36$ mm; $t = 4$ mm; $\alpha = 240°$; $d_m = ?$; $l = ?$

$d_m = D - t = 36\text{ mm} - 4\text{ mm} = 32\text{ mm}$

$$l = \frac{\pi \cdot d_m \cdot \alpha}{360°} = \frac{\pi \cdot 32\text{ mm} \cdot 240°}{360°} = \mathbf{67.02\text{ mm}}$$

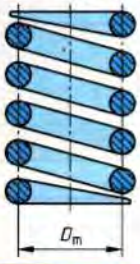
**Mean diameter**

$$d_m = D - t$$

$$d_m = d + t$$

## Spring wire length

**Example: Compression spring**




$l$ effective length of the helix
$D_m$ mean coil diameter
$i$ number of active coils

**Effective length of the helix**

$$l = \pi \cdot D_m \cdot i + 2 \cdot \pi \cdot D_m$$

$$l = \pi \cdot D_m \cdot (i + 2)$$

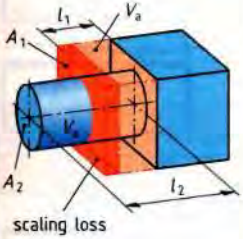
**Example:**

$D_m = 16$ mm; $i = 8.5$; $l = ?$

$l = \pi \cdot D_m \cdot i + 2 \cdot \pi \cdot D_m$

$= \pi \cdot 16\text{ mm} \cdot 8.5 + 2 \cdot \pi \cdot 16\text{ mm} = \mathbf{528\text{ mm}}$

## Rough length of forged parts and pressed parts




When forming without scaling loss the volume of the rough part is the same as the volume of the finished part. If there is scaling loss or burr formation, this is compensated by a factor that is applied to the volume of the finished piece.

$V_a$ volume of the rough part
$V_e$ volume of the finished part
$q$ addition factor for scaling loss or loss due to burrs
$A_1$ cross-sectional area of the rough part
$A_2$ cross-sectional area of the finished part
$l_1$ initial length of the addition
$l_2$ length of the solid forged part

**Volume without scaling loss**

$$V_a = V_e$$

**Volume with scaling loss**

$$V_a = V_e + q \cdot V_e$$

$$V_a = V_e \cdot (1 + q)$$

$$A_1 \cdot l_1 = A_2 \cdot l_2 \cdot (1 + q)$$

**Example:**

A cylindrical peg d = 24 mm and $l_2 = 60$ mm is pressed onto a flat steel workpiece 50 x 30 mm. The scaling loss is 10 %. What is the initial length $l_1$ of the forged addition?

$V_a = V_e \cdot (1 + q)$

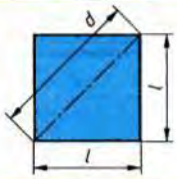
$A_1 \cdot l_1 = A_2 \cdot l_2 \cdot (1 + q)$

$$l_1 = \frac{A_2 \cdot l_2 \cdot (1 + q)}{A_1} =$$

$$= \frac{\pi \cdot (24\text{ mm})^2 \cdot 60\text{ mm} \cdot (1 + 0.1)}{4 \cdot 50\text{ mm} \cdot 30\text{ mm}} = \mathbf{20\text{ mm}}$$

# Angular areas

## Square




$A$ area
$l$ length of side
$d$ length of diagonal

**Example:**

$l = 14$ mm; $A = ?$; $d = ?$
$\boldsymbol{A = l^2 = (14\text{ mm})^2 = 196\text{ mm}^2}$
$\boldsymbol{d = \sqrt{2} \cdot l = \sqrt{2} \cdot 14\text{ mm} = 19.8\text{ mm}}$

**Area**

$$A = l^2$$

**Length of diagonal**

$$d = \sqrt{2} \cdot l$$

## Rhombus (lozenge)




$A$ area
$l$ length of side
$w$ width

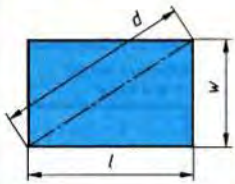
**Example:**

$l = 9$ mm; $w = 8.5$ mm; $A = ?$
$\boldsymbol{A = l \cdot w = 9\text{ mm} \cdot 8.5\text{ mm} = 76.5\text{ mm}^2}$

**Area**

$$A = l \cdot w$$

## Rectangle




$A$ area
$l$ length
$w$ width
$d$ length of diagonal

**Example:**

$l = 12$ mm; $w = 11$ mm; $A = ?$; $d = ?$
$\boldsymbol{A = l \cdot w = 12\text{ mm} \cdot 11\text{ mm} = 132\text{ mm}^2}$
$\boldsymbol{d = \sqrt{l^2 + w^2} = \sqrt{(12\text{ mm})^2 + (11\text{ mm})^2} = \sqrt{265\text{ mm}^2}}$
$\boldsymbol{= 16.28\text{ mm}}$

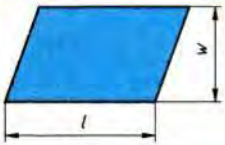
**Area**

$$A = l \cdot w$$

**Length of diagonal**

$$d = \sqrt{l^2 + w^2}$$

## Rhomboid (parallelogram)




$A$ area
$l$ length
$w$ width

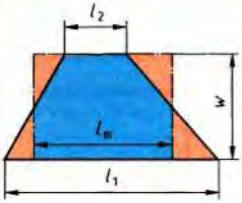
**Example:**

$l = 36$ mm; $w = 15$ mm; $A = ?$
$\boldsymbol{A = l \cdot w = 36\text{ mm} \cdot 15\text{ mm} = 540\text{ mm}^2}$

**Area**

$$A = l \cdot w$$

## Trapezoid




$A$ area
$l_1$ longer length
$l_2$ shorter length
$l_m$ average length
$w$ width

**Example:**

$l_1 = 23$ mm; $l_2 = 20$ mm; $w = 17$ mm; $A = ?$
$\boldsymbol{A = \frac{l_1 + l_2}{2} \cdot w = \frac{23\text{ mm} + 20\text{ mm}}{2} \cdot 17\text{ mm}}$
$\boldsymbol{= 365.5\text{ mm}^2}$

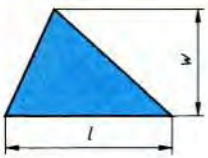
**Area**

$$A = \frac{l_1 + l_2}{2} \cdot w$$

**Average length**

$$l_m = \frac{l_1 + l_2}{2}$$

## Triangle




$A$ area
$l$ length of side
$w$ width

**Example:**

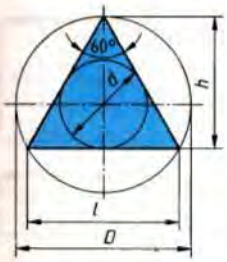
$l_1 = 62$ mm; $w = 29$ mm; $A = ?$
$\boldsymbol{A = \frac{l_1 \cdot w}{2} = \frac{62\text{ mm} \cdot 29\text{ mm}}{2} = 899\text{ mm}^2}$

**Area**

$$A = \frac{l \cdot w}{2}$$

# Triangle, Polygon, Circle

## Equilateral triangle




$A$ area
$d$ diameter of inscribed circle
$l$ length of side
$h$ height
$D$ diameter of circumscribed circle

**Example:**

$l = 42$ mm; $A = ?$;

$$A = \frac{1}{4} \cdot \sqrt{3} \cdot l^2 = \frac{1}{4} \cdot \sqrt{3} \cdot (42\text{ mm})^2 = \mathbf{763.9\text{ mm}^2}$$

**Diameter of circumscribed circle**

$$D = \frac{2}{3} \cdot \sqrt{3} \cdot l = 2 \cdot d$$

**Area**

$$A = \frac{1}{4} \cdot \sqrt{3} \cdot l^2$$

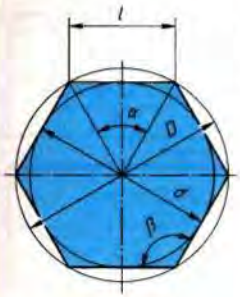
**Diameter of inscribed circle**

$$d = \frac{1}{3} \cdot \sqrt{3} \cdot l = \frac{D}{2}$$

**Triangle height**

$$h = \frac{1}{2} \cdot \sqrt{3} \cdot l$$

## Regular polygons




$A$ area
$l$ length of side
$D$ diameter of circumscribed circle
$d$ diameter of inscribed circle
$n$ no. of vertices
$\alpha$ angle at center
$\beta$ vertex angle

**Example:**

Hexagon with $D = 80$ mm; $l = ?$; $d = ?$; $A = ?$

$$l = D \cdot \sin\left(\frac{180^\circ}{n}\right) = 80\text{ mm} \cdot \sin\left(\frac{180^\circ}{6}\right) = \mathbf{40\text{ mm}}$$

$$d = \sqrt{D^2 - l^2} = \sqrt{6400\text{ mm}^2 - 1600\text{ mm}^2} = \mathbf{69.282\text{ mm}}$$

$$A = \frac{n \cdot l \cdot d}{4} = \frac{6 \cdot 40\text{ mm} \cdot 69.282\text{ mm}}{4} = \mathbf{4156.92\text{ mm}^2}$$

**Diameter of inscribed circle**

$$d = \sqrt{D^2 - l^2}$$

**Area**

$$A = \frac{n \cdot l \cdot d}{4}$$

**Diameter of circumscribed circle**

$$D = \sqrt{d^2 + l^2}$$

**Length of side**

$$l = D \cdot \sin\left(\frac{180^\circ}{n}\right)$$

**Angle at center**

$$\alpha = \frac{360^\circ}{n}$$

**Corner angle**

$$\beta = 180^\circ - \alpha$$

### Calculation of regular polygon using table values

| No. of Vertices $n$ | Area $A \approx$ | | | Diameter of circumscribed circle $D \approx$ | | Diameter of inscribed circle $d \approx$ | | Length of side $l \approx$ | |
|---|---|---|---|---|---|---|---|---|---|
| 3 | $0.325 \cdot D^2$ | $1.299 \cdot d^2$ | $0.433 \cdot l^2$ | $1.154 \cdot l$ | $2.000 \cdot d$ | $0.578 \cdot l$ | $0.500 \cdot D$ | $0.867 \cdot D$ | $1.732 \cdot d$ |
| 4 | $0.500 \cdot D^2$ | $1.000 \cdot d^2$ | $1.000 \cdot l^2$ | $1.414 \cdot l$ | $1.414 \cdot d$ | $1.000 \cdot l$ | $0.707 \cdot D$ | $0.707 \cdot D$ | $1.000 \cdot d$ |
| 5 | $0.595 \cdot D^2$ | $0.908 \cdot d^2$ | $1.721 \cdot l^2$ | $1.702 \cdot l$ | $1.236 \cdot d$ | $1.376 \cdot l$ | $0.809 \cdot D$ | $0.588 \cdot D$ | $0.727 \cdot d$ |
| 6 | $0.649 \cdot D^2$ | $0.866 \cdot d^2$ | $2.598 \cdot l^2$ | $2.000 \cdot l$ | $1.155 \cdot d$ | $1.732 \cdot l$ | $0.866 \cdot D$ | $0.500 \cdot D$ | $0.577 \cdot d$ |
| 8 | $0.707 \cdot D^2$ | $0.829 \cdot d^2$ | $4.828 \cdot l^2$ | $2.614 \cdot l$ | $1.082 \cdot d$ | $2.414 \cdot l$ | $0.924 \cdot D$ | $0.383 \cdot D$ | $0.414 \cdot d$ |
| 10 | $0.735 \cdot D^2$ | $0.812 \cdot d^2$ | $7.694 \cdot l^2$ | $3.236 \cdot l$ | $1.052 \cdot d$ | $3.078 \cdot l$ | $0.951 \cdot D$ | $0.309 \cdot D$ | $0.325 \cdot d$ |
| 12 | $0.750 \cdot D^2$ | $0.804 \cdot d^2$ | $11.196 \cdot l^2$ | $3.864 \cdot l$ | $1.035 \cdot d$ | $3.732 \cdot l$ | $0.966 \cdot D$ | $0.259 \cdot D$ | $0.268 \cdot d$ |

Example: **Octagon** with $l = 20$ mm $A = ?$; $D = ?$

$A \approx 4.828 \cdot l^2 = 4.828 \cdot (20\text{ mm})^2 = \mathbf{1931.2\text{ mm}^2}$; $D \approx 2.614 \cdot l = 2.614 \cdot 20\text{ mm} = \mathbf{52.28\text{ mm}}$

## Circle




$A$ area
$C$ circumference
$d$ diameter

**Example:**

$d = 60$ mm; $A = ?$; $C = ?$

$$A = \frac{\pi \cdot d^2}{4} = \frac{\pi \cdot (60\text{ mm})^2}{4} = \mathbf{2827\text{ mm}^2}$$

$$C = \pi \cdot d = \pi \cdot 60\text{ mm} = \mathbf{188.5\text{ mm}}$$

**Area**

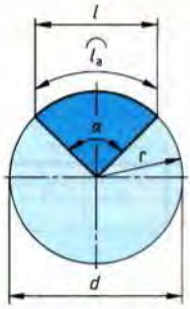
$$A = \frac{\pi \cdot d^2}{4}$$

**Circumference**

$$C = \pi \cdot d$$

# Circular sector, Circular segment, Circular ring, Ellipse

## Circular sector




$A$ area
$d$ diameter
$l_a$ arc length
$l$ chord length
$r$ radius
$\alpha$ angle at center

**Example:**

$d = 48$ mm; $\alpha = 110°$; $l_a = ?$; $A = ?$

$$l_a = \frac{\pi \cdot r \cdot \alpha}{180°} = \frac{\pi \cdot 24\,\text{mm} \cdot 110°}{180°} = \mathbf{46.1\,mm}$$

$$A = \frac{l_a \cdot r}{2} = \frac{46.1\,\text{mm} \cdot 24\,\text{mm}}{2} = \mathbf{553\,mm^2}$$

**Area**

$$A = \frac{\pi \cdot d^2}{4} \cdot \frac{\alpha}{360°}$$

$$A = \frac{l_a \cdot r}{2}$$

**Chord length**

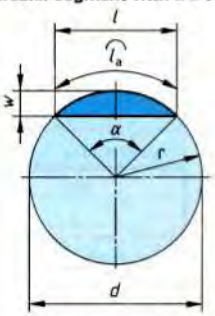
$$l = 2 \cdot r \cdot \sin\frac{\alpha}{2}$$

**Arc length**

$$l_a = \frac{\pi \cdot r \cdot \alpha}{180°}$$

## Circular segment

**Circular segment with $\alpha \le 180°$**




$A$ area
$d$ diameter
$l_a$ arc length
$l$ chord length
$w$ width of segment
$r$ radius
$\alpha$ angle at center

**Example:**

$r = 30$ mm; $\alpha = 120°$; $l = ?$; $w = ?$; $A = ?$

$$l = 2 \cdot r \cdot \sin\frac{\alpha}{2} = 2 \cdot 30\,\text{mm} \cdot \sin\frac{120°}{2} = \mathbf{51.96\,mm}$$

$$w = \frac{l}{2} \cdot \tan\frac{\alpha}{4} = \frac{51.96\,\text{mm}}{2} \cdot \tan\frac{120°}{4} = 14.999\,\text{mm} = \mathbf{15\,mm}$$

$$A = \frac{\pi \cdot d^2}{4} \cdot \frac{\alpha}{360°} - \frac{l \cdot (r - w)}{2}$$

$$= \frac{\pi \cdot (60\,\text{mm})^2}{4} \cdot \frac{120°}{360°} - \frac{51.96\,\text{mm} \cdot (30\,\text{mm} - 15\,\text{mm})}{2}$$

$$= \mathbf{552.8\,mm^2}$$

**Radius**

$$r = \frac{w}{2} + \frac{l^2}{8 \cdot w}$$

**Arc length**

$$l_a = \frac{\pi \cdot r \cdot \alpha}{180°}$$

**Area**

$$A = \frac{\pi \cdot d^2}{4} \cdot \frac{\alpha}{360°} - \frac{l \cdot (r - w)}{2}$$

$$A = \frac{l_a \cdot r - l \cdot (r - w)}{2}$$

**Chord length**

$$l = 2 \cdot r \cdot \sin\frac{\alpha}{2}$$

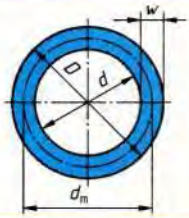
$$l = 2 \cdot \sqrt{w \cdot (2 \cdot r - w)}$$

**Height of segment**

$$w = \frac{l}{2} \cdot \tan\frac{\alpha}{4}$$

$$w = r - \sqrt{r^2 - \frac{l^2}{4}}$$

## Circular ring




$A$ area
$D$ outside diameter
$d$ inside diameter
$d_m$ mean diameter
$w$ width

**Example:**

$D = 160$ mm; $d = 125$ mm; $A = ?$

$$A = \frac{\pi}{4} \cdot (D^2 - d^2) = \frac{\pi}{4} \cdot (160^2\,\text{mm}^2 - 125^2\,\text{mm}^2)$$

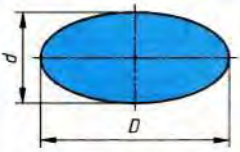
$$= \mathbf{7834\,mm^2}$$

**Area**

$$A = \pi \cdot d_m \cdot w$$

$$A = \frac{\pi}{4} \cdot (D^2 - d^2)$$

## Ellipse




$A$ area
$D$ length
$d$ diameter
$C$ Circumference

**Example:**

$D = 65$ mm; $d = 20$ mm; $A = ?$

$$A = \frac{\pi \cdot D \cdot d}{4} = \frac{\pi \cdot 65\,\text{mm} \cdot 20\,\text{mm}}{4}$$

$$= \mathbf{1021\,mm^2}$$

**Area**

$$A = \frac{\pi \cdot D \cdot d}{4}$$

**Circumference**

$$C \approx \pi \cdot \frac{D + d}{2}$$

# Cube, Square prism, Cylinder, Hollow cylinder, Pyramid

## Cube




$V$ volume
$A_s$ surface area
$l$ length of side

**Example:**

$l = 20$ mm; $V = ?$; $A_s = ?$

$V = l^3 = (20\text{ mm})^3 = \mathbf{8000\ mm^3}$

$A_s = 6 \cdot l^2 = 6 \cdot (20\text{ mm})^2 = \mathbf{2400\ mm^2}$

**Volume**

$$V = l^3$$

**Surface area**

$$A_s = 6 \cdot l^2$$

## Square prism




$V$ volume
$A_s$ surface area
$l$ length of side
$h$ height
$w$ width

**Example:**

$l = 6$ cm; $w = 3$ cm; $h = 2$ cm; $V = ?$

$V = l \cdot w \cdot h = 6\text{ cm} \cdot 3\text{ cm} \cdot 2\text{ cm} = \mathbf{36\ cm^3}$

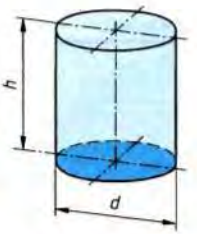
**Volume**

$$V = l \cdot w \cdot h$$

**Surface area**

$$A_s = 2 \cdot (l \cdot w + l \cdot h + w \cdot h)$$

## Cylinder




$V$ volume
$A_s$ surface area
$A_c$ cylindrical surface area
$d$ diameter
$h$ height

**Example:**

$d = 14$ mm; $h = 25$ mm; $V = ?$

$$V = \frac{\pi \cdot d^2}{4} \cdot h$$

$$= \frac{\pi \cdot (14\text{ mm})^2}{4} \cdot 25\text{ mm}$$

$$= \mathbf{3848\ mm^3}$$

**Volume**

$$V = \frac{\pi \cdot d^2}{4} \cdot h$$

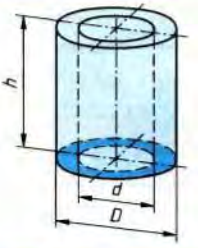
**Surface area**

$$A_s = \pi \cdot d \cdot h + 2 \cdot \frac{\pi \cdot d^2}{4}$$

**Cylindrical surface area**

$$A_c = \pi \cdot d \cdot h$$

## Hollow cylinder




$V$ volume
$A_s$ surface area
$D, d$ diameter
$h$ height

**Example:**

$D = 42$ mm; $d = 20$ mm; $h = 80$ mm; $V = ?$

$$V = \frac{\pi \cdot h}{4} \cdot (D^2 - d^2)$$

$$= \frac{\pi \cdot 80\text{ mm}}{4} \cdot (42^2\text{ mm}^2 - 20^2\text{ mm}^2)$$

$$= \mathbf{85\,703\ mm^3}$$

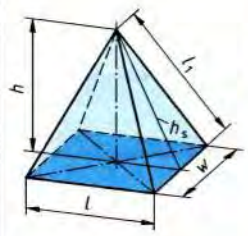
**Volume**

$$V = \frac{\pi \cdot h}{4} \cdot (D^2 - d^2)$$

**Surface area**

$$A_s = \pi \cdot (D + d) \cdot \left[\frac{1}{2} \cdot (D - d) + h\right]$$

## Pyramid




$V$ volume
$h$ height
$h_s$ slant height
$l$ length of base
$l_1$ edge length
$w$ width of base

**Example:**

$l = 16$ mm; $w = 21$ mm; $h = 45$ mm; $V = ?$

$$V = \frac{l \cdot w \cdot h}{3} = \frac{16\text{ mm} \cdot 21\text{ mm} \cdot 45\text{ mm}}{3}$$

$$= \mathbf{5040\ mm^3}$$

**Volume**

$$V = \frac{l \cdot w \cdot h}{3}$$

**Edge length**

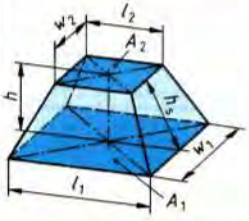
$$l_1 = \sqrt{h_s^2 + \frac{w^2}{4}}$$

**Slant height**

$$h_s = \sqrt{h^2 + \frac{l^2}{4}}$$

# Truncated pyramid, Cone, Truncated cone, Sphere, Spherical segment

## Truncated pyramid




$V$ volume; $A_1$ area of base surface; $h_s$ slant height; $l_1, l_2$ lengths of base; $A_2$ top surface; $h$ height; $w_1, w_2$ widths

**Example:**

$l_1 = 40$ mm; $l_2 = 22$ mm; $w_1 = 28$ mm; $w_2 = 15$ mm; $h = 50$ mm; $V = ?$

$$V = \frac{h}{3} \cdot (A_1 + A_2 + \sqrt{A_1 \cdot A_2})$$

$$= \frac{50\,\text{mm}}{3} \cdot (1120 + 330 + \sqrt{1120 \cdot 330})\,\text{mm}^2$$

$$= \mathbf{34\,299\,mm^3}$$

**Volume**

$$V = \frac{h}{3} \cdot (A_1 + A_2 + \sqrt{A_1 \cdot A_2})$$

**Slant height**

$$h_s = \sqrt{h^2 + \left(\frac{l_1 - l_2}{2}\right)^2}$$

## Cone




$V$ volume; $h$ height; $A_c$ conical surface area; $h_s$ slant height; $d$ diameter

**Example:**

$d = 52$ mm; $h = 110$ mm; $V = ?$

$$V = \frac{\pi \cdot d^2}{4} \cdot \frac{h}{3}$$

$$= \frac{\pi \cdot (52\,\text{mm})^2}{4} \cdot \frac{110\,\text{mm}}{3}$$

$$= \mathbf{77870\,mm^3}$$

**Volume**

$$V = \frac{\pi \cdot d^2}{4} \cdot \frac{h}{3}$$

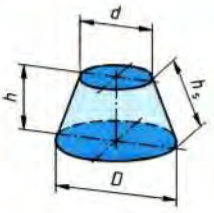
**Conical surface area**

$$A_c = \frac{\pi \cdot d \cdot h_s}{2}$$

**Slant height**

$$h_s = \sqrt{\frac{d^2}{4} + h^2}$$

## Truncated cone




$V$ volume; $A_c$ conical surface area; $D$ diameter of base; $d$ diameter of top; $h$ height; $h_s$ slant height

**Example:**

$D = 100$ mm; $d = 62$ mm; $h = 80$ mm; $V = ?$

$$V = \frac{\pi \cdot h}{12} \cdot (D^2 + d^2 + D \cdot d)$$

$$= \frac{\pi \cdot 80\,\text{mm}}{12} \cdot (100^2 + 62^2 + 100 \cdot 62)\,\text{mm}^2$$

$$= \mathbf{419\,800\,mm^3}$$

**Volume**

$$V = \frac{\pi \cdot h}{12} \cdot (D^2 + d^2 + D \cdot d)$$

**Conical surface area**

$$A_c = \frac{\pi \cdot h_s}{2} \cdot (D + d)$$

**Slant height**

$$h_s = \sqrt{h^2 + \left(\frac{D - d}{2}\right)^2}$$

## Sphere




$V$ volume; $A_s$ surface area; $d$ diameter of sphere

**Example:**

$d = 9$ mm; $V = ?$

$$V = \frac{\pi \cdot d^3}{6} \cdot \frac{\pi \cdot (9\,\text{mm})^3}{6} = \mathbf{382\,mm^3}$$

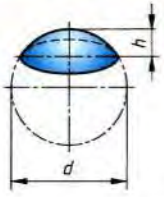
**Volume**

$$V = \frac{\pi \cdot d^3}{6}$$

**Surface area**

$$A_s = \pi \cdot d^2$$

## Spherical segment




$V$ volume; $A_l$ lateral surface area; $A_s$ surface area; $d$ diameter of sphere; $h$ height

**Example:**

$d = 8$ mm; $h = 6$ mm; $V = ?$

$$V = \pi \cdot h^2 \cdot \left(\frac{d}{2} - \frac{h}{3}\right)$$

$$= \pi \cdot 6^2\,\text{mm}^2 \cdot \left(\frac{8\,\text{mm}}{2} - \frac{6\,\text{mm}}{3}\right)$$

$$= \mathbf{226\,mm^3}$$

**Volume**

$$V = \pi \cdot h^2 \cdot \left(\frac{d}{2} - \frac{h}{3}\right)$$

**Surface area**

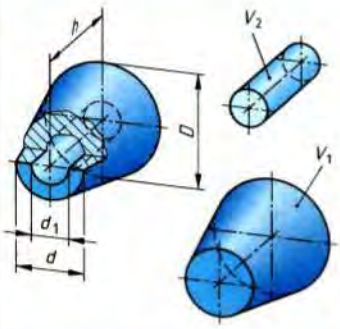
$$A_s = \pi \cdot h \cdot (2 \cdot d - h)$$

**Lateral surface area**

$$A_l = \pi \cdot d \cdot h$$

# Volumes of composite solids, Calculation of mass

## Volumes of composite solids




$V$ total volume
$V_1$, $V_2$ partial volumes

**Total volume**

$$V = V_1 + V_2 + \ldots - V_3 - V_4$$

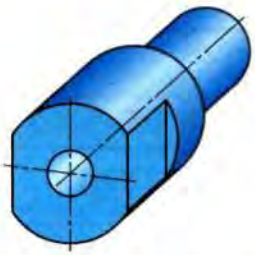
**Example:**

Tapered sleeve; $D = 42$ mm; $d = 26$ mm;
$d_1 = 16$ mm; $h = 45$ mm; $V = ?$

$$V_1 = \frac{\pi \cdot h}{12} \cdot (D^2 + d^2 + D \cdot d)$$
$$= \frac{\pi \cdot 45\,\text{mm}}{12} \cdot (42^2 + 26^2 + 42 \cdot 26)\,\text{mm}^2$$
$$= 41610\,\text{mm}^3$$
$$V_2 = \frac{\pi \cdot d_1^2}{4} \cdot h = \frac{\pi \cdot 16^2\,\text{mm}^2}{4} \cdot 45\,\text{mm} = 9048\,\text{mm}^3$$
$$V = V_1 - V_2 = 41610\,\text{mm}^3 - 9048\,\text{mm}^3 = \mathbf{32562\,mm^3}$$

## Calculation of mass

### Mass, general



$m$ mass
$V$ volume
$\varrho$ density

**Mass**

$$m = V \cdot \varrho$$

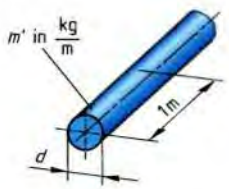
**Example:**

Workpiece made of aluminum;
$V = 6.4\,\text{dm}^3$; $\varrho = 2.7\,\text{kg/dm}^3$; $m = ?$

$$m = V \cdot \varrho = 6.4\,\text{dm}^3 \cdot 2.7\,\frac{\text{kg}}{\text{dm}^3}$$
$$= \mathbf{17.28\,kg}$$

Values for density of solids, liquids and gases: pages 116 and 117

### Linear mass density




$m$ mass
$m'$ linear mass density
$l$ length

**Linear mass density**

$$m = m' \cdot l$$

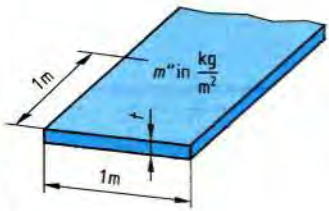
**Example:**

Steel bar with $d = 15$ mm;
$m' = 1.39$ kg/m; $l = 3.86$ m; $m = ?$

$$m = m' \cdot l = 1.39\,\frac{\text{kg}}{\text{m}} \cdot 3.86\,\text{m}$$
$$= \mathbf{5.37\,kg}$$

Application: Calculating the mass of profile sections, pipes, wires, etc. using the table values for $m'$

### Area mass density




$m$ mass
$m''$ area mass density
$A$ area

**Area mass density**

$$m = m'' \cdot A$$

**Example:**

Steel sheet
$t = 1.5$ mm; $m'' = 11.8\,\text{kg/m}^2$;
$A = 7.5\,\text{m}^2$; $m = ?$

$$m = m'' \cdot A = 11.8\,\frac{\text{kg}}{\text{m}^2} \cdot 7.5\,\text{m}^2$$
$$= \mathbf{88.5\,kg}$$

Application: Calculating the mass of sheet metal, foils, coatings, etc using the table values for $m''$

# Centroids of Lines and Plane Areas

## Centroids of lines

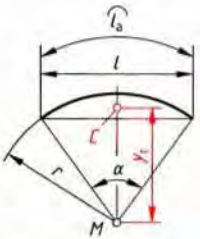
$l, l_1, l_2$ lengths of the lines $C, C_1, C_2$ centroids of the lines
$x_c, x_1, x_2$ horizontal distances of the line centroids from the $y$-axis
$y_c, y_1, y_2$ vertical distances of the line centroids from the $x$-axis

### Line segment




$$x_c = \frac{l}{2}$$

### Circular arc




Calculation of $l$ and $l_a$: Page 28

**General**

$$y_c = \frac{r \cdot l}{l_a}$$

$$y_c = \frac{l \cdot 180^\circ}{\pi \cdot \alpha}$$

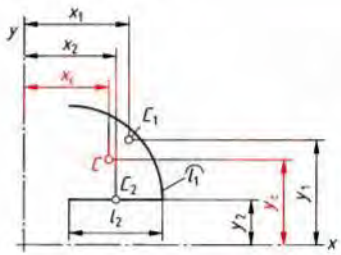
**Semicircular arc**

$$y_c \approx 0.6366 \cdot r$$

**Quarter circle arc**

$$y_c \approx 0.9003 \cdot r$$

### Composite continuous lines



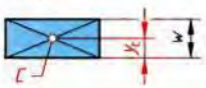

$$x_c = \frac{l_1 \cdot x_1 + l_2 \cdot x_2 + \ldots}{l_1 + l_2 + \ldots}$$

$$y_c = \frac{l_1 \cdot y_1 + l_2 \cdot y_2 + \ldots}{l_1 + l_2 + \ldots}$$

## Centroids of plane areas

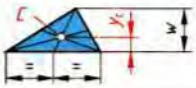
$A, A_1, A_2$ areas $C, C_1, C_2$ centroids of the areas
$x_c, x_1, x_2$ horizontal distances of the area centroids from the $y$-axis
$y_c, y_1, y_2$ vertical distances of the area centroids from the $x$-axis

### Rectangle



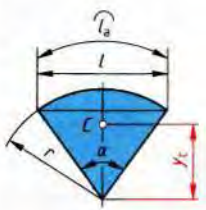

$$y_c = \frac{w}{2}$$

### Triangle




$$y_c = \frac{w}{3}$$

### Circular sector




**General**

$$y_c = \frac{2 \cdot r \cdot l}{3 \cdot l_a}$$

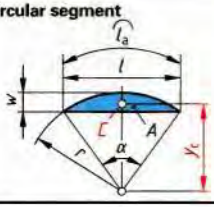
**Semi-circle area**

$$y_c \approx 0.4244 \cdot r$$

**Quarter circle area**

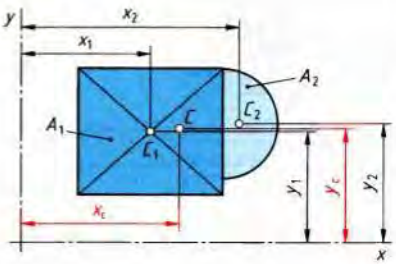
$$y_c \approx 0.6002 \cdot r$$

### Circular segment




$$y_c = \frac{l^3}{12 \cdot A}$$

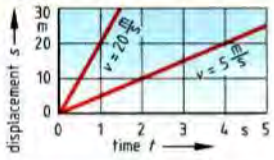
### Composite areas




$$x_c = \frac{A_1 \cdot x_1 + A_2 \cdot x_2 + \ldots}{A_1 + A_2 + \ldots}$$

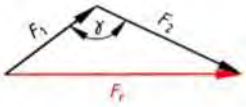
$$y_c = \frac{A_1 \cdot y_1 + A_2 \cdot y_2 + \ldots}{A_1 + A_2 + \ldots}$$

# 2 Physics



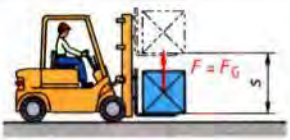

## 2.1 Motion

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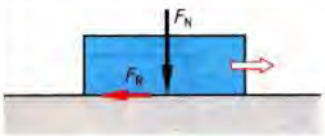

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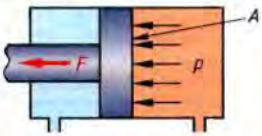

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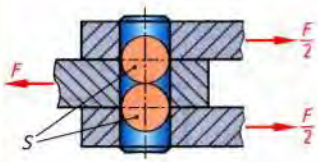

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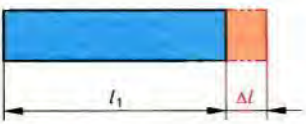

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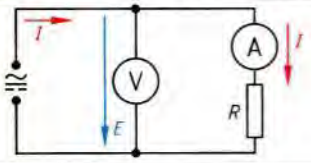

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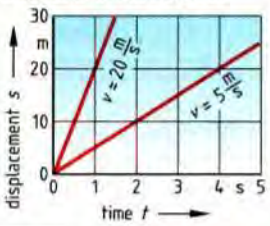
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# Uniform motion and uniformly accelerated motion

## Uniform motion

### Linear motion

**Displacement-time diagram**




$v$ velocity
$t$ time
$s$ displacement

**Example:**

$v = 48$ km/h; $s = 12$ m; $t = ?$

Conversion: $48\,\frac{\text{km}}{\text{h}} = \frac{48000\,\text{m}}{3600\,\text{s}} = 13.33\,\frac{\text{m}}{\text{s}}$

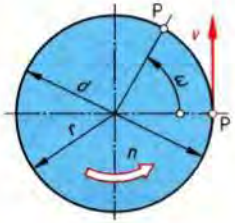
$$t = \frac{s}{v} = \frac{12\,\text{m}}{13.33\,\text{m/s}} = \mathbf{0.9\,s}$$

**Velocity**

$$v = \frac{s}{t}$$

$$1\,\frac{\text{m}}{\text{s}} = 60\,\frac{\text{m}}{\text{min}} = 3.6\,\frac{\text{km}}{\text{h}}$$
$$1\,\frac{\text{km}}{\text{h}} = 16.667\,\frac{\text{m}}{\text{min}} = 0.2778\,\frac{\text{m}}{\text{s}}$$

### Circular motion




$v$ circumferential velocity, cutting speed
$n$ rotational speed
$\omega$ angular velocity
$r$ radius
$d$ diameter

**Example:**

Pulley, $d = 250$ mm; $n = 1400\ \text{min}^{-1}$; $v = ?$; $\omega = ?$

Conversion: $n = 1400\,\text{min}^{-1} = \frac{1400}{60\,\text{s}} = 23.33\,\text{s}^{-1}$

$$v = \pi \cdot d \cdot n = \pi \cdot 0.25\,\text{m} \cdot 23.33\,\text{s}^{-1} = \mathbf{18.3\,\frac{m}{s}}$$

$$\omega = 2 \cdot \pi \cdot n = 2 \cdot \pi \cdot 23.33\,\text{s}^{-1} = \mathbf{146.6\,s^{-1}}$$

**Circumferential velocity**

$$v = \pi \cdot d \cdot n$$
$$v = \omega \cdot r$$

**Angular velocity**

$$\omega = 2 \cdot \pi \cdot n$$

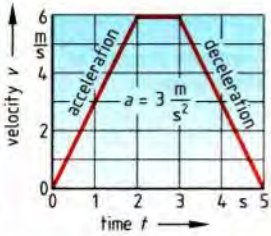
$$\frac{1}{\text{min}} = \text{min}^{-1} = \frac{1}{60\,\text{s}}$$

For a cutting speed of a circumferential velocity see page 35.

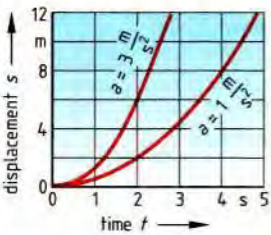
## Uniformly accelerated motion

### Linear accelerated motion

**Velocity-time diagram**




**Displacement-time diagram**




The increase in velocity per second is called **acceleration;** and a decrease is **deceleration.** Free fall is uniformly accelerated motion on which gravitational acceleration $g$ is acting.

$v$ terminal velocity (acceleration), or initial velocity (deceleration)
$s$ displacement
$t$ time
$a$ acceleration
$g$ gravitational acceleration

**1st example:**

Object, free fall from $s = 3$ m; $v = ?$

$a = g = 9.81\,\frac{\text{m}}{\text{s}^2}$

$$v = \sqrt{2 \cdot a \cdot s} = \sqrt{2 \cdot 9.81\,\text{m/s}^2 \cdot 3\,\text{m}} = \mathbf{7.7\,\frac{m}{s}}$$

**2nd example:**

Vehicle, $v = 80$ km/h; $a = 7$ m/s²;
Braking distance $s = ?$

Conversion: $v = 80\,\frac{\text{km}}{\text{h}} = \frac{80000\,\text{m}}{3600\,\text{s}} = 22.22\,\frac{\text{m}}{\text{s}}$

$$v = \sqrt{2 \cdot a \cdot s}$$

$$s = \frac{v^2}{2 \cdot a} = \frac{(22.22\,\text{m/s})^2}{2 \cdot 7\,\text{m/s}^2} = \mathbf{35.3\,m}$$

The following applies to acceleration from rest or deceleration to rest:

**Terminal or initial velocity**

$$v = a \cdot t$$
$$v = \sqrt{2 \cdot a \cdot s}$$

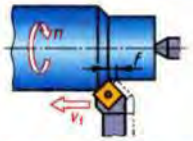
**Displacement due to acceleration/ deceleration**

$$s = \frac{1}{2} \cdot v \cdot t$$
$$s = \frac{1}{2} \cdot a \cdot t^2$$
$$s = \frac{v^2}{2 \cdot a}$$

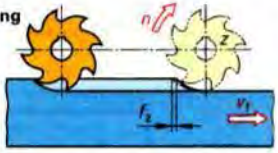
# Speeds of machines

## Feed rate

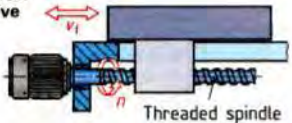
**Turning**



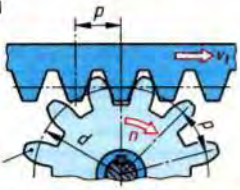

**Milling**




**Screw drive**




**Rack and pinion**




$v_f$ feed rate
$n$ rotational speed
$f$ feed
$f_t$ feed per cutting edge
$N$ number of cutting edges, or number of teeth on the pinion
$P$ thread pitch
$p$ pitch of rack and pinion

**1st example:**

Cylindrical milling cutter, $z = 8$; $f_t = 0.2$ mm; $n = 45$/min; $v_f = ?$

$$v_f = n \cdot f_t \cdot N = 45 \frac{1}{\text{min}} \cdot 0.2 \text{ mm} \cdot 8 = \mathbf{72 \frac{mm}{min}}$$

**2nd example:**

Feed drive with threaded spindle, $P = 5$ mm; $n = 112$/min; $v_f = ?$

$$v_f = n \cdot P = 112 \frac{1}{\text{min}} \cdot 5 \text{ mm} = \mathbf{560 \frac{mm}{min}}$$

**3rd example:**

Feed of rack and pinion, $n = 80$/min; $d = 75$ mm; $v_f = ?$

$$v_f = \pi \cdot d \cdot n = \pi \cdot 75 \text{ mm} \cdot 80 \frac{1}{\text{min}}$$

$$= 18\,850 \frac{\text{mm}}{\text{min}} = \mathbf{18.85 \frac{m}{min}}$$

**Feed rate**
for drilling, turning

$$v_f = n \cdot f$$

**Feed rate**
for milling

$$v_f = n \cdot f_t \cdot N$$

**Feed rate**
for screw drive

$$v_f = n \cdot P$$

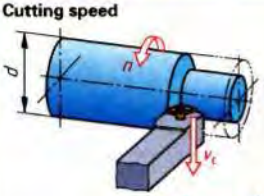
**Feed rate for**
rack and pinion

$$v_f = n \cdot N \cdot p$$

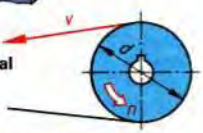
$$v_f = \pi \cdot d \cdot n$$

## Cutting speed, Circumferential velocity

**Cutting speed**




**Circumferential velocity**




$v_c$ cutting speed
$v$ circumferential velocity
$d$ diameter
$n$ rotational speed

**Example:**

Turning, $n = 1200$/min; $d = 35$ mm; $v_c = ?$

$$v_c = \pi \cdot d \cdot n = \pi \cdot 0.035 \text{ m} \cdot 1200 \frac{1}{\text{min}}$$

$$= \mathbf{132 \frac{m}{min}}$$

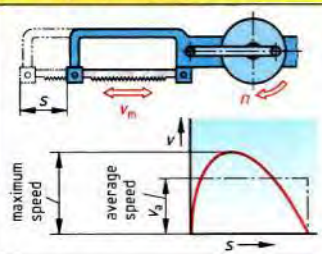
**Cutting speed**

$$v_c = \pi \cdot d \cdot n$$

**Circumferential velocity**

$$v = \pi \cdot d \cdot n$$

## Average speed of crank mechanism




$v_a$ average speed
$n$ number of double strokes
$s$ stroke length

**Example:**

Power hacksaw, $s = 280$ mm; $n = 45$/min; $v_a = ?$

$$v_a = 2 \cdot s \cdot n = 2 \cdot 0.28 \text{ m} \cdot 45 \frac{1}{\text{min}}$$

$$= \mathbf{25.2 \frac{m}{min}}$$

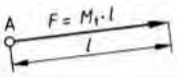
**Average speed**

$$v_a = 2 \cdot s \cdot n$$

# Types of forces

## Adding and resolving forces

Chosen for the following examples $M_f = 10\ \frac{N}{mm}$



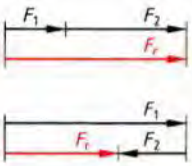

$F_1$, $F_2$ component forces
$F_r$ resultant force
$l$ vector magnitude (length)
$M_f$ scale of forces

**Representing forces**

Forces are represented by vectors. The length $l$ of the vector corresponds to the magnitude of the force $F$.

**Vector magnitude**

$$l = \frac{F}{M_f}$$




**Adding collinear forces acting in the same direction**

**Example:** $F_1 = 80$ N; $F_2 = 160$ N; $F_r = ?$

$F_r = F_1 + F_2 = 80\ N + 160\ N = \mathbf{240\ N}$

**Sum**

$$F_r = F_1 + F_2$$

**Subtracting collinear forces acting in opposite directions**

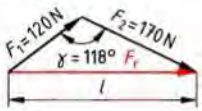
**Example:** $F_1 = 240$ N; $F_2 = 90$ N; $F_r = ?$

$F_r = F_1 - F_2 = 240\ N - 90\ N = \mathbf{150\ N}$

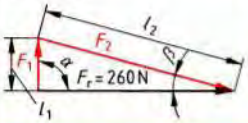
**Difference**

$$F_r = F_1 - F_2$$

**Addition**




**Resolution**




**Addition and resolution of forces whose lines of action intersect**

**Example of graphical addition:**

$F_1 = 120$ N; $F_2 = 170$ N; $\gamma = 118°$;
$M_f = 10$ N/mm; $F_r = ?$; measured: $l = 25$ mm

$F_r = l \cdot M_f = 25\ mm \cdot 10\ N/mm = \mathbf{250\ N}$

**Example of graphical resolution:**

$F_r = 260$ N; $\alpha = 90°$; $\beta = 15°$; $M_f = 10$ N/mm;
$F_1 = ?$; $F_2 = ?$; measured: $l_1 = 7$ mm; $l_2 = 27$ mm

$F_1 = l_1 \cdot M_f = 7\ mm \cdot 10\ N/mm = \mathbf{70\ N}$

$F_2 = l_2 \cdot M_f = 27\ mm \cdot 10\ N/mm = \mathbf{270\ N}$

**Solving a force diagram by adding or resolving (force vectors)**

| Shape of the force diagram | Required trigonometric function |
|---|---|
| Force diagram with right angles | sine, cosine, tangent |
| Force diagram with oblique angles | Law of sines, Law of cosines |

## Forces of acceleration and deceleration




A force is required to accelerate or decelerate a mass.

$F$ acceleration force
$m$ mass
$a$ acceleration

**Example:**

$m = 50\ kg$; $a = 3\ \frac{m}{s^2}$; $F = ?$

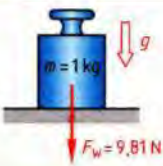
$F = m \cdot a = 50\ kg \cdot 3\ \frac{m}{s^2} = 150\ kg \cdot \frac{m}{s^2} = \mathbf{150\ N}$

**Acceleration force**

$$F = m \cdot a$$

$1\ N = 1\ kg \cdot \frac{m}{s^2}$

## Weight




Gravity generates a weight force on a mass.

$F_W$ weight
$m$ mass
$g$ gravitational acceleration

**Example:**

I-beam, $m = 1200$ kg; $F_W = ?$

$F_W = m \cdot g = 1200\ kg \cdot 9.81\ \frac{m}{s^2} = \mathbf{11\,772\ N}$

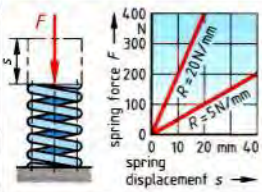
**Weight**

$$F_W = m \cdot g$$

$g = 9.81\ \frac{m}{s^2} \approx 10\ \frac{m}{s^2}$

Calculation of mass: page 31

## Spring force (Hooke's law)




The force and corresponding linear expansion of a spring are proportional within the elastic range.

$F$ spring force
$R$ spring constant
$s$ spring displacement

**Example:**

Compression spring, $R = 8$ N/mm; $s = 12$ mm; $F = ?$

$F = R \cdot s = 8\ \frac{N}{mm} \cdot 12\ mm = \mathbf{96\ N}$

**Spring force**

$$F = R \cdot s$$

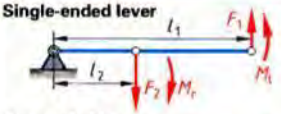
**Change in spring force**

$$\Delta F = R \cdot \Delta s$$

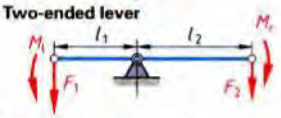
# Torque, Levers, Centrifugal force

## Torque and levers

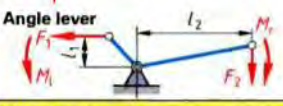
**Single-ended lever**




**Two-ended lever**




**Angle lever**




The **effective lever arm** is the right angle distance between the fulcrum and the line of application of the force. For disk shaped rotating parts the lever arm corresponds to the radius *r*.

$M$ moment — $F$ force
$l$ effective lever arm
$\Sigma M_l$ sum of all counter-clockwise moments
$\Sigma M_r$ sum of all clockwise moments

**Example:**

Angle lever, $F_1 = 30$ N; $l_1 = 0.15$ m; $l_2 = 0.45$ m; $F_2 = ?$

$$F_2 = \frac{F_1 \cdot l_1}{l_2} = \frac{30\ \text{N} \cdot 0.15\ \text{m}}{0.45\ \text{m}} = \mathbf{10\ N}$$

**Moment**

$$M = F \cdot l$$

**Lever principle**

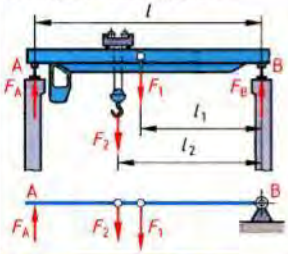
$$\Sigma M_l = \Sigma M_r$$

**Lever principle with only 2 applied forces**

$$F_1 \cdot l_1 = F_2 \cdot l_2$$

## Bearing forces

**Example of bearing forces**




A bearing point is treated as a fulcrum in calculating bearing forces.

$F_A$, $F_B$ bearing forces — $l$, $l_1$, $l_2$ effective lever arms
$F_1$, $F_2$ forces

**Example:**

Overhead travelling crane, $F_1 = 40$ kN; $F_2 = 15$ kN; $l_1 = 6$ m; $l_2 = 8$ m; $l = 12$ m; $F_A = ?$

Solution: B is selected as fulcrum point; the bearing force $F_A$ is assumed on a single-ended lever.

$$F_A = \frac{F_1 \cdot l_1 + F_2 \cdot l_2}{l} = \frac{40\ \text{kN} \cdot 6\ \text{m} + 15\ \text{kN} \cdot 8\ \text{m}}{12\ \text{m}} = \mathbf{30\ kN}$$

**Lever principle**

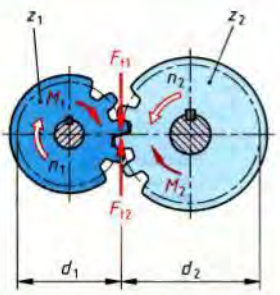
$$\Sigma M_l = \Sigma M_r$$

**Bearing force at A**

$$F_A = \frac{F_1 \cdot l_1 + F_2 \cdot l_2 \ldots}{l}$$

$$F_A + F_B = F_1 + F_2 \ldots$$

## Torque in gear drives




The lever arm of a gear is half of its reference diameter *d*. Different torques result if two engaging gears do not have the same number of teeth.

| **Driving gear** | | **Driven gear** | |
|---|---|---|---|
| $F_{t1}$ | tangential force | $F_{t2}$ | tangential force |
| $M_1$ | torque | $M_2$ | torque |
| $d_1$ | reference diameter | $d_2$ | reference diameter |
| $z_1$ | number of teeth | $z_2$ | number of teeth |
| $n_1$ | rotational speed | $n_2$ | rotational speed |
| $i$ | gear ratio | | |

**Example:**

Gears, $i = 12$; $M_1 = 60$ N · m; $M_2 = ?$

$$M_2 = i \cdot M_1 = 12 \cdot 60\ \text{N} \cdot \text{m} = \mathbf{720\ N \cdot m}$$

For gear ratios for gear drives see page 259.

**Torques**

$$M_1 = \frac{F_{t1} \cdot d_1}{2}$$

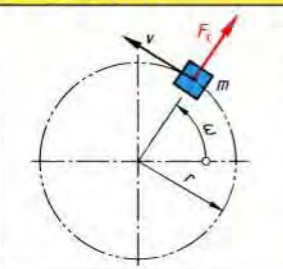
$$M_2 = \frac{F_{t2} \cdot d_2}{2}$$

$$M_2 = i \cdot M_1$$

$$\frac{M_2}{M_1} = \frac{z_2}{z_1}$$

$$\frac{M_2}{M_1} = \frac{n_1}{n_2}$$

## Centrifugal force




**Centrifugal force $F_c$** when a mass is made to move along a curvilinear path, e.g. a circle.

$F_c$ centrifugal force — $\omega$ angular velocity
$m$ mass — $v$ circumferential velocity
$r$ radius

**Example:**

Turbine blade, $m = 160$ g; $v = 80$ m/s; $d = 400$ mm; $F_c = ?$

$$F_c = \frac{m \cdot v^2}{r} = \frac{0.16\ \text{kg} \cdot (80\ \text{m/s})^2}{0.2\ \text{m}} = 5120\ \frac{\text{kg} \cdot \text{m}}{\text{s}^2} = \mathbf{5120\ N}$$

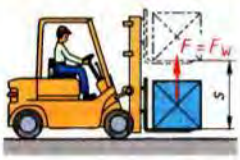
**Centrifugal force**

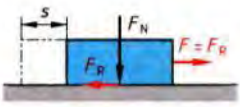
$$F_c = m \cdot r \cdot \omega^2$$

$$F_c = \frac{m \cdot v^2}{r}$$

# Work and Energy

## Mechanical work, lifting work and frictional work




Work is performed when a force acts along a distance.

| | | | |
|---|---|---|---|
| $F$ | force in direction of travel | $W$ | work |
| $F_W$ | weight | $s$ | force distance |
| $F_R$ | friction force | $s, h$ | height of lift |
| $F_N$ | normal force | $\mu$ | coefficient of friction |

**1st example:**

$F = 300\ \text{N};\ s = 4\ \text{m};\ W = ?$

$\boldsymbol{W = F \cdot s = 300\ \text{N} \cdot 4\ \text{m} = 1200\ \text{N} \cdot \text{m} = 1200\ \text{J}}$

**2nd example:**

Frictional work, $F_N = 0.8\ \text{kN};\ s = 1.2\ \text{m};\ \mu = 0.4;\ W = ?$

$\boldsymbol{W = \mu \cdot F_N \cdot s = 0.4 \cdot 800\ \text{N} \cdot 1.2\ \text{m} = 384\ \text{N} \cdot \text{m} = 384\ \text{J}}$

**Work**

$$W = F \cdot s$$

**Lifting work**

$$W = F_W \cdot h$$

**Frictional work**

$$W = \mu \cdot F_N \cdot s$$

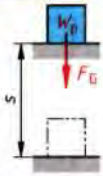
$1\ \text{J} = 1\ \text{N} \cdot 1\ \text{m}$

$= 1\ \text{W} \cdot \text{s} = 1\ \frac{\text{kg} \cdot \text{m}^2}{\text{s}^2}$

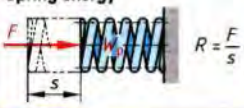
$1\ \text{kW} \cdot \text{h} = 3.6\ \text{MJ}$

## Energie of position

**Energy of position**




**Spring energy**




Energie of position is stored work (energy of position, spring energy).

| | | | |
|---|---|---|---|
| $E, W_p$ | energy of position | $R$ | spring constant |
| $F_W$ | weight | $s, h$ | travel, lift or fall height, spring displacement |
| $F$ | force | | |

**Example:**

Drop hammer, $m = 30\ \text{kg};\ s = 2.6\ \text{m};\ W_p = ?$

$\boldsymbol{W_p = F_W \cdot s = 30\ \text{kg} \cdot 9.81\ \frac{\text{m}}{\text{s}^2} \cdot 2.6\ \text{m} = 765\ \text{J}}$

**Energy of position**

$$W_p = F_W \cdot s$$

**Energy of the spring**

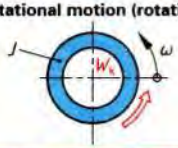
$$W_p = \frac{R \cdot s^2}{2}$$

## Kinetic energy

**Linear motion**




**Rotational motion (rotation)**




Kinetic energy is energy of motion.

| | | | |
|---|---|---|---|
| $E, W_k$ | kinetic energy or work | $v$ | velocity |
| $\omega$ | angular velocity | $m$ | mass |
| $J$ | mass moment of inertia | | |

**Example:**

Drop hammer, $m = 30\ \text{kg};\ s = 2.6\ \text{m};\ W_k = ?$

$v = \sqrt{2 \cdot g \cdot s} = \sqrt{2 \cdot 9.81\ \text{m/s}^2 \cdot 2.6\ \text{m}} = 7.14\ \text{m/s}$

$\boldsymbol{W_k = \frac{m \cdot v^2}{2} = \frac{30\ \text{kg} \cdot (7.14\ \text{m/s})^2}{2} = 765\ \text{J}}$

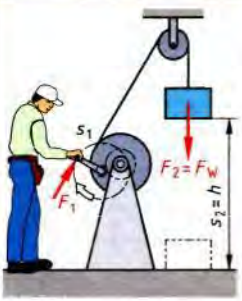
**Kinetic energy of linear motion**

$$W_k = \frac{m \cdot v^2}{2}$$

**Kinetic energy of rotational motion**

$$W_k = \frac{J \cdot \omega^2}{2}$$

## Golden Rule of Mechanics




"What is gained in force is lost in distance".

| | | | |
|---|---|---|---|
| $W_1$ | input work | $W_2$ | output work |
| $F_1$ | input force | $F_2$ | output force |
| $s_1$ | displacement of force $F_1$ | $s_2$ | displacement of force $F_2$ |
| $F_W$ | weight | $\eta$ | efficiency |
| $h$ | height of lift | | |

**Example:**

Lifting device, $F_W = 5\ \text{kN};\ h = 2\ \text{m};\ F = 300\ \text{N};\ s = ?$

$\boldsymbol{s = \frac{F_W \cdot h}{F} = \frac{5000\ \text{N} \cdot 2\ \text{m}}{300\ \text{N}} = 33.3\ \text{m}}$

**"Golden Rule" of Mechanics**

$$W_1 = W_2$$

$$F_1 \cdot s_1 = F_2 \cdot s_2$$

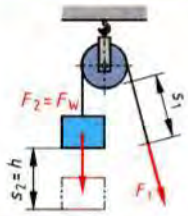
$$F_1 \cdot s_1 = F_W \cdot h$$

**Allowing for friction**

$$W_1 = \frac{W_2}{\eta}$$

# Simple machines

## Fixed pulley[1)]

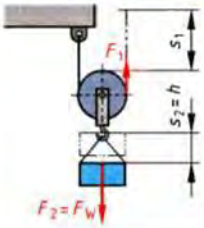



$$F_1 = F_W$$

$$s_1 = h$$

$$W_2 = F_W \cdot h$$

## Movable pulley[1)]

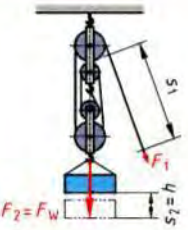



$$F_1 = \frac{F_W}{2}$$

$$s_1 = 2 \cdot h$$

$$W_2 = F_W \cdot h$$

## Block and tackle[1)]



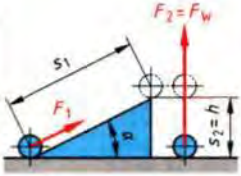

$n$ no. of load-bearing ropes, pulleys

$$F_1 = \frac{F_W}{n}$$

$$s_1 = n \cdot h$$

$$W_2 = F_W \cdot h$$

## Inclined plane[1)]



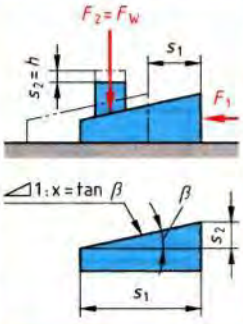

$\alpha$ angle of inclination

$$F_1 \cdot s_1 = F_W \cdot h$$

$$F_1 = F_W \cdot \sin\alpha$$

$$W_2 = F_W \cdot h$$

## Wedge[1)]




$\beta$ angle of inclination
$\tan\beta$ incline

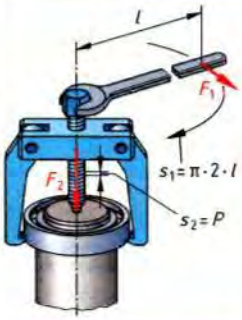
$$F_1 \cdot s_1 = F_2 \cdot h$$

$$F_2 = \frac{F_1}{\tan\beta}$$

$$s_2 = s_1 \cdot \tan\beta$$

$$W_2 = F_2 \cdot h$$

## Bolt[1)]




$P$ thread pitch
$l$ lever arm
For 1 full turn

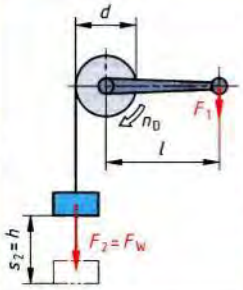
$$F_1 \cdot 2 \cdot \pi \cdot l = F_2 \cdot P$$

$$s_1 = 2 \cdot \pi \cdot l$$

$$W_1 = F_1 \cdot 2 \cdot \pi \cdot l$$

$$W_2 = F_2 \cdot P$$

## Hoisting winch[1)]



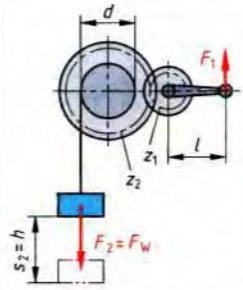

$l$ crank length
$d$ drum diameter
$n_D$ number of turns of the drum

$$F_1 \cdot l = \frac{F_W \cdot d}{2}$$

$$h = \pi \cdot d \cdot n_D$$

$$W_2 = F_W \cdot h$$

## Gear winch[1)]




$l$ crank length
$d$ drum diameter
$i$ gear ratio

$$F_1 \cdot l \cdot i = \frac{F_W \cdot d}{2}$$

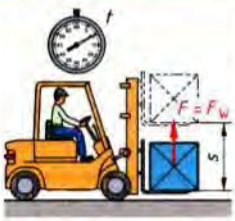
$$i = \frac{z_2}{z_1}$$

$$W_2 = F_W \cdot h$$

[1)] The formulae apply to a hypothetical frictionless condition, wherein the output work $W_1$ is equal to the input work $W_2$.

# Power and Efficiency

## Power in linear motion



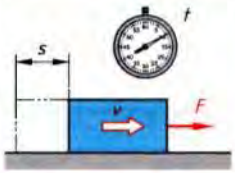

Power is work per unit time.

| | | | |
|---|---|---|---|
| $P$ | power | $s$ | displacement in the force direction |
| $W$ | work | | |
| $v$ | velocity | $t$ | time |

**1st example:**

Forklift, $F = 15$ kN; $v = 25$ m/min; $P = ?$

$$P = F \cdot v = 15000\,\text{N} \cdot \frac{25\,\text{m}}{60\,\text{s}} = 6250\,\frac{\text{N}\cdot\text{m}}{\text{s}} = 6250\,\text{W} = \mathbf{6.25\,kW}$$




**2nd example:**

Crane lifts a machine. $m = 1.2$ t; $s = 2.5$ m; $t = 4.5$ s; $P = ?$

$$F_W = m \cdot g = 1200\,\text{kg} \cdot 9.81\,\text{m/s}^2 = 11772\,\text{N}$$

$$P = \frac{F_W \cdot s}{t} = \frac{11772\,\text{N} \cdot 2.5\,\text{m}}{4.5\,\text{s}} = 6540\,\text{W} = \mathbf{6.5\,kW}$$

For power in pumps and cylinders see page 371.

**Power**

$$P = \frac{W}{t}$$

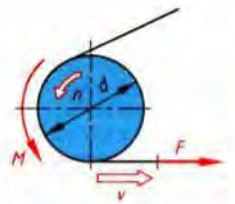
$$P = \frac{F \cdot s}{t}$$

$$P = F \cdot v$$

$$1\,\text{W} = 1\,\frac{\text{J}}{\text{s}} = 1\,\frac{\text{N}\cdot\text{m}}{\text{s}}$$

$1\,\text{kW} = 1.36\,\text{PS}$

## Power in circular motion




| | | | |
|---|---|---|---|
| $P$ | power | $s$ | displacement in the force direction |
| $M$ | torque | $t$ | time |
| $F$ | tangential force | $n$ | rotational speed |
| $v$ | velocity | $\omega$ | angular velocity |

**Example:**

Belt drive, $F = 1.2$ kN; $d = 200$ mm; $n = 2800$/min; $P = ?$

$$P = F \cdot \pi \cdot d \cdot n$$

$$= 1.2\,\text{kN} \cdot \pi \cdot 0.2\,\text{m} \cdot \frac{2800}{60\,\text{s}} = 35.2\,\frac{\text{kN}\cdot\text{m}}{\text{s}} = \mathbf{35.2\,kW}$$

**Numerical equation:**
Enter → $M$ in N · m, $n$ in 1/min
Result → $P$ in kW

For cutting power in machine tools see pages 299 and 300.

**Power**

$$P = F \cdot v$$

$$P = F \cdot \pi \cdot d \cdot n$$

$$P = M \cdot 2 \cdot \pi \cdot n$$

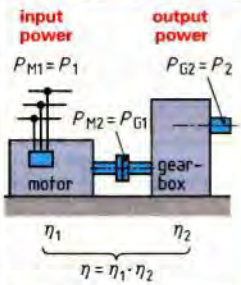
$$P = M \cdot \omega$$

**or:**

**Power**

$$P = \frac{M \cdot n}{9550}$$

## Efficiency




Efficiency refers to the ratio of power or work output to the power or work input.

| | | | |
|---|---|---|---|
| $P_1$ | input power | $P_2$ | output power |
| $W_1$ | input work | $W_2$ | output work |
| $\eta$ | total efficiency | $\eta_1, \eta_2$ | partial efficiencies |

**Example:**

Belt drive, $P_1 = 4$ kW; $P_2 = 3$ kW; $\eta_1 = 85\%$; $\eta = ?$; $\eta_2 = ?$

$$\eta = \frac{P_2}{P_1} = \frac{3\,\text{kW}}{4\,\text{kW}} = \mathbf{0.75}; \qquad \eta_2 = \frac{\eta}{\eta_1} = \frac{0.75}{0.85} = \mathbf{0.88}$$

**Efficiency**

$$\eta = \frac{P_2}{P_1}$$

$$\eta = \frac{W_2}{W_1}$$

**Total efficiency**

$$\eta = \eta_1 \cdot \eta_2 \cdot \eta_3 \cdots$$

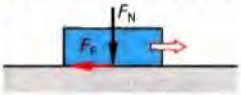
**Efficiencies $\eta$ (approximate values)**

| | | | | | |
|---|---|---|---|---|---|
| Brown coal power station | 0.32 | Gasoline engine | 0.27 | Screw thread | 0.30 |
| Coal power station | 0.41 | Automobile diesel engine (partial load) | 0.24 | Pinion gear | 0.97 |
| Natural gas power station | 0.50 | Automobile diesel engine (full load) | 0.40 | Worm gear, $i = 40$ | 0.65 |
| Gas turbine | 0.38 | Large diesel engine (partial load) | 0.33 | Friction drive | 0.80 |
| Steam turbine (high pressure) | 0.45 | Large diesel engine (full load) | 0.55 | Chain drive | 0.90 |
| Water turbine | 0.85 | Three phase AC motor | 0.85 | Wide V-belt drive | 0.85 |
| Cogeneration | 0.75 | Machine tools | 0.75 | Hydrostatic transmission | 0.75 |

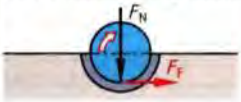
# Types of friction, Coefficients of friction

## Friction force

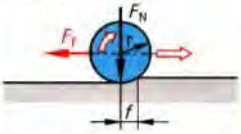
**Static friction, sliding friction**




**Static friction, sliding friction**




**Rolling friction**




The resulting friction force is dependent on the normal force $F_N$ and the

- type of friction, i.e. static, sliding or rolling friction
- frictional condition (lubrication condition): dry, mixed or viscous friction.
- surface roughness
- material pairing (material combination)

These effects are all incorporated into the experimentally determined coefficient of friction $\mu$.

$F_N$ normal force $f$ coefficient of rolling friction
$F_F$ friction force $\mu$ coefficient of friction $r$ radius

**1st example:**

Plain bearing, $F_N = 100$ N; $\mu = 0.03$; $F_F = ?$

$F_F = \mu \cdot F_N = 0.03 \cdot 100\ \text{N} = \mathbf{3\ N}$

**2nd example:**

Crane wheel on steel rail, $F_N = 45$ kN; $d = 320$ mm; $f = 0.5$ mm; $F_F = ?$

$$F_F = \frac{f \cdot F_N}{r} = \frac{0.5\ \text{mm} \cdot 45\,000\ \text{N}}{160\ \text{mm}} = \mathbf{140.6\ N}$$

**Friction force for static and sliding friction**

$$F_F = \mu \cdot F_N$$

**Friction force for rolling friction**[1]

$$F_F = \frac{f \cdot F_N}{r}$$

[1] caused by elastic deformation between roller body and rolling surface

## Coefficients of friction (guideline values)

| Material pairing | Example of application | Coefficient of static friction $\mu$ | | Coefficient of sliding friction $\mu$ | |
|---|---|---|---|---|---|
| | | dry | lubricated | dry | lubricated |
| steel/steel | vise guide | 0.20 | 0.10 | 0.15 | 0.10–0.05 |
| steel/cast iron | machine guide | 0.20 | 0.15 | 0.18 | 0.10–0.08 |
| steel/Cu-Sn alloy | shaft in solid plain bearing | 0.20 | 0.10 | 0.10 | 0.06–0.03[2] |
| steel/Pb-Sn alloy | shaft in multilayer plain bearing | 0.15 | 0.10 | 0.10 | 0.05–0.03[2] |
| steel/polyamide | shaft in PA plain bearing | 0.30 | 0.15 | 0.30 | 0.12–0.03[2] |
| steel/PTFE | low temperature bearing | 0.04 | 0.04 | 0.04 | 0.04[2] |
| steel/friction lining | shoe brake | 0.60 | 0.30 | 0.55 | 0.3–0.2 |
| steel/wood | part on an assembly stand | 0.55 | 0.10 | 0.35 | 0.05 |
| wood/wood | underlay blocks | 0.50 | 0.20 | 0.30 | 0.10 |
| cast iron/Cu-Sn alloy | adjustment gib | 0.28 | 0.16 | 0.20 | 0.20–0.10 |
| rubber/cast iron | belts on a pulley | 0.50 | – | – | – |
| rolling element/steel | anti-friction bearing[3], guideway[3] | – | – | – | 0.003–0.001 |

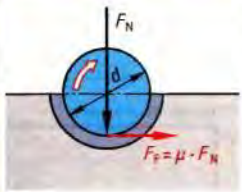
[2] The significance of the material pairing decreases with increasing sliding speed and presence of mixed and viscous friction.
[3] Calculation performed in spite of rolling movement, because it is typically similar to calculations of static or sliding friction.

## Coefficients of rolling friction (guideline values)[4]

| Material pairing | Example of application | Coefficient of rolling friction $f$ in mm |
|---|---|---|
| steel/steel | steel wheel on a guide rail | 0.5 |
| plastic/concrete | caster wheel on concrete floor | 5 |
| rubber/asphalt | car tires on the street | 8 |

[4] Data on coefficients of rolling friction can vary considerably in technical literature.

## Friction moment and friction power in bearings




$M$ friction moment
$F_N$ normal force
$P$ friction power
$\mu$ coefficient of friction
$d$ diameter
$n$ rotational speed

**Example:**

Steel shaft in a Cu-Sn plain bearing, $\mu = 0.05$; $F_N = 6$ kN; $d = 160$ mm; $M = ?$

$$M = \frac{\mu \cdot F_N \cdot d}{2} = \frac{0.05 \cdot 6000\ \text{N} \cdot 0.16\ \text{m}}{2} = \mathbf{24\ N \cdot m}$$

**Friction moment**

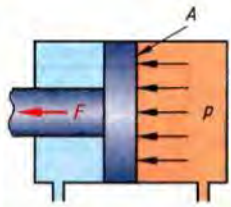
$$M = \frac{\mu \cdot F_N \cdot d}{2}$$

**Friction power**

$$P = \mu \cdot F_N \cdot \pi \cdot d \cdot n$$

# Types of pressure

## Pressure




$p$ pressure
$F$ force
$A$ area

**Example:**

$F = 2$ MN; piston ∅ $d = 400$ mm; $p = ?$

$$p = \frac{F}{A} = \frac{2000000\ \text{N}}{\frac{\pi \cdot (40\ \text{cm})^2}{4}} = 1591 \frac{\text{N}}{\text{cm}^2} = \mathbf{159.1\ bar}$$

For calculations on hydraulics and pneumatics see page 370.

**Pressure**

$$p = \frac{F}{A}$$

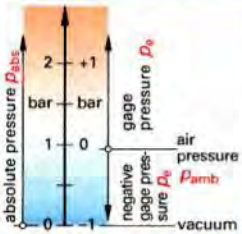
Units of pressure

$1\ \text{Pa} = 1 \frac{\text{N}}{\text{m}^2} = 0.00001\ \text{bar}$

$1\ \text{bar} = 10 \frac{\text{N}}{\text{cm}^2} = 0.1 \frac{\text{N}}{\text{mm}^2}$

$1\ \text{mbar} = 100\ \text{Pa} = 1\ \text{hPa}$

## Gage pressure, air pressure, absolute pressure




$p_e$ gage pressure (excedens, excess)
$p_{amb}$ air pressure (ambient, surroundings)
$p_{abs}$ absolute pressure

The gage pressure is
positive, if $p_{abs} > p_{amb}$ and
negative, if $p_{abs} < p_{amb}$ (vacuum)

**Example:**

Car tires, $p_e = 2.2$ bar; $p_{amb} = 1$ bar; $p_{abs} = ?$

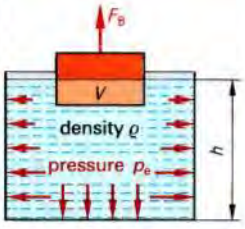
$\mathbf{p_{abs}} = p_e + p_{amb} = 2.2\ \text{bar} + 1\ \text{bar} = \mathbf{3.2\ bar}$

**Gage pressure**

$$p_e = p_{abs} - p_{amb}$$

$p_{amb} = 1.013\ \text{bar} \approx 1\ \text{bar}$
(standard air pressure)

## Hydrostatic pressure, buoyancy




$p_e$ hydrostatic pressure, inherent pressure
$\varrho$ density of the liquid
$g$ gravitational acceleration
$F_B$ buoyant force
$V$ displaced volume
$h$ depth of liquid

**Example:**

What is the pressure in a water depth of 10 m?

$$\mathbf{p_e} = g \cdot \varrho \cdot h = 9.81 \frac{\text{m}}{\text{s}^2} \cdot 1000 \frac{\text{kg}}{\text{m}^3} \cdot 10\ \text{m}$$

$$= 98100 \frac{\text{kg}}{\text{m} \cdot \text{s}^2} = 98100\ \text{Pa} \approx \mathbf{1\ bar}$$

**Hydrostatic pressure**

$$p_e = g \cdot \varrho \cdot h$$

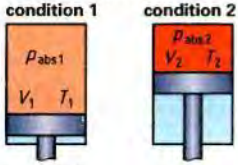
**Buoyant force**

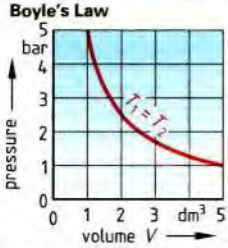
$$F_B = g \cdot \varrho \cdot V$$

$g = 9.81 \frac{\text{m}}{\text{s}^2} \approx 10 \frac{\text{m}}{\text{s}^2}$

For density values, see page 117.

## Pressure changes in gases




**Condition 1**
$p_{abs1}$ absolute pressure
$V_1$ volume
$T_1$ absolute temperature

**Condition 2**
$p_{abs2}$ absolute pressure
$V_2$ volume
$T_2$ absolute temperature

**Example:**

A compressor aspirates $V_1 = 30\ \text{m}^3$ of air at $p_{abs1} = 1$ bar and $t_1 = 15\,^\circ\text{C}$ and compresses it to $V_2 = 3.5\ \text{m}^3$ and $t_2 = 150\,^\circ\text{C}$.

What is the pressure $p_{abs2}$?

Calculation of absolute temperatures (page 51):

$T_1 = t_1 + 273 = (15 + 273)\ \text{K} = 288\ \text{K}$

$T_2 = t_2 + 273 = (150 + 273)\ \text{K} = 423\ \text{K}$

$$\mathbf{p_{abs2}} = \frac{p_{abs1} \cdot V_1 \cdot T_2}{T_1 \cdot V_2}$$

$$= \frac{1\ \text{bar} \cdot 30\ \text{m}^3 \cdot 423\ \text{K}}{288\ \text{K} \cdot 3.5\ \text{m}^3} = \mathbf{12.6\ bar}$$

**Ideal gas law**

$$\frac{p_{abs1} \cdot V_1}{T_1} = \frac{p_{abs2} \cdot V_2}{T_2}$$

**Special cases:**

**constant temperature**

$$p_{abs1} \cdot V_1 = p_{abs2} \cdot V_2$$

**constant volume**

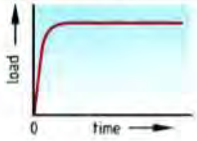
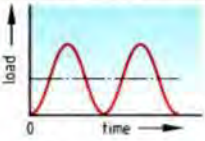
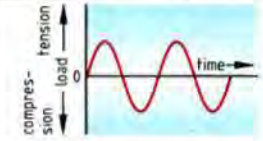
$$\frac{p_{abs1}}{T_1} = \frac{p_{abs2}}{T_2}$$

**constant pressure**

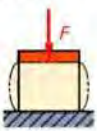
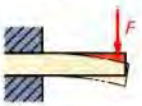
$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

# Load cases, Types of loading, Material properties, Stress limits

## Load cases

| static loading | dynamic loading | |
|---|---|---|
| stationary | pulsating | alternating |
|   |   |   |
| **Load case I** Magnitude and direction of the load remain the same, e.g. for a weight load on columns. | **Load case II** The load increases to a maximum value and then falls back to zero, e.g. for crane cables and springs. | **Load case III** The load alternates between a positive and a negative maximum value of equal magnitude, e.g. for rotating axles. |

## Types of loading, material properties, stress limits

| Type of load | Stress | Material properties: Strength | Material properties: Limit values for plastic deformation | Material properties: Deformation | Standard stress limits $\sigma_{lim}$ for load case I | Standard stress limits $\sigma_{lim}$ for load case II | Standard stress limits $\sigma_{lim}$ for load case III |
|---|---|---|---|---|---|---|---|
| **Tension**   | tensile stress $\sigma_t$ | tensile strength $R_m$ | yield strength $R_e$<br>0.2%-yield point $R_{p0.2}$ | elongation $\varepsilon$<br>elongation at fracture $A$ | material: ductile (steel) $R_e$ $R_{p0.2}$; brittle (cast iron) $R_m$ | pulsating tensile fatigue strength $\sigma_{tpuls}$ | alternating tensile fatigue strength $\sigma_{tA}$ |
| **Compression**   | compression stress $\sigma_c$ | compression strength $\sigma_{cB}$ | natural compression yield point $\sigma_{cF}$<br>0.2%-offset yield strength $\sigma_{c0.2}$ | compression set $\varepsilon_c$<br>compressive failure $\varepsilon_{cB}$ | material: ductile (steel) $\sigma_{cF}$ $\sigma_{c0.2}$; brittle (cast iron) $\sigma_{cB}$ | pulsating compression fatigue strength $\sigma_{cpuls}$ | alternating compression fatigue strength $\sigma_{cA}$ |
| **Bending**   | bending stress $\sigma_b$ | bending strength $\sigma_{bB}$ | bending limit $\sigma_{bF}$ | deflection $f$ | bending limit $\sigma_{bF}$ | pulsating bending fatigue strength $\sigma_{bpuls}$ | alternating bending fatigue strength $\sigma_{bA}$ |
| **Shear**   | shear stress $\tau_s$ | shear strength $\tau_{sB}$ | – | – | shear strength $\tau_{sB}$ | – | – |
| **Torsion**   | torsional stress $\tau_t$ | torsional strength $\tau_{tB}$ | torsional limit $\tau_{tF}$ | angular deflection $\varphi$ | torsional limit $\tau_{tF}$ | pulsating torsional fatigue strength $\tau_{tpuls}$ | alternating torsional fatigue strength $\tau_{tA}$ |
| **Buckling**   | buckling stress $\sigma_{bu}$ | buckling strength $\sigma_{buB}$ | – | – | buckling strength $\sigma_{buB}$ | – | – |

# Mechanical strength properties, Allowable stresses, Safety factors

## Mechanical strength properties in static and dynamic loading[1)]

| Type of load | Tension, Compression | | | Shear | Bending | | | Torsion | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Load case | I | II | III | I | I | II | III | I | II | III |
| Stress limit $\sigma_{lim}$ | $R_e$, $R_{p0.2}$ $\sigma_{cF}$, $\sigma_{c0.2}$ | $\sigma_{tpuls}$ $\sigma_{cpuls}$ | $\sigma_{tA}$ $\sigma_{cA}$ | $\tau_{sB}$ | $\sigma_{bF}$ | $\sigma_{bpuls}$ | $\sigma_{bA}$ | $\tau_{tF}$ | $\tau_{tpuls}$ | $\tau_{tA}$ |
| Material | Stress limit $\sigma_{lim}$ in N/mm² | | | | | | | | | |
| S235 | 235 | 235 | 150 | 290 | 330 | 290 | 170 | 140 | 140 | 120 |
| S275 | 275 | 275 | 180 | 340 | 380 | 350 | 200 | 160 | 160 | 140 |
| E295 | 295 | 295 | 210 | 390 | 410 | 410 | 240 | 170 | 170 | 150 |
| E335 | 335 | 335 | 250 | 470 | 470 | 470 | 280 | 190 | 190 | 160 |
| E360 | 365 | 365 | 300 | 550 | 510 | 510 | 330 | 210 | 210 | 190 |
| C15 | 440 | 440 | 330 | 600 | 610 | 610 | 370 | 250 | 250 | 210 |
| 17Cr3 | 510 | 510 | 390 | 800 | 710 | 670 | 390 | 290 | 290 | 220 |
| 16MnCr5 | 635 | 635 | 430 | 880 | 890 | 740 | 440 | 360 | 360 | 270 |
| 20MnCr5 | 735 | 735 | 480 | 940 | 1030 | 920 | 540 | 420 | 420 | 310 |
| 18CrNiMo7-6 | 835 | 835 | 550 | 960 | 1170 | 1040 | 610 | 470 | 470 | 350 |
| C22E | 340 | 340 | 220 | 400 | 490 | 410 | 240 | 245 | 245 | 165 |
| C45E | 490 | 490 | 280 | 560 | 700 | 520 | 310 | 350 | 350 | 210 |
| C60E | 580 | 580 | 325 | 680 | 800 | 600 | 350 | 400 | 480 | 240 |
| 46Cr2 | 650 | 630 | 370 | 720 | 910 | 670 | 390 | 455 | 455 | 270 |
| 41Cr4 | 800 | 710 | 410 | 800 | 1120 | 750 | 440 | 560 | 510 | 330 |
| 50CrMo4 | 900 | 760 | 450 | 880 | 1260 | 820 | 480 | 630 | 560 | 330 |
| 30CrNiMo8 | 1050 | 870 | 510 | 1000 | 1470 | 930 | 550 | 735 | 640 | 375 |
| GS-38 | 200 | 200 | 160 | 300 | 260 | 260 | 150 | 115 | 115 | 90 |
| GS-45 | 230 | 230 | 185 | 360 | 300 | 300 | 180 | 135 | 135 | 105 |
| GS-52 | 260 | 260 | 210 | 420 | 340 | 340 | 210 | 150 | 150 | 120 |
| GS-60 | 300 | 300 | 240 | 480 | 390 | 390 | 240 | 175 | 175 | 140 |
| EN-GJS-400 | 250 | 240 | 140 | 400 | 350 | 345 | 220 | 200 | 195 | 115 |
| EN-GJS-500 | 300 | 270 | 155 | 500 | 420 | 380 | 240 | 240 | 225 | 130 |
| EN-GJS-600 | 360 | 330 | 190 | 600 | 500 | 470 | 270 | 290 | 275 | 160 |
| EN-GJS-700 | 400 | 355 | 205 | 700 | 560 | 520 | 300 | 320 | 305 | 175 |

[1)] Values were determined using cylindrical samples having $d \leq 16$ mm with polished surface. They apply to structural steels in normalized condition; case hardened steels for achieving core strength after case hardening and grain refinement; heat treatable steels in tempered condition.
The compression strength of cast iron with flake graphite is $\sigma_{cB} \approx 4 \cdot R_m$.
Values according to DIN 18800 are to be used for structural steelwork.

## Allowable stress for (pre-)sizing of machine parts

For safety reasons parts may only be loaded with a portion of the stress limit $\sigma_{lim}$ which will lead to permanent deformation, fracture or fatigue fracture.

$\sigma_{allow}$ allowable stress
$\nu$ safety factor (table below)
$\sigma_{lim}$ stress limit depending on type of loading and load case

**Allowable stress** (preliminary design)

$$\sigma_{allow} = \frac{\sigma_{lim}}{\nu}$$

**Example:**

What is the allowable tensile stress $\sigma_{t\,allow}$ for a hexagonal bolt ISO 4017 – M12 x 50 – 10.9, if a safety factor of 1.5 is required with static loading?

$$\sigma_{lim} = R_e = 10 \cdot 9 \cdot 10\,\frac{N}{mm^2} = 900\,\frac{N}{mm^2};\ \sigma_{t,allow} = \frac{\sigma_{lim}}{\nu} = \frac{900\ N/mm^2}{1.5} = 600\,\frac{N}{mm^2}$$

For mechanical strength properties for bolts see page 211.

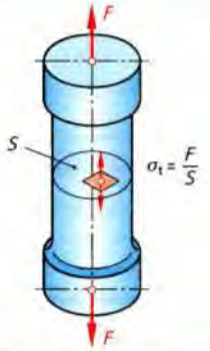
## Safety factors $\nu$ for (pre-)sizing machine parts

| Load case | I (static) | | II and III (dynamic) | |
|---|---|---|---|---|
| Type of material | ductile materials, e.g. steel | brittle materials, e.g. cast iron | ductile materials, e.g. steel | brittle materials, e.g. cast iron |
| Safety factor $\nu$ | 1.2–1.8 | 2.0–4.0 | 3–4[1)] | 3–6[1)] |

[1)] The high margins of safety in part sizing relative to the stress limits are intended to compensate for yet unknown strength-reducing effects due to part shape (for shape-related strength factors see page 48).

# Tensile stress, Compressive stress, Surface pressure

## Tensile stress




The calculation of allowable stress only applies to static loading (Load case I).

| | | | |
|---|---|---|---|
| $\sigma_t$ | tensile stress | $R_e$ | yield strength |
| $F$ | tensile force | $R_m$ | tensile strength |
| $S$ | cross-sectional area | $\nu$ | safety factor |
| $\sigma_{t,allow}$ | allowable tensile stress | $F_{allow}$ | allowable tensile force |

**Example:**

Round bar steel, $\sigma_{t,allow} = 130\ N/mm^2$ (S235JR, $\nu = 1.8$); $F_{allow} = 13.7\ kN$; $d = ?$

$$S = \frac{F_{allow}}{\sigma_{t,allow}} = \frac{13\,700\ N}{130\ N/mm^2} = 105\ mm^2$$

$c = 12\ mm$ (according to table, page 10)

For mechanical strength properties $R_e$ and $R_m$ see pages 130 to 138. For calculation of elastic elongation see page 190.

**Tensile stress**

$$\sigma_t = \frac{F}{S}$$

**Allowable tensile force**

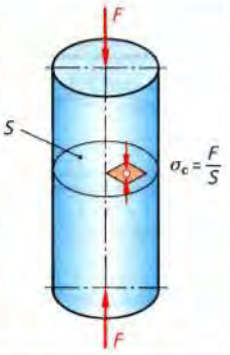
$$F_{allow} = \sigma_{t,allow} \cdot S$$

**Allowable tensile stress**

for steel: $$\sigma_{t,allow} = \frac{R_e}{\nu}$$

for cast iron: $$\sigma_{t,allow} = \frac{R_m}{\nu}$$

## Compressive stress




The calculation of allowable stress only applies to static loading (Load case I).

| | | | |
|---|---|---|---|
| $\sigma_{cF}$ | compression yield point | $F$ | compressive force |
| $\sigma_c$ | compressive stress | $F_{allow}$ | allowable comp. force |
| $\sigma_{c,allow}$ | allowable comp. stress | $S$ | cross-sectional area |
| $\nu$ | safety factor | $R_m$ | tensile strength |

**Example:**

Rack made of EN-GJL-300; $S = 2800\ mm^2$; $\nu = 2.5$; $F_{allow} = ?$

$$F_{allow} = \sigma_{c,allow} \cdot S = \frac{4 \cdot R_m}{\nu} \cdot S$$

$$= \frac{4 \cdot 300\ N/mm^2}{2.5} \cdot 2800\ mm^2 = 1\,344\,000\ N$$

For mechanical strength properties see page 44 and pages 160-161

**Compressive stress**

$$\sigma_c = \frac{F}{S}$$

**Allowable compressive force**

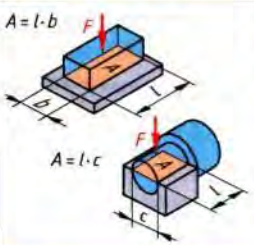
$$F_{allow} = \sigma_{c,allow} \cdot S$$

**Allowable compressive stress**

for steel: $$\sigma_{c,allow} = \frac{\sigma_{cF}}{\nu}$$

for cast iron: $$\sigma_{c,allow} \approx \frac{4 \cdot R_m}{\nu}$$

## Surface pressure




| | | | |
|---|---|---|---|
| $F$ | force | $A$ | contact surface, projected area |
| $p$ | surface pressure | | |

**Example:**

Two metal sheets, each 8 mm thick, are joined with a bolt DIN 1445-10h11 x 16 x 30. How great a force may be applied given a maximum allowable surface pressure of 280 N/mm²?

$$F = p \cdot A = 280\ \frac{N}{mm^2} \cdot 8\ mm \cdot 10\ mm$$

$$= 22\,400\ N$$

**Surface pressure**

$$p = \frac{F}{A}$$

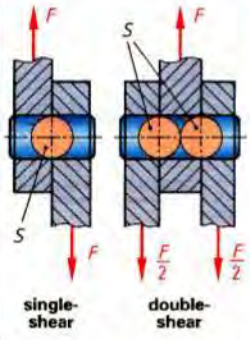
## Allowable surface pressure for joints with pins and bolts made of steel (standard values)

| Assembly type | Press fit smooth pin | | | Fit with notched piece | | | Sliding fit smooth bolt | | |
|---|---|---|---|---|---|---|---|---|---|
| Load case | I | II | III | I | II | III | I | II | III |
| Component material | allowable surface pressure in N/mm² | | | | | | | | |
| S235 | 100 | 70 | 35 | 70 | 50 | 25 | 30 | 25 | 10 |
| E295 | 105 | 75 | 40 | 75 | 55 | 30 | 30 | 25 | 10 |
| cast steel | 85 | 60 | 30 | 60 | 45 | 20 | 30 | 25 | 10 |
| cast iron | 70 | 50 | 25 | 50 | 35 | 20 | 40 | 30 | 15 |
| CuSn, CuZn alloy | 40 | 30 | 15 | 30 | 20 | 10 | 40 | 30 | 15 |
| AlCuMg alloy | 65 | 45 | 25 | 45 | 35 | 15 | 20 | 15 | 10 |

For reference values for allowable specific bearing load of various plain bearing materials see page 261.

# Shear and buckling stress

## Shear stress




The loaded cross-section must not shear.

| | | | |
|---|---|---|---|
| $\tau_s$ | shear stress | $F_{allow}$ | allowable shear force |
| $\tau_{s,allow}$ | allowable shear stress | $S$ | cross-sectional area |
| $\tau_{sB}$ | shear strength | $\nu$ | safety factor |

**Example:**

Dowel pin ∅ 6 mm, single-shear loaded, E 295, $\nu = 3$; $F_{allow} = ?$

$$\tau_{s,allow} = \frac{\tau_{sB}}{\nu} = \frac{390\ N/mm^2}{3} = 130\ \frac{N}{mm^2}$$

$$S = \frac{\pi \cdot d^2}{4} = \frac{\pi \cdot (6\ mm)^2}{4} = 28.3\ mm^2$$

$$F_{allow} = S \cdot \tau_{s,allow} = 28.3\ mm^2 \cdot 130\ \frac{N}{mm^2} = \mathbf{3679\ N}$$

For mechanical strength properties $\tau_{sB}$ and safety factors see page 44.

**Shear stress**

$$\tau_s = \frac{F}{S}$$

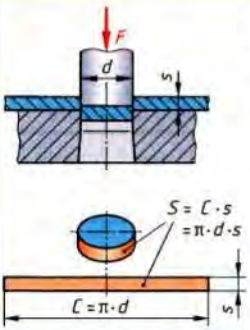
**Allowable shear stress**

$$\tau_{s,allow} = \frac{\tau_{sB}}{\nu}$$

**Allowable shear force**

$$F_{allow} = S \cdot \tau_{s,allow}$$

## Cutting of materials




The loaded cross-section must be sheared.

| | | | |
|---|---|---|---|
| $\tau_{sB\,max}$ | max. shear strength | $S$ | shear area |
| $R_{m\,max}$ | max. tensile strength | $F$ | cutting force |

**Example:**

Punching a 3 mm thick steel sheet S235JR; $d = 16$ mm; $F = ?$

$R_{m\,max} = 470\ N/mm^2$ (Table page 130)

$\tau_{sB\,max} \approx 0.8 \cdot R_{m\,max} = 0.8 \cdot 470\ N/mm^2 = 376\ N/mm^2$

$S = \pi \cdot d \cdot s = \pi \cdot 16\ mm \cdot 3\ mm = 150.8\ mm^2$

$F = S \cdot \tau_{sB\,max} = 150.8\ mm^2 \cdot 376\ N/mm^2 = 56701\ N$

$= \mathbf{56.7\ kN}$

For mechanical strength properties $R_{m\,max}$ for steel, see pages 130 to 138

**Maximum shear strength**

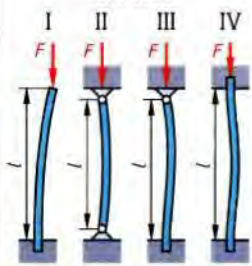
$$\tau_{sB\,max} \approx 0.8 \cdot R_{m\,max}$$

**Cutting force**

$$F = S \cdot \tau_{sB\,max}$$

## Buckling stress (Euler columns)

Load case and free buckling lengths (Euler columns)




Calculation for buckling of Euler columns applies only to thin (profile) parts and within the elastic range of the workpiece.

| | | | |
|---|---|---|---|
| $F_{bu,allow}$ | allowable buckling force | $E$ | Modulus of elasticity |
| $l$ | length | $I$ | Moment of inertia |
| $l_{bu}$ | free buckling length | | |
| $\nu$ | safety factor (in machine construction ≈ 3–10) | | |

**Example:**

Beam IPB200, $l = 3.5$ m; clamped at both ends; $\nu = 10$; $F_{bu\,allow} = ?$; $E = 210000\ N/mm^2 = 21 \cdot 10^6\ N/cm^2$ (table below); $I^{1)} = 2000\ cm^4$

$$F_{bu,allow} = \frac{\pi^2 \cdot E \cdot I}{l_{bu}^2 \cdot \nu} = \frac{\pi^2 \cdot 21 \cdot 10^6\ \frac{N}{cm^2} \cdot 2000\ cm^4}{(0.5 \cdot 350\ cm)^2 \cdot 10}$$

$$= 1.35 \cdot 10^6\ N = \mathbf{1.35\ MN}$$

[1)] for moments of inertia of an area (2nd moment), see pages 49 and 146–151. Special calculation methods are stipulated for structural steel according to DIN 18800 and DIN 4114.

**Allowable buckling force**

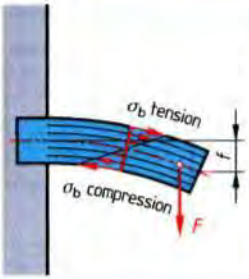
$$F_{bu,allow} = \frac{\pi^2 \cdot E \cdot I}{l_{bu}^2 \cdot \nu}$$

## Modulus of elasticity $E$ in kN/mm²

| steel | EN-GJL-150 | EN-GJL-300 | EN-GJS-400 | GS-38 | EN-GJMW-350-4 | CuZn40 | Al alloy | Ti alloy |
|---|---|---|---|---|---|---|---|---|
| 196–216 | 80–90 | 110–140 | 170–185 | 210 | 170 | 80–100 | 60–80 | 112–130 |

# Bending and torsional stress

## Bending stress




Tensile and compressive stresses occur in a member during bending. The maximum stress is calculated in boundary areas of the member; they may not exceed the allowable bending stress.

$\sigma_b$ bending stress
$M_b$ bending moment
$W$ axial section modulus
$F$ bending force
$f$ deflection

**Example:**

Beam IPE-240, $W = 324\ cm^3$ (page 149); clamped at one end; concentrated load $F = 25\ kN$; $l = 2.6\ m$; $\sigma_b = ?$

$$\sigma_b = \frac{M_b}{W} = \frac{25\,000\ N \cdot 260\ cm}{324\ cm^3} = 20\,061\ \frac{N}{cm^2} \approx 200\ \frac{N}{mm^2}$$

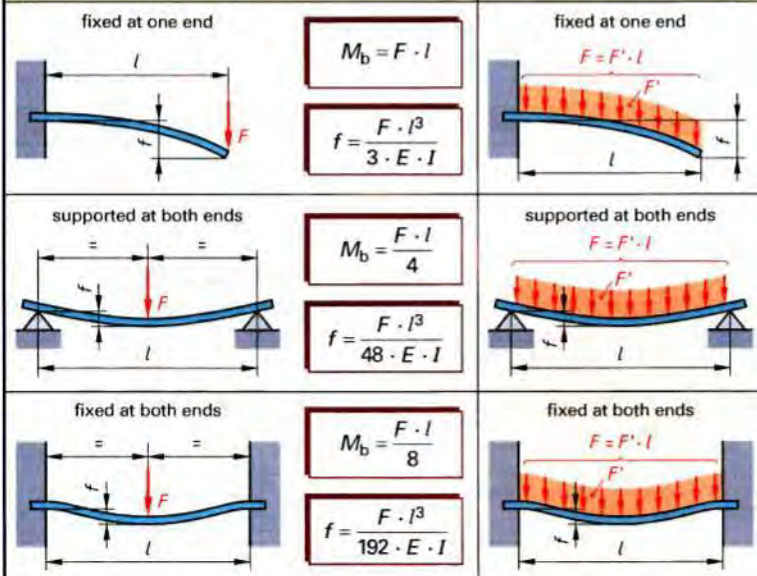
**Bending stress**

$$\sigma_b = \frac{M_b}{W}$$

Allowable bending stress $\sigma_{b\,allow}$ from page 44

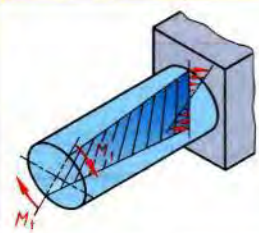
### Bending load cases in beams

| Beam loaded with a concentrated load | | Beam with a uniformly distributed load | |
|---|---|---|---|
| fixed at one end | $M_b = F \cdot l$ <br> $f = \frac{F \cdot l^3}{3 \cdot E \cdot I}$ | fixed at one end | $M_b = \frac{F \cdot l}{2}$ <br> $f = \frac{F \cdot l^3}{8 \cdot E \cdot I}$ |
| supported at both ends | $M_b = \frac{F \cdot l}{4}$ <br> $f = \frac{F \cdot l^3}{48 \cdot E \cdot I}$ | supported at both ends | $M_b = \frac{F \cdot l}{8}$ <br> $f = \frac{5 \cdot F \cdot l^3}{384 \cdot E \cdot I}$ |
| fixed at both ends | $M_b = \frac{F \cdot l}{8}$ <br> $f = \frac{F \cdot l^3}{192 \cdot E \cdot I}$ | fixed at both ends | $M_b = \frac{F \cdot l}{12}$ <br> $f = \frac{F \cdot l^3}{384 \cdot E \cdot I}$ |




$E$ Modulus of elasticity; values: page 46 $I$ 2nd moment of inertia; formulae: page 49; values: pages 146 to 151.
$F'$ Distributed load (load per unit length, e.g. N/cm) $l$ Length of distributed load

## Torsional stress




$M_t$ torsional moment
$W_p$ polar section modulus
$\tau_t$ torsional stress

**Example:**

Shaft, $d = 32\ mm$; $M_t = 420\ N \cdot m$; $\tau_t = ?$

$$W_p = \frac{\pi \cdot d^3}{16} = \frac{\pi \cdot (32\ mm)^3}{16} = 6434\ mm^3$$

$$\tau_t = \frac{M_t}{W_p} = \frac{420\,000\ N \cdot mm}{6434\ mm^3} = 65.3\ \frac{N}{mm^2}$$

**Torsional stress**

$$\tau_t = \frac{M_t}{W_p}$$

Allowable torsional-stress $\tau_{t\,allow}$ from page 44 or page 48

For polar section moduli see pages 49 and 151

# Shape factors in strength

## Shape-related strength and allowable stress for dynamic loading

Shape-related strength is the fatigue strength of the cross-section of a dynamically loaded member with an additional allowance for the strength reducing effects of the component's shape. Important factors include

- the shape of the component (presence of stress concentration)
- machining quality (surface roughness)
- stock dimensions (member thickness).

When compensating for the required safety factor this yields the allowable stress needed to verify the strength of a member which is dynamically loaded.

$\sigma_S$ shape-related strength
$\sigma_{lim}$ stress limit of the unnotched cross-section, e.g. $\sigma_{bA}$ or $\tau_{tpuls}$ (page 44)
$\nu_F$ safety factor for fatigue fracture
$b_1$ surface condition factor
$b_2$ size factor
$\beta_k$ stress concentration factor
$\sigma(\tau)_{allow}$ allowable stress

**Example:**

Rotating axle, E335, transverse hole, surface roughness $Rz = 25\ \mu m$, rough part diameter $d = 50$ mm, safety factor $\nu_F = 1.7$; $\sigma_S = ?$; $\sigma_{allow} = ?$

$\sigma_{bW} = 280\ N/mm^2$ (page 44); $b_1 = 0.8$ ($R_m = 570\ N/mm^2$, diagram below);
$b_2 = 0.8$ (diagram below); $\beta_k = 1.7$ (table below)

$$\sigma_S = \frac{\sigma_{bW} \cdot b_1 \cdot b_2}{\beta_k} = \frac{280\ N/mm^2 \cdot 0.8 \cdot 0.8}{1.7} = \mathbf{105\ N/mm^2}$$

$$\sigma_{allow} = \sigma_S / \nu_F = 105\ N/mm^2 / 1.7 = \mathbf{62\ N/mm^2}$$

**Shape-related strength** (dynamic loading)

$$\sigma_S = \frac{\sigma_{lim} \cdot b_1 \cdot b_2}{\beta_k}$$

$$\tau_S = \frac{\tau_{lim} \cdot b_1 \cdot b_2}{\beta_k}$$

**Allowable stress** (dynamic loading)

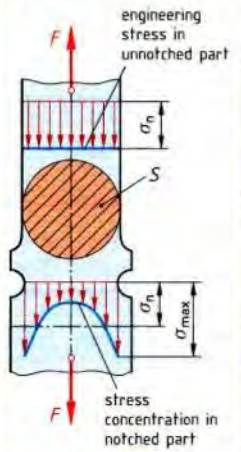
$$\sigma_{allow} = \frac{\sigma_S}{\nu_F}$$

$$\tau_{allow} = \frac{\tau_S}{\nu_F}$$

$\nu_F$ for steel ≈ 1.7

## Stress concentration and stress concentration factors $\beta_k$ for steel

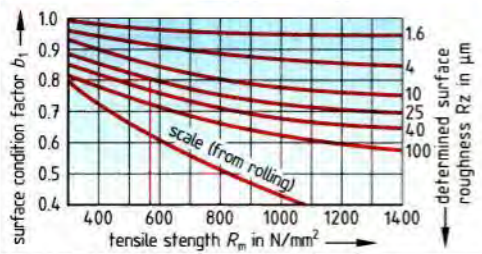
**Example:** Stress distribution for tensile loading

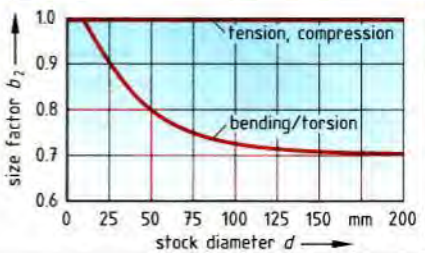



Unnotched cross-sections have an uninterrupted distribution of forces and therefore a uniform stress distribution. Changes in cross-sections lead to concentrations of lines of force where stresses are concentrated. The ensuing reduction of strength is primarily influenced by the notch shape, but also by the notch sensitivity of the material.

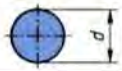
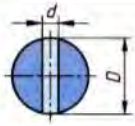
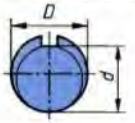
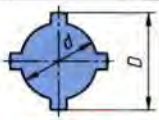
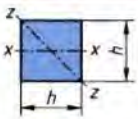
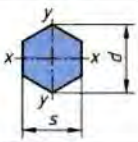
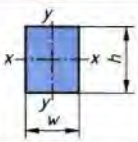
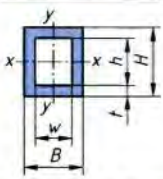
| Notch shape | Material | Stress concentration factor $\beta_k$ bending | Stress concentration factor $\beta_k$ torsion |
|---|---|---|---|
| Shaft with shoulder<br>Shaft with semicircular notch<br>Shaft with retaining ring groove | S185–E335<br>S185–E335<br>S185–E335 | 1.5–2.0<br>1.5–2.2<br>2.5–3.0 | 1.3–1.8<br>1.3–1.8<br>2.5–3.0 |
| Key way in shaft | S185–E335<br>C45E+QT<br>50CrMo4+QT | 1.9–1.9<br>1.9–2.1<br>2.1–2.3 | 1.5–1.6<br>1.6–1.7<br>1.7–1.8 |
| Woodruff key way in shaft<br>Spline shaft | S185–E335<br>S185–E335 | 2.0–3.0<br>– | 2.0–3.0<br>1.6–1.8 |
| Shaft interface to snug fit hub | S185–E335 | 2.0 | 1.5 |
| Shaft or axle with transverse through hole | S185–E335 | 1.4–1.7 | 1.4–1.8 |
| Flat bar with hole | S185–E335 | 1.3–1.5 | tensile loading 1.6–1.8 |

## Surface condition factor $b_1$ and size factor $b_2$ for steel



# Moments of area and Polar section moduli[1)]

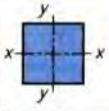
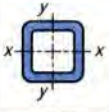
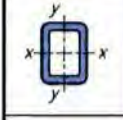
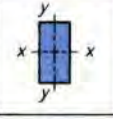
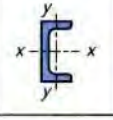
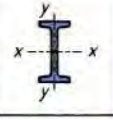
| Shape of the cross-section | Bending and Buckling: Area moment of inertia $I$ | Bending and Buckling: Axial section modulus $W$ | Torsion: Polar section modulus $W_p$ |
|---|---|---|---|
|  | $I = \frac{\pi \cdot d^4}{64}$ | $W = \frac{\pi \cdot d^3}{32}$ | $W_p = \frac{\pi \cdot d^3}{16}$ |
|  | $I = \frac{\pi \cdot (D^4 - d^4)}{64}$ | $W = \frac{\pi \cdot (D^4 - d^4)}{32 \cdot D}$ | $W_p = \frac{\pi \cdot (D^4 - d^4)}{16 \cdot D}$ |
|  | $I = 0.05 \cdot D^4 - 0.083\ d \cdot D^3$ | $W = 0.1 \cdot D^3 - 0.17\ d \cdot D^2$ | $W_p = 0.2 \cdot D^3 - 0.34\ d \cdot D^2$ |
|  | $I = 0.003 \cdot (D + d)^4$ | $W = 0.012 \cdot (D + d)^3$ | $W_p = 0.2 \cdot d^3$ |
|  also applies for more keys | $I = 0.003 \cdot (D + d)^4$ | $W = 0.012 \cdot (D + d)^3$ | $W_p = 0.024 \cdot (D + d)^3$ |
|  | $I_x = I_z = \frac{h^4}{12}$ | $W_x = \frac{h^3}{6}$<br>$W_z = \frac{\sqrt{2} \cdot h^3}{12}$ | $W_p = 0.208 \cdot h^3$ |
|  | $I_x = I_y = \frac{5 \cdot \sqrt{3} \cdot s^4}{144}$<br>$I_x = I_y = \frac{5 \cdot \sqrt{3} \cdot d^4}{256}$ | $W_x = \frac{5 \cdot s^3}{48} = \frac{5 \cdot \sqrt{3} \cdot d^3}{128}$<br>$W_y = \frac{5 \cdot s^3}{24 \cdot \sqrt{3}} = \frac{5 \cdot d^3}{64}$ | $W_p = 0.188 \cdot s^3$<br>$W_p = 0.123 \cdot d^3$ |
|  | $I_x = \frac{w \cdot h^3}{12}$<br>$I_y = \frac{h \cdot w^3}{12}$ | $W_x = \frac{w \cdot h^2}{6}$<br>$W_y = \frac{h \cdot w^2}{6}$ | $W_p = \eta \cdot w^2 \cdot h$<br>Values for $\eta$ see table below |
|  | $I_x = \frac{B \cdot H^3 - w \cdot h^3}{12}$<br>$I_y = \frac{H \cdot B^3 - h \cdot w^3}{12}$ | $W_x = \frac{B \cdot H^3 - w \cdot h^3}{6 \cdot H}$<br>$W_y = \frac{H \cdot B^3 - h \cdot w^3}{6 \cdot B}$ | $W_p = \frac{t \cdot (H + h) \cdot (B + w)}{2}$ |

[1)] 2nd moments of inertia and axial section moduli for profiles see pages 146 to 151.

**Auxiliary value $\eta$ for polar section moduli of rectangular cross-sections**

| h/w | 1 | 1.5 | 2 | 3 | 4 | 6 | 8 | 10 | ∞ |
|---|---|---|---|---|---|---|---|---|---|
| $\eta$ | 0.208 | 0.231 | 0.246 | 0.267 | 0.282 | 0.299 | 0.307 | 0.313 | 0.333 |

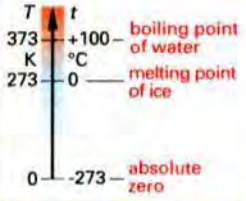
## Comparison of various cross-sectional shapes

| Cross-section | | Linear mass density | | Section moduli or static moments for type of loading | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Bending | | | | Buckling | | Torsion | |
| Shape | Standard designation | $m'$ | | $W_x$ | | $W_y$ | | $I_{min}$ | | $W_p$ | |
| | | kg/m | factor[1] | $cm^3$ | factor[1] | $cm^3$ | factor[1] | $cm^3$ | factor[1] | $cm^3$ | factor[1] |
|  | round bar EN 10060 – 100 | 61.7 | 1.00 | 98 | 1.00 | 98 | 1.00 | 491 | 1.00 | 196 | 1.00 |
|  | square bar EN 10059 – 100 | 78.5 | 1.27 | 167 | 1.70 | 167 | 1.70 | 833 | 1.70 | 208 | 1.06 |
|  | pipe EN 10220 – 114.3 x 6.3 | 16.8 | 0.27 | 55 | 0.56 | 55 | 0.56 | 313 | 0.64 | 110 | 0.56 |
|  | hollow structural section EN 10210-2 100 x 100 x 6.3 | 18.3 | 0.30 | 67.8 | 0.69 | 67.8 | 0.69 | 339 | 0.69 | 110 | 0.56 |
|  | hollow structural section EN 10210-2 120 x 60 x 6.3 | 16.1 | 0.26 | 59 | 0.60 | 38.6 | 0.39 | 116 | 0.24 | 77 | 0.39 |
|  | flat bar EN 10058 – 100 x 50 | 39.3 | 0.64 | 83 | 0.85 | 41.7 | 0.43 | 104 | 0.21 | – | – |
|  | T-section EN 10055 – T100 | 16.4 | 0.27 | 24.6 | 0.25 | 17.7 | 0.18 | 88.3 | 0.18 | – | – |
|  | U-Channel section EN 1026 – U100 | 10.6 | 0.17 | 41.2 | 0.42 | 8.5 | 0.08 | 29.3 | 0.06 | – | – |
|  | I-beam section DIN 1025-I100 | 8.3 | 0.13 | 34.2 | 0.35 | 4.9 | 0.05 | 12.2 | 0.02 | – | – |
|  | I-beam section DIN 1025-IPB100 | 20.4 | 0.33 | 89.9 | 0.92 | 33.5 | 0.34 | 167 | 0.34 | – | – |

[1] Factor referenced to round bar EN 10060-100 (cross-section in first row of table)

# Effects of changes in temperature

## Temperature




Temperatures are measured in **Kelvin** (K), **degrees Celsius** (Centigrade, °C) or **degrees Fahrenheit** (°F). The Kelvin scale originates at the lowest possible temperature, absolute zero; the origin of the Celsius scale is at the melting point of ice.

$T$ temperature in K (thermodynamic temperature) — $t, \vartheta$ temperature in °C — $t_F$ temperature in °F

**Example:**

$t = 20\,°C;\ T = ?$

$T = t + 273 = (20 + 273)\ K = \mathbf{293\ K}$

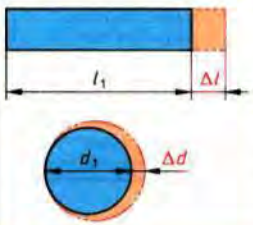
**Temperature in Kelvin**

$$T = t + 273$$

**Temperature in degrees Fahrenheit**

$$t_F = 1.8 \cdot t + 32$$

## Linear expansion, Change in diameter




$\alpha_l$ coefficient of linear expansion — $\Delta l$ linear expansion — $\Delta d$ change in diameter — $\Delta t, \Delta\vartheta$ temperature change — $l_1$ initial length — $d_1$ initial diameter

**Example:**

Plate of unalloyed steel, $l_1 = 120$ mm; $\alpha_l = 0.000\,0119\ \frac{1}{°C}$

$\Delta t = 550\,°C;\ \Delta l = ?$

$\Delta l = \alpha_l \cdot l_1 \cdot \Delta t$

$= 0.000\,0119\ \frac{1}{°C} \cdot 120\ mm \cdot 550\,°C = \mathbf{0.785\ mm}$

**Linear expansion**

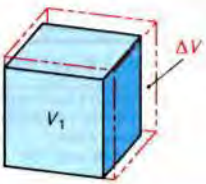
$$\Delta l = \alpha_l \cdot l_1 \cdot \Delta t$$

**Change in diameter**

$$\Delta d = \alpha_l \cdot d_1 \cdot \Delta t$$

For coefficients of linear expansion see pages 116 and 117

## Change in volume




$\alpha_V$ coefficient of volumetric expansion — $\Delta V$ change in volume — $V_1$ initial volume — $\Delta t, \Delta\vartheta$ temperature change

**Example:**

Gasoline, $V_1 = 60\ l;\ \alpha_V = 0.001\ \frac{1}{°C};\ \Delta t = 32\,°C;\ \Delta V = ?$

$\Delta V = \alpha_V \cdot V_1 \cdot \Delta t = 0.001\ \frac{1}{°C} \cdot 60\ l \cdot 32\,°C = \mathbf{1.9\ l}$

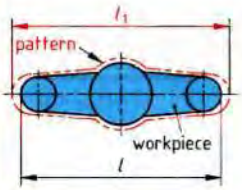
**Change in volume**

$$\Delta V = \alpha_V \cdot V_1 \cdot \Delta t$$

For solids $\alpha_V = 3 \cdot \alpha_l$

For coefficients of volumetric expansion see page 117.
For volumetric expansion of gases see page 42.

## Shrinkage




$S$ shrinkage allowance in % — $l_1$ pattern length — $l$ workpiece length

**Example:**

Al casting, $l = 680$ mm; $S = 1.2\%$; $l_1 = ?$

$$l_1 = \frac{l \cdot 100\%}{100\% - S} = \frac{680\ mm \cdot 100\%}{100\% - 1.2\%}$$

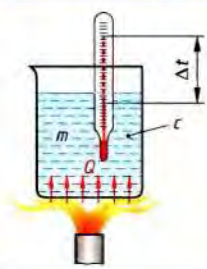
$= \mathbf{688.2\ mm}$

**Pattern length**

$$l_1 = \frac{l \cdot 100\%}{100\% - S}$$

For shrinkage allowances see page 163

## Quantity of heat with changes in temperature




The **specific heat** $c$ indicates how much heat is needed to warm up 1 kg of a substance by 1 °C. The same quantity of heat is released again during cooling.

$c$ spec. heat capacity — $Q$ quantity of heat — $\Delta t, \Delta\vartheta$ temperature change — $m$ mass

**Example:**

Steel shaft, $m = 2$ kg; $c = 0.48\ \frac{kJ}{kg \cdot °C}$;

$\Delta t = 800\,°C;\ Q = ?$

$Q = c \cdot m \cdot \Delta t = 0.48\ \frac{kJ}{kg \cdot °C} \cdot 2\ kg \cdot 800\,°C = \mathbf{768\ kJ}$

**Quantity of heat**

$$Q = c \cdot m \cdot \Delta t$$

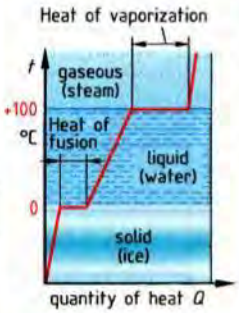
$$1\,kJ = \frac{1\,kW \cdot h}{3600}$$

$1\ kW \cdot h = 3.6\ MJ$

For specific heat see pages 116 and 117.

# Heat for Melting, Vaporizing, Combustion

## Heat of fusion, Heat of vaporization




Heat energy is necessary to transform substances from a solid state to a liquid state or from a liquid state to a gaseous state. This is known as the heat of fusion or heat of vaporization.

$Q$ heat of fusion / heat of evaporation
$q$ specific heat of fusion
$r$ specific heat of evaporation
$m$ mass

**Example:**

Copper, $m = 6.5\ \text{kg}$; $q = 213\ \frac{\text{kJ}}{\text{kg}}$; $Q = ?$

$Q = q \cdot m = 213\ \frac{\text{kJ}}{\text{kg}} \cdot 6.5\ \text{kg} = 1384.5\ \text{kJ} \approx \mathbf{1.4\ MJ}$

**Heat of fusion**

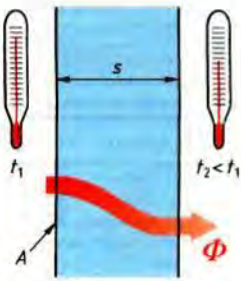
$$Q = q \cdot m$$

**Heat of vaporization**

$$Q = r \cdot m$$

For specific heat of fusion and heat of evaporation see pages 116 and 117.

## Heat flux




The **heat flux** $\Phi$ continually occurs within a substance with movement from higher to lower temperatures.

The **heat transmission coefficient** $k$ also compensates, along with the thermal conductivity of a part, for the heat transmission resistance on the surfaces of the part.

$\Phi$ heat flux
$\lambda$ thermal conductivity
$k$ heat transmission coefficient
$\Delta t, \Delta\vartheta$ temperature difference
$s$ component thickness
$A$ area of the component

**Example:**

Heat protection glass, $k = 1.9\ \frac{\text{W}}{\text{m}^2 \cdot \text{°C}}$; $A = 2.8\ \text{m}^2$; $\Delta t = 32\ \text{°C}$; $\Phi = ?$

$\Phi = k \cdot A \cdot \Delta t = 1.9\ \frac{\text{W}}{\text{m}^2 \cdot \text{°C}} \cdot 2.8\ \text{m}^2 \cdot 32\ \text{°C} = \mathbf{170\ W}$

**Heat flux with thermal conduction**

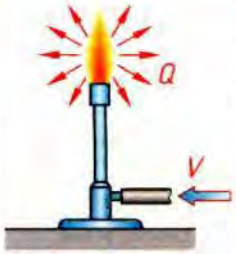
$$\Phi = \frac{\lambda \cdot A \cdot \Delta t}{s}$$

**Heat flux with heat transmission**

$$\Phi = k \cdot A \cdot \Delta t$$

For thermal conductivity values $\lambda$ see pages 116 and 117. For heat transmission coefficients $k$ see below.

## Heat of combustion




The **net calorific value** $H_{net}$ **(**$H$**)** of a substance refers to the heat quantity released during the complete combustion of 1 kg or 1 m³ of that substance.

$Q$ heat of combustion
$H_{net}$, $H$ net calorific value
$m$ mass of solid and liquid fuels
$V$ volume of fuel gas

**Example:**

Natural gas, $V = 3.8\ \text{m}^3$; $H_{net} = 35\ \frac{\text{MJ}}{\text{m}^3}$; $Q = ?$

$Q = H_{net} \cdot V = 35\ \frac{\text{MJ}}{\text{m}^3} \cdot 3.8\ \text{m}^3 = \mathbf{133\ MJ}$

**Heat of combustion of solid and liquid substances**

$$Q = H_{net} \cdot m$$

**Heat of combustion of gases**

$$Q = H_{net} \cdot V$$

**Net calorific value $H_{net}$ ($H$) for fuels**

| Solid fuels | $Q_{net}$ MJ/kg | Liquid fuels | $Q_{net}$ MJ/kg | Gaseous fuels | $Q_{net}$ MJ/m³ |
|---|---|---|---|---|---|
| wood | 15–17 | alcohol | 27 | hydrogen | 10 |
| biomass (dry) | 14–18 | benzene | 40 | natural gas | 34–36 |
| brown coal | 16–20 | gasoline | 43 | acetylene | 57 |
| coke | 30 | diesel | 41–43 | propane | 93 |
| pit coal | 30–34 | fuel oil | 40–43 | butane | 123 |

**Heat transmission coefficients $k$ for construction materials and parts**

| Construction elements | $s$ mm | $k$ W/m² · °C |
|---|---|---|
| outer door, steel | 50 | 5.8 |
| sash window | 12 | 1.3 |
| brick wall | 365 | 1.1 |
| intermediate floor | 125 | 3.2 |
| heat insulating board | 80 | 0.39 |

# Quantities and Units, Ohm's Law, Resistance

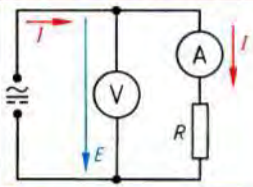
## Electrical quantities and units

| Quantity Name | Symbol | Unit Name | Symbol |
|---|---|---|---|
| electrical voltage | $E$ | volt | V |
| electric current | $I$ | ampere | A |
| electrical resistance | $R$ | ohm | Ω |
| electrical conductance | $G$ | Siemens | S |
| electrical power | $P$ | watt | W |

$$1\,\Omega = \frac{1\,V}{1\,A}$$

$$1\,W = 1\,V \cdot 1\,A$$

## Ohm's Law




$E$ voltage in V
$I$ electric current in A
$R$ resistance in Ω

**Example:**

$R = 88\,\Omega$; $E = 230$ V; $I = ?$

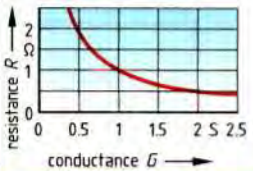
$$I = \frac{E}{R} = \frac{230\,V}{88\,\Omega} = \mathbf{2.6\,A}$$

**Electric current**

$$I = \frac{E}{R}$$

For circuit symbols see page 351.

## Electrical resistance and conductance




$R$ resistance in Ω
$G$ conductance in S

**Example:**

$R = 20\,\Omega$; $G = ?$

$$G = \frac{1}{R} = \frac{1}{20\,\Omega} = \mathbf{0.05\,S}$$

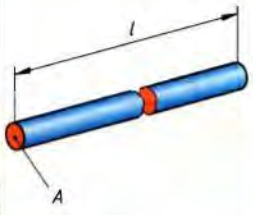
**Resistance**

$$R = \frac{1}{G}$$

**Conductance**

$$G = \frac{1}{R}$$

## Electrical resistivity, electrical conductivity, conductor resistance




$\varrho$ electrical resistivity in $\Omega \cdot mm^2/m$
$\gamma$ electrical conductivity in $m/(\Omega \cdot mm^2)$
$R$ resistance in Ω
$A$ wire cross section in $mm^2$
$l$ wire length in m

**Example:**

Copper wire, $l = 100$ m;
$A = 1.5\,mm^2$; $\varrho = 0.0179\,\frac{\Omega \cdot mm^2}{m}$; $R = ?$

$$R = \frac{\varrho \cdot l}{A} = \frac{0.0179\,\frac{\Omega \cdot mm^2}{m} \cdot 100\,m}{1.5\,mm^2} = \mathbf{1.19\,\Omega}$$

**Electrical resistivity**

$$\varrho = \frac{1}{\gamma}$$

**Conductor resistance**

$$R = \frac{\varrho \cdot l}{A}$$

For electrical resistivities, see pages 116 and 117.

## Resistance and Temperature

| Material | $T_k$ value $\alpha$ in 1/K |
|---|---|
| aluminum | 0.0040 |
| lead | 0.0039 |
| gold | 0.0037 |
| copper | 0.0039 |
| silver | 0.0038 |
| tungsten | 0.0044 |
| tin | 0.0045 |
| zinc | 0.0042 |
| graphite | − 0.0013 |
| constantan | ± 0.00001 |

$\Delta R$ change in resistance in Ω
$R_{20}$ resistance at 20°C in Ω
$R_t$ resistance at the temperature $t$ in Ω
$\alpha$ temperature coefficient ($T_k$ value) in 1/K
$\Delta t$ temperature difference in K

**Example:**

Resistance of Cu; $R_{20} = 150\,\Omega$; $t = 75$°C; $R_t = ?$

$\alpha = \mathbf{0.0039\,1/K}$; $\Delta t = 75$°C − 20°C = 55°C ≙ **55 K**

$R_t = R_{20} \cdot (1 + \alpha \cdot \Delta t)$
$= 150\,\Omega \cdot (1 + 0.0039\,1/K \cdot 55\,K) = \mathbf{182.2\,\Omega}$

**Change in resistance**

$$\Delta R = \alpha \cdot R_{20} \cdot \Delta t$$

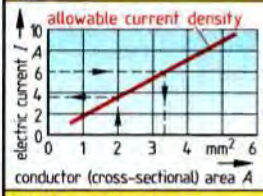
**Resistance at temperature $t$**

$$R_t = R_{20} + \Delta R$$

$$R_t = R_{20} \cdot (1 + \alpha \cdot \Delta t)$$

# Current density, Resistor circuits

## Current density in wires




$J$ current density in A/mm²
$I$ electric current in A
$A$ conductor cross section in mm²

**Example:**

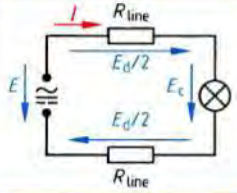
$A = 2.5\ \text{mm}^2$; $I = 4\ \text{A}$; $J = ?$

$$J = \frac{I}{A} = \frac{4\ \text{A}}{2.5\ \text{mm}^2} = \mathbf{1.6\ \frac{A}{mm^2}}$$

**Current density**

$$J = \frac{I}{A}$$

## Voltage drop in wires




$E_d$ voltage drop in wire in V
$E$ voltage at terminal in V
$E_c$ voltage across load in V
$I$ electric current in A
$R_{line}$ resistance for feed or return line in Ω

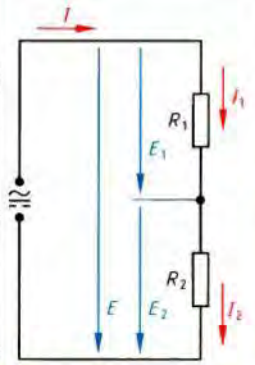
**Voltage drop**

$$E_d = 2 \cdot I \cdot R_{line}$$

**Voltage at load**

$$E_c = E - E_d$$

## Series resistor circuit




$R$ total resistance, equivalent resistance in Ω
$I$ total current in A
$E$ total voltage in V
$R_1$, $R_2$ individual resistances in Ω
$I_1$, $I_2$ partial current in A
$E_1$, $E_2$ voltage drop across $R_1$ & $R_2$ in V

**Example:**

$R_1 = 10\ \Omega$; $R_2 = 20\ \Omega$; $E = 12\ \text{V}$; $R = ?$; $I = ?$;
$E_1 = ?$; $E_2 = ?$

$$R = R_1 + R_2 = 10\ \Omega + 20\ \Omega = \mathbf{30\ \Omega}$$

$$I = \frac{E}{R} = \frac{12\ \text{V}}{30\ \Omega} = \mathbf{0.4\ A}$$

$$E_1 = R_1 \cdot I = 10\ \Omega \cdot 0.4\ \text{A} = \mathbf{4\ V}$$

$$E_2 = R_2 \cdot I = 20\ \Omega \cdot 0.4\ \text{A} = \mathbf{8\ V}$$

**Total resistance**

$$R = R_1 + R_2 + \ldots$$

**Total voltage**

$$E = E_1 + E_2 + \ldots$$

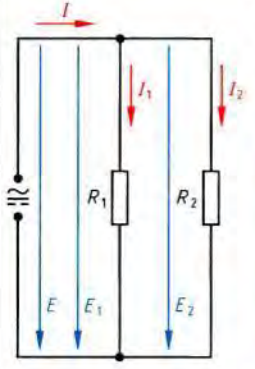
**Total current**

$$I = I_1 = I_2 = \ldots$$

**Voltage drops**

$$\frac{E_1}{E_2} = \frac{R_1}{R_2}$$

## Parallel resistor circuit




$R$ total resistance, equivalent resistance in Ω
$I$ total current in A
$E$ total voltage in V
$R_1$, $R_2$ individual resistances in Ω
$I_1$, $I_2$ partial current in A
$E_1$, $E_2$ voltage drop across $R_1$ & $R_2$ in V

**Example:**

$R_1 = 15\ \Omega$; $R_2 = 30\ \Omega$; $E = 12\ \text{V}$; $R = ?$; $I = ?$;
$I_1 = ?$; $I_2 = ?$

$$R = \frac{R_1 \cdot R_2}{R_1 + R_2} = \frac{15\ \Omega \cdot 30\ \Omega}{15\ \Omega + 30\ \Omega} = \mathbf{10\ \Omega}$$

$$I = \frac{E}{R} = \frac{12\ \text{V}}{10\ \Omega} = \mathbf{1.2\ A}$$

$$I_1 = \frac{E_1}{R_1} = \frac{12\ \text{V}}{15\ \Omega} = \mathbf{0.8\ A}; \qquad I_2 = \frac{E_2}{R_2} = \frac{12\ \text{V}}{30\ \Omega} = \mathbf{0.4\ A}$$

[1] Use this formula if there are only two parallel resistors in the circuit.

**Total resistance**

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots$$

$$R^{1)} = \frac{R_1 \cdot R_2}{R_1 + R_2}$$

**Total voltage**

$$E = E_1 = E_2 = \ldots$$

**Total current**

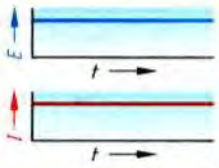
$$I = I_1 + I_2 + \ldots$$

**Partial currents**

$$\frac{I_1}{I_2} = \frac{R_2}{R_1}$$

# Types of current

## Direct current (DC; symbol –), DC voltage




Direct current flows in one direction only and maintains a constant level of current. The voltage is also constant.

- $I$ electric current in A
- $E$ voltage in V
- $t$ time in s

**Electric current**

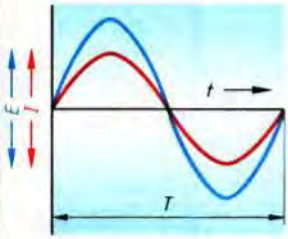
$$I = \text{constant}$$

**Voltage**

$$E = \text{constant}$$

## Alternating current (AC); symbol ~), AC voltage

### Cycle duration and Frequency




While the voltage is continuously changing in a sinusoidal pattern, the free electrons are also continuously alternating their direction of flow.

- $f$ frequency in 1/s, Hz
- $T$ period in s
- $\omega$ angular frequency in 1/s
- $I$ electric current in A
- $E$ voltage in V
- $t$ time in s

**Example:**

Frequency 50 Hz; $T$ = ?

$$T = \frac{1}{50\,\frac{1}{s}} = \mathbf{0.02\ s}$$

**Cycle duration**

$$T = \frac{1}{f}$$

**Frequency**

$$f = \frac{1}{T}$$

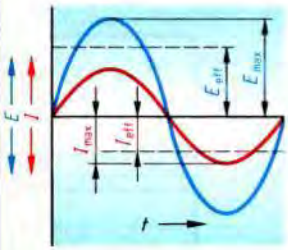
**Angular frequency**

$$\omega = 2 \cdot \pi \cdot f$$

$$\omega = \frac{2 \cdot \pi}{T}$$

1 Hertz = 1 Hz = 1/s = 1 period per second

### Maximum value and effective value of current and voltage




- $I_{max}$ maximum value of the electric current in A
- $I_{eff}$ effective value of the electric current in A
- $E_{max}$ maximum value of the voltage in V
- $E_{eff}$ effective value of the voltage in V (voltage that produces the same power as an identical DC voltage across an ohmic resistor).
- $I$ electric current in A
- $E$ voltage in V
- $t$ time in s

**Example:**

$E_{eff}$ = 230 V; $E_{max}$ = ?

$E_{max} = \sqrt{2} \cdot 230\ \text{V} = \mathbf{325\ V}$

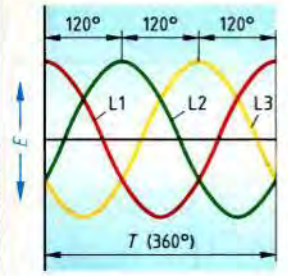
**Maximum value of the electric current**

$$I_{max} = \sqrt{2} \cdot I_{eff}$$

**Maximum value of the voltage**

$$E_{max} = \sqrt{2} \cdot E_{eff}$$

## Three-phase current




Three-phase current is created from three AC voltages each offset by 120°.

- $E$ voltage in V
- $T$ period in s
- L1 phase 1
- L2 phase 2
- L3 phase 3
- $E_{eff}$ effective voltage between phase wire and neutral wire = 230 V
- $E_{eff}$ effective voltage between two phase wires = 400 V

**Maximum value of the voltage**

$$E_{max} = \sqrt{2} \cdot E_{eff}$$

# Electrical Work and Power, Transformers

## Electrical work




$W$ electrical work in kW · h
$P$ electrical power in W
$t$ time (power-on time) in h

**Example:**

Hot plate, $P = 1.8$ kW; $t = 3$ h;
$W = ?$ in kW · h and MJ

$W = P \cdot t = 1.8\ \text{kW} \cdot 3\ \text{h} = \mathbf{5.4\ kW \cdot h = 19.44\ MJ}$

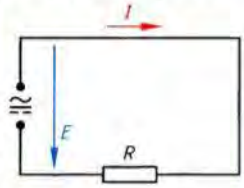
**Electrical work**

$$W = P \cdot t$$

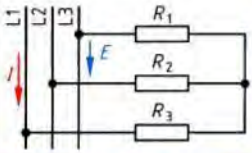
1 kW · h = 3.6 MJ
= 3600000 W · s

## Electrical power with direct current and alternating or three-phase current with non-reactive load[1]

**Direct or alternating current**




**Three-phase current**




$P$ electrical power in W
$E$ voltage (phase-to-phase voltage) in V
$I$ electric current in A
$R$ resistance in Ω

**1st example:**

Light bulb, $E = 6$ V; $I = 5$ A; $P = ?$; $R = ?$

$P = E \cdot I = 6\ \text{V} \cdot 5\ \text{A} = \mathbf{30\ W}$

$R = \frac{E}{I} = \frac{6\ \text{V}}{5\ \text{A}} = \mathbf{1.2\ \Omega}$

**2nd example:**

Annealing furnace, three-phase current,
$E = 400$ V; $P = 12$ kW; $I = ?$

$I = \frac{P}{\sqrt{3} \cdot E} = \frac{12000\ \text{W}}{\sqrt{3} \cdot 400\ \text{V}} = \mathbf{17.3\ A}$

**Power with direct or alternating current**

$$P = E \cdot I$$

$$P = I^2 \cdot R$$

$$P = \frac{E^2}{R}$$

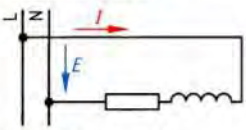
**Power with three-phase current**

$$P = \sqrt{3} \cdot E \cdot I$$

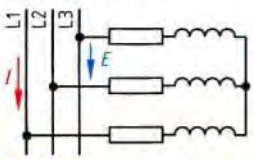
[1] i.e. only with heating devices (ohmic resistors)

## Electrical power with alternating and three-phase current with reactive load component I[2]

**Alternating current**




**Three-phase current**




$P$ electrical power output in W
$E$ voltage (phase-to-phase voltage) in V
$I$ electric current in A
$\cos\varphi$ power factor

**Example:**

Three-phase motor, $E = 400$ V; $I = 2$ A;
$\cos\varphi = 0.85$; $P = ?$

$P = \sqrt{3} \cdot E \cdot I \cdot \cos\varphi = \sqrt{3} \cdot 400\ \text{V} \cdot 2\ \text{A} \cdot 0.85$
$= 1178\ \text{W} \approx \mathbf{1.2\ kW}$

**Electric power output with alternating current**

$$P = E \cdot I \cdot \cos\varphi$$

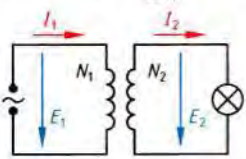
**Electric power output with three-phase current**

$$P = \sqrt{3} \cdot E \cdot I \cdot \cos\varphi$$

[2] i.e. in electric motors and generators

## Transformers

**Input side** (primary coil)
**Output side** (secondary coil)




$N_1$, $N_2$ number of turns
$E_1$, $E_2$ voltages in V
$I_1$, $I_2$ current level in A

**Example:**

$N_1 = 2875$; $N_2 = 100$; $E_1 = 230$ V; $I_1 = 0.25$ A; $E_2 = ?$; $I_2 = ?$

$E_2 = \frac{E_1 \cdot N_2}{N_1} = \frac{230\ \text{V} \cdot 100}{2875} = \mathbf{8\ V}$

$I_2 = \frac{I_1 \cdot N_1}{N_2} = \frac{0.25\ \text{A} \cdot 2875}{100} = \mathbf{7.2\ A}$

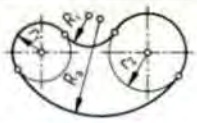
**Voltages**

$$\frac{E_1}{E_2} = \frac{N_1}{N_2}$$

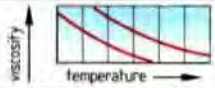
**Electric current**

$$\frac{I_1}{I_2} = \frac{N_2}{N_1}$$

# 3 Technical drawing




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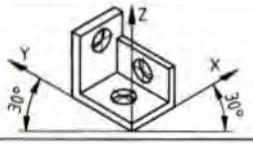


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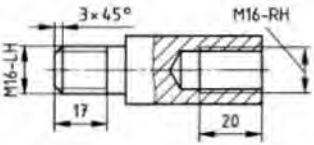



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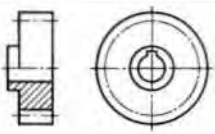


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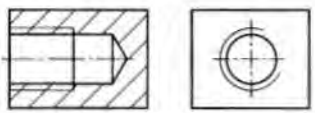





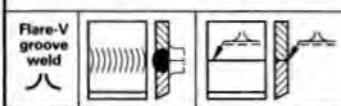
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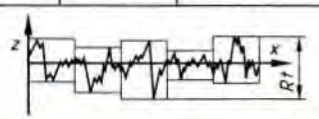




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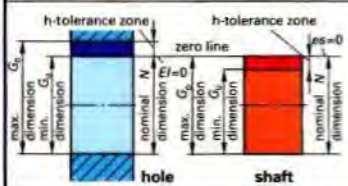


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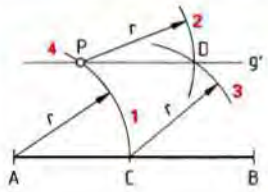





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# Line segments, Perpendiculars and Angles

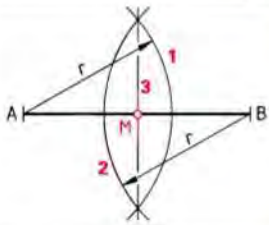
## Parallels to a line




**Given:** Line segment $\overline{AB}$ and point P on the desired parallel line g'

1. Arc with radius *r* about A results in intersecting point C.
2. Arc with radius *r* about P.
3. Arc with radius *r* about C results in intersecting point D.
4. Connecting line segment $\overline{PD}$ is parallel line g' to $\overline{AB}$.

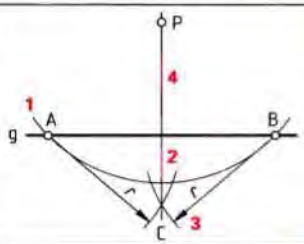
## Bisecting a line




**Given:** Line segment $\overline{AB}$

1. Arc 1 with radius *r* about A; $r > \frac{1}{2}\overline{AB}$.
2. Arc 2 with equal radius *r* about B.
3. The line connecting the intersecting points is the perpendicular bisector or the bisector of line segment $\overline{AB}$.

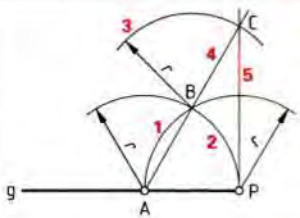
## Dropping a perpendicular




**Given:** Straight line g and point P

1. Any arc 1 about P results in intersecting point A and B.
2. Arc 2 with radius *r* about A; $r > \frac{1}{2}\overline{AB}$.
3. Arc 3 with equal radius *r* about B (intersecting point C).
4. The line joining intersecting point C with P is the desired perpendicular.

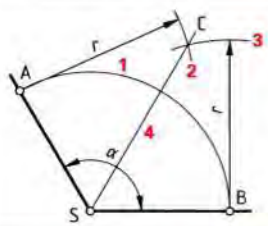
## Constructing a vertical line at point P




**Given:** Straight line g and point P

1. Arc 1 about P with any radius *r* results in intersecting point A.
2. Arc 2 with same radius *r* about point A results in intersecting point B.
3. Arc 3 with equal radius *r* about B.
4. Construct a line from A to B and extend it (to intersecting point C).
5. Construct a line from point C to point P to obtain the vertical at P.

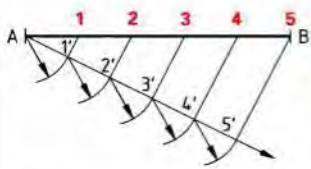
## Bisecting an angle




**Given:** Angle $\alpha$

1. Any arc 1 about S yields intersecting points A and B.
2. Arc 2 with radius *r* about A; $r > \frac{1}{2}\overline{AB}$.
3. Arc 3 with equal radius *r* about B results in intersecting point C.
4. The line joining intersecting point C with S is the desired bisected angle.

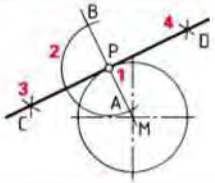
## Dividing a line




**Given:** Line $\overline{AB}$ should be divided into 5 equal parts.

1. Construct a ray from A at any desired angle.
2. Mark 5 equal lengths with a compass on the ray from A.
3. Construct a line from point 5' to B.
4. Construct parallels to $\overline{5'B}$ through the other division points 1'–4'.

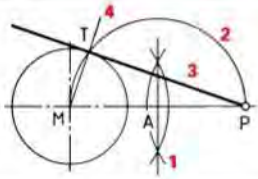
# Tangents, Circular arcs, Polygons




## Tangent through point P on a circle

**Given:** Circle and point P

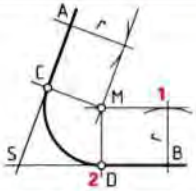
1. Construct line segment $\overline{MP}$ and extend it.
2. Arc about P gives intersecting points A and B.
3. Arcs about A and B with the same radius yield intersecting points C and D.
4. The line passing through C and D is perpendicular to $\overline{PM}$.




## Tangent from a point P to a circle

**Given:** Circle and point P

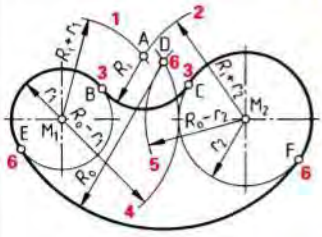
1. Bisect $\overline{MP}$. A is the midpoint.
2. Arc about A with radius $r = \overline{AM}$ yields intersecting point P. T is the tangent point.
3. Connect T and P.
4. $\overline{MT}$ is perpendicular to $\overline{PT}$.




## Rounding an angle (arc tangent to two straight lines)

**Given:** Angle ASB and radius $r$

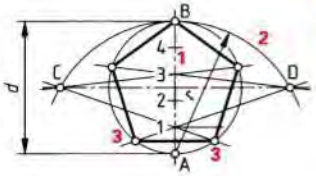
1. Construct parallels to $\overline{AS}$ and $\overline{BS}$ of distance $r$. Their intersection M is the desired center of the circular arc of radius $r$.
2. The intersection of the perpendiculars from M to the line segments $\overline{AS}$ and $\overline{BS}$ are the transition points C and D for the arc.




## Connecting two circles by arcs

**Given:** Circle 1 and circle 2; radii $R_i$ and $R_o$

1. Circle about $M_1$ with radius $R_i + r_1$.
2. Circle about $M_2$ with radius $R_i + r_2$ intersects with 1 to yield intersecting point A.
3. Connecting $M_1$ and $M_2$ with A yields contact points B and C for the inside radius $R_i$.
4. Circle about $M_1$ with radius $R_o - r_1$.
5. Circle about $M_2$ with radius $R_o - r_2$ combined with step 4 results in the intersecting point D.
6. D connected to $M_1$ and $M_2$ and extended gives the contact points E and F for the outside radius $R_o$.

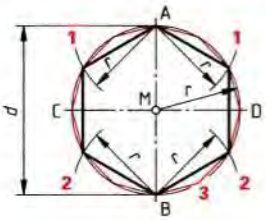



## Circumscribed regular polygon (e.g. pentagon)

**Given:** Circle of diameter $d$

1. Divide $\overline{AB}$ into 5 equal parts (page 58).
2. An arc centered at A with radius $r = \overline{AB}$ yields points C and D.
3. Construct lines from C and D to 1, 3, etc. (all odd numbers). The intersecting points on the circle yield the desired vertices of the pentagon.

   For **polygons** with an **even number of angles** C and D are connected to 2, 4, 6 etc. (all even numbers).



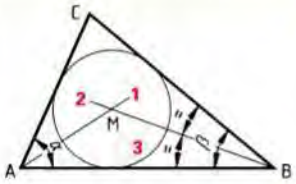

## Circumscribed hexagon, dodecagon

**Given:** Circle of diameter $d$

1. Arc centered at A with radius $r = \frac{d}{2}$
2. Arc with radius $r$ about B and A.
3. Construct line segments connecting the intersecting points to yield the hexagon.

   For a dodecagon find intermediate points including intersections at C and D.

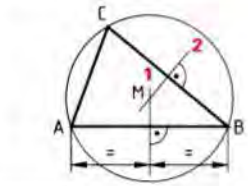
# Inscribed and circumscribed circles for triangles, Circle center point, Ellipse, Spiral




## Circle inscribed in a triangle

**Given:** Triangle A, B, C

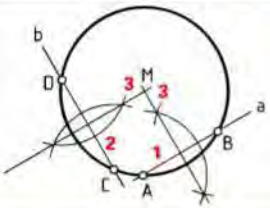
1. Bisect angle $\alpha$.
2. Bisect angle $\beta$ (intersecting at point M).
3. Inscribed circle about M.




## Circle circumscribing a triangle

**Given:** Triangle A, B, C

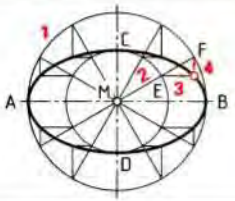
1. Construct the perpendicular bisector of line segment $\overline{AB}$.
2. Construct a perpendicular bisector on line segment $\overline{BC}$ (intersecting at point M).
3. Circumscribed circle about M.




## Finding the center of a circle

**Given:** Circle

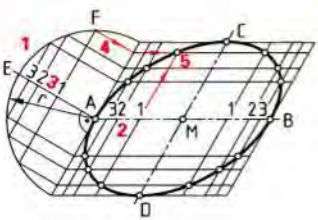
1. Choose any straight line a that intersects the circle at A and B.
2. Straight line b (approximately perpendicular to straight line a) intersects circle at C and D.
3. Construct perpendicular bisectors on line segments $\overline{AB}$ and $\overline{CD}$.
4. Intersecting point of the perpendicular bisectors is the center M of the circle.




## Constructing an ellipse from two circles

**Given:** Axes $\overline{AB}$ and $\overline{CD}$

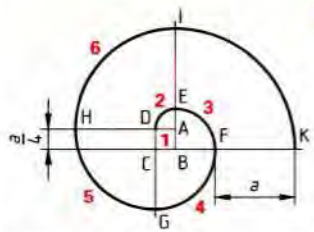
1. Two circles about M with diameters $\overline{AB}$ and $\overline{CD}$.
2. Construct several rays through M which intersect both circles (E, F).
3. Construct parallels to the two principle axes $\overline{AB}$ and $\overline{CD}$ through E and F. Intersecting points are points on the ellipse.




## Constructing an ellipse in a parallelogram

**Given:** Parallelogram with axes $\overline{AB}$ and $\overline{CD}$

1. A semi-circle with radius $r = \overline{MC}$ about A yields point E.
2. Subdividing $\overline{AM}$ (or $\overline{BM}$) into halves, quarters and eighths yields points 1, 2 and 3. Construct parallels to axis $\overline{CD}$ through these points.
3. Dividing $\overline{EA}$ in halves, quarters and eighths yields points 1, 2 and 3 on the axis $\overline{AE}$. Parallels to axis $\overline{CD}$ through those points give intersecting points F on the circular arc.
4. Construct parallels to $\overline{AE}$ through intersection points F to the semi-circle axis, from there construct parallels to axis $\overline{AB}$.
5. Parallel intersection points of matching numbers are points on the ellipse.



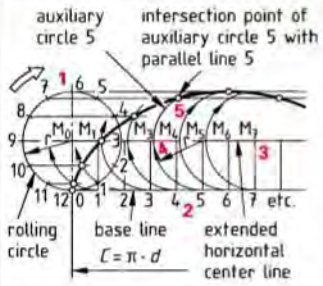

## Spiral (approximate construction using a compass)

**Given:** Rise *a*

1. Construct square ABCD with *a*/4.
2. A quarter circle of radius $\overline{AD}$ centered at A yields E.
3. A quarter circle of radius $\overline{BE}$ centered at B yields F.
4. A quarter circle of radius $\overline{CF}$ centered at C yields G.
5. A quarter circle of radius $\overline{DG}$ centered at D yields H.
6. A quarter circle of radius AH centered at A yields I (etc).

# Cycloid, Involute, Parabola, Hyperbola, Helix

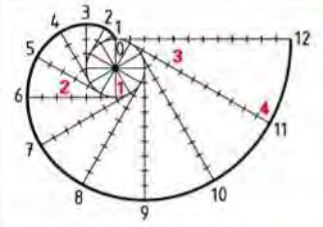
## Cycloid




**Given:** Rolling circle of radius *r*

1. Subdivide the pitch circle into any number of equal sized parts, e.g. 12.
2. Divide the base line (= extent of the pitch circle = $\pi \cdot d$) into equal parts, in this case 12.
3. Vertical lines from segment points 1–12 on the base line to the extended vertical center line of the rolling circle yield the midpoints $M_1$–$M_{12}$.
4. Construct auxiliary circles about the midpoints $M_1$–$M_{12}$ with radius *r*.
5. The intersecting points of these auxiliary circles with the parallels through the points on the rolling circle having the same numbers give the points of the cycloid.

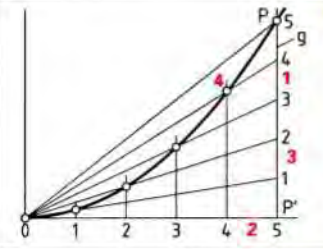
## Involute



**Given:** Circle

1. Subdivide the circle into any desired number of equal sized parts, e.g. 12.
2. Construct tangents to the circle at each section.
3. Mark off the length of the developed circumference on each tangent from its contact point.
4. The curve through the endpoints forms the involute.

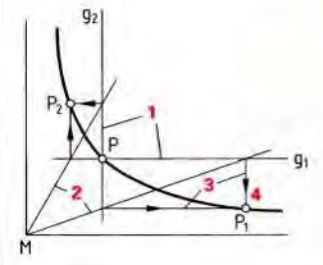
## Parabola



**Given:** Orthogonal parabola axes and parabola point P

1. Parallel g to vertical axis through point P gives P′.
2. Divide distance $\overline{0P'}$ on the horizontal axis into any desired number of parts (e.g. 5) and construct parallels to the vertical axis.
3. Subdivide distance $\overline{PP'}$ into the same number of segments and connect to origin at 0.
4. Intersecting points of the lines with the matching number yield points on the parabola.

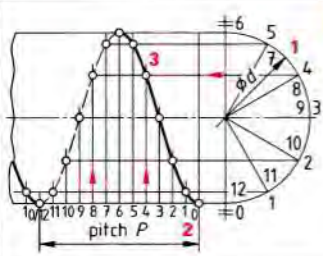
## Hyperbola



**Given:** Orthogonal asymptotes through M and point P on the hyperbola.

1. Construct lines $g_1$ and $g_2$ parallel to the asymptotes through point P on the hyperbola.
2. Construct any desired number of rays from M.
3. Construct lines through the intersections of the rays with $g_1$ and $g_2$ parallel to the asymptotes.
4. Intersecting points of the parallel lines ($P_1$, $P_2$, ...) are points on the hyperbola.

## Heliocoidal line (Helix)

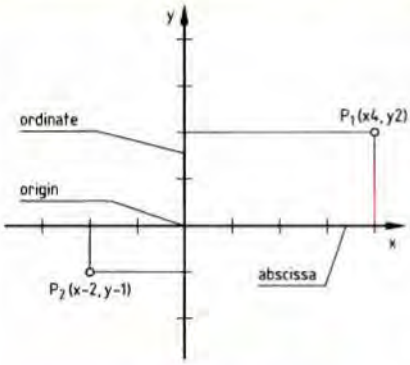



**Given:** Circle of diameter *d* and pitch *P*

1. Divide semicircle into equal sections, e.g. 6.
2. Divide the pitch *P* into twice the number of equal segments, e.g. 12.
3. Extend the same number of horizontal and vertical lines to intersection. The intersecting points yield points on the heliocoidal line.

# Cartesian coordinate system

cf. DIN 461 (1973-03)




**Coordinate axes**

- abscissa (horizontal axis; x-axis)
- ordinate (vertical axis; y-axis)

**Values to be plotted**

- positive: from the origin towards the right, or up
- negative: from the origin towards the left, or down

**Marking the positive axis direction** with

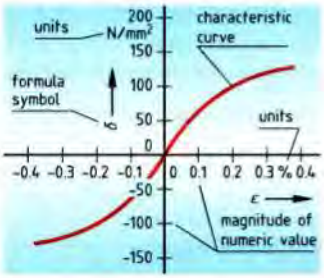
- arrow heads on the axes, or
- arrows parallel to the axes

**Formula symbols** are entered in italics on the

- abscissa below the arrow point
- ordinate to the left next to the arrow point

or in front of the arrows parallel to the axes.

**Scales** are normally linear, but sometimes they are divided logarithmically.




**Magnitudes of values.** They are placed next to the scale ticks. All negative values have a minus sign.

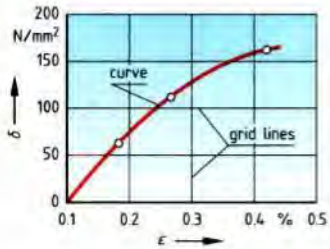
**Value units** are placed between the two last positive numbers on the abscissa and ordinate or after the formula symbol.

**Grid marks** simplify plotting of the values.

**Lines (curves)** connect the values that have been plotted on the graph.

**Line widths.** Lines are drawn in the following proportion:
Gridlines : axes : curves = 1 : 2 : 4 .

**Graph sections** are constructed if values are not to be plotted in each direction from the origin. The origin may also be hidden.




**Example (spring characteristic curve):**

The following disk spring values are known:

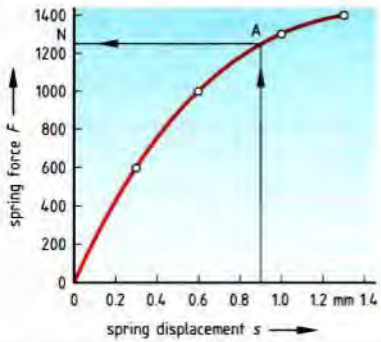
| Spring displacement $s$ in mm | 0 | 0.3 | 0.6 | 1.0 | 1.3 |
|---|---|---|---|---|---|
| Spring force $F$ in N | 0 | 600 | 1000 | 1300 | 1400 |

What is the spring force $F$ with a spring displacement of $s = 0.9$ mm?

Solution:

The values are plotted on a graph and the points are connected by a curve. A vertical line at $s = 0.9$ mm intersects the curve at point A.

With the help of a horizontal line through A, a spring force of $F \approx 1250$ N is read from the ordinate.

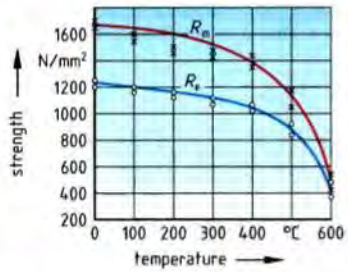



[1)] Graphs are used to represent value-based relationships between changing variables.

# Polar coordinate systems, Area graphs

## Cartesian coordinate system (continued)

cf. DIN 461 (1973-03)




**Graphs with multiple curves**

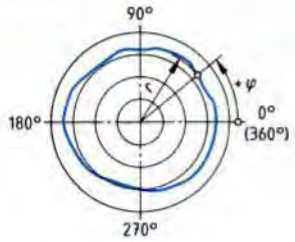
When measured values are highly scattered, a different special symbol is used for each curve, e.g: ○, ×, □

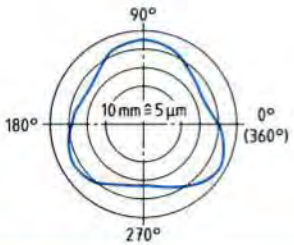
Marking the curves

- when the same type of line is used, by using the names or formula symbols of the variables or by using different colors for the curves
- by different types of lines

## Polar coordinate system

cf. DIN 461 (1973-03)




**Polar coordinate systems** have a 360° division.

**Origin (pole).** Intersection of horizontal and vertical axis.

**Angle layout.** The angle 0° is assigned to the horizontal axis to the right of the origin.

**Angle position.** Positive angles are plotted counter-clockwise.

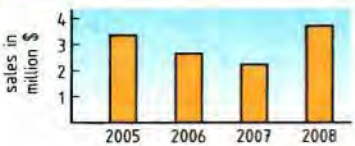
**Radius.** The radius corresponds to the magnitude of the value to be plotted. Concentric circles may be drawn about the origin to simplify plotting of the values.

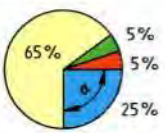
**Example:**

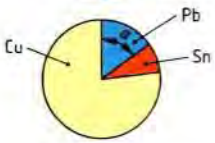
Using a measuring machine, the roundness of a turned bushing is checked to see if it lies within the required tolerance.

The out-of-roundness found was probably caused by clamping the bushing forcefully in the chuck.

## Area graphs




**Bar graphs**

In bar graphs the quantities to be represented are drawn as horizontal or vertical columns of equal width.

**Pie charts**

Percent values are normally represented by pie charts. In these the circumference of a circular area corresponds to 100% (≙ 360°).

**Central angle.** The percentage $x$ to be plotted determines the corresponding central angle:

$$\alpha = \frac{360° \cdot x\,\%}{100\,\%}$$

**Example:**

What is the central angle for the percentage of lead in the alloy CuPb15Sn8?

Solution: $\alpha = \frac{360° \cdot 15\,\%}{100\,\%} = 54°$

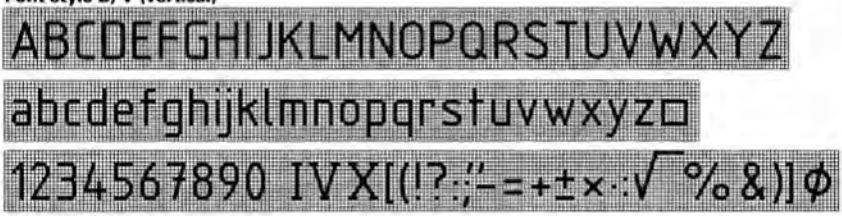
# Fonts

## Lettering, fonts

cf. DIN EN ISO 3098-0 (1998-04) and DIN EN ISO 3098-2 (2000-11)

The lettering of technical drawings can be done using type style A (close-spaced) or type style B. Both styles may be drawn vertical (V) or slanted by 15° to the right (I = italics). To ensure good legibility, the distance between the characters should be two line widths. The distance may be reduced to one line width if certain characters are together, e.g. LA, TV, Tr.

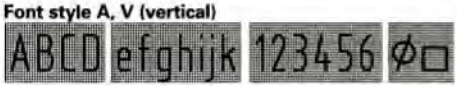
**Font style B, V (vertical)**




**Font style B, I (italic)**




**Font style A, V (vertical)**

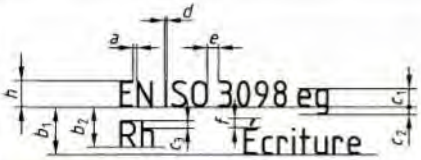



**Font style A, I (italic)**




## Dimensions

cf. DIN EN ISO 3098-0 (1998-04)




$b_1$ with diacritic[1] characters
$b_2$ without diacritic characters
$b_3$ with upper case letters and numbers

[1] diacritic = used to further differentiate, especially for letters

| Character height *h* or height of upper case letters (nominal size) in mm | 1.8 | 2.5 | 3.5 | 5 | 7 | 10 | 14 | 20 |
|---|---|---|---|---|---|---|---|---|

**Ratio of dimension to character height *h***

cf. DIN EN ISO 3098-3 (1998-04)

| Type style | *a* | $b_1$ | $b_2$ | $b_3$ | $c_1$ | $c_2$ | $c_3$ | *d* | *e* | *f* |
|---|---|---|---|---|---|---|---|---|---|---|
| A | $\frac{2}{14}h$ | $\frac{25}{14}h$ | $\frac{21}{14}h$ | $\frac{17}{14}h$ | $\frac{10}{14}h$ | $\frac{4}{14}h$ | $\frac{4}{14}h$ | $\frac{1}{14}h$ | $\frac{6}{14}h$ | $\frac{5}{14}h$ |
| B | $\frac{2}{10}h$ | $\frac{19}{10}h$ | $\frac{15}{10}h$ | $\frac{13}{10}h$ | $\frac{7}{10}h$ | $\frac{3}{10}h$ | $\frac{3}{10}h$ | $\frac{1}{10}h$ | $\frac{6}{10}h$ | $\frac{4}{10}h$ |

*Greek alphabet*

cf. DIN EN ISO 3098-3 (2000-11)

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A | α | alpha | Z | ζ | zeta | Λ | λ | lambda | Π | π | pi | Φ | φ | phi |
| B | β | beta | H | η | eta | M | μ | mu | P | ρ | rho | X | χ | chi |
| Γ | γ | gamma | Θ | ϑ | theta | N | ν | nu | Σ | σ | sigma | Ψ | ψ | psi |
| Δ | δ | delta | I | ι | iota | Ξ | ξ | xi | T | τ | tau | Ω | ω | omega |
| E | ε | epsilon | K | κ | kappa | O | ο | omicron | Y | υ | upsilon | | | |

## Roman numerals

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| I = 1 | II = 2 | III = 3 | IV = 4 | V = 5 | VI = 6 | VII = 7 | VIII = 8 | IX = 9 |
| X = 10 | XX = 20 | XXX = 30 | XL = 40 | L = 50 | LX = 60 | LXX = 70 | LXXX = 80 | XC = 90 |
| C = 100 | CC = 200 | CCC = 300 | CD = 400 | D = 500 | DC = 600 | DCC = 700 | DCCC = 800 | CM = 900 |
| M = 1000 | MM = 2000 | Examples: MDCLXXXVII = 1687 | | | MCMXCIX = 1999 | | MMVIII = 2008 | |

# Preferred numbers, Radii, Scales

## Preferred numbers and series of preferred numbers[1)]

cf. DIN 323-1 (1974-08)

| R 5 | R 10 | R 20 | R 40 | R 5 | R 10 | R 20 | R 40 |
|---|---|---|---|---|---|---|---|
| 1.00 | 1.00 | 1.00 | 1.00 | 4.00 | 4.00 | 4.00 | 4.00 |
| | | | 1.06 | | | | 4.25 |
| | | 1.12 | 1.12 | | | 4.50 | 4.50 |
| | | | 1.18 | | | | 4.75 |
| | 1.25 | 1.25 | 1.25 | | 5.00 | 5.00 | 5.00 |
| | | | 1.32 | | | | 5.30 |
| | | 1.40 | 1.40 | | | 5.60 | 5.60 |
| | | | 1.50 | | | | 6.00 |
| 1.60 | 1.60 | 1.60 | 1.60 | 6.30 | 6.30 | 6.30 | 6.30 |
| | | | 1.70 | | | | 6.70 |
| | | 1.80 | 1.80 | | | 7.10 | 7.10 |
| | | | 1.90 | | | | 7.50 |
| | 2.00 | 2.00 | 2.00 | | 8.00 | 8.00 | 8.00 |
| | | | 2.12 | | | | 8.50 |
| | | 2.24 | 2.24 | | | 9.00 | 9.00 |
| | | | 2.36 | | | | 9.50 |
| 2.50 | 2.50 | 2.50 | 2.50 | 10.00 | 10.00 | 10.00 | 10.00 |
| | | | 2.65 | | | | |
| | | 2.80 | 2.80 | | | | |
| | | | 3.00 | | | | |
| | 3.15 | 3.15 | 3.15 | | | | |
| | | | 3.35 | | | | |
| | | 3.55 | 3.55 | | | | |
| | | | 3.75 | | | | |

| Series | Multiplier |
|---|---|
| R 5 | $q_5 = \sqrt[5]{10} \approx 1.6$ |
| R 10 | $q_{10} = \sqrt[10]{10} \approx 1.25$ |
| R 20 | $q_{20} = \sqrt[20]{10} \approx 1.12$ |
| R 40 | $q_{40} = \sqrt[40]{10} \approx 1.06$ |

## Radii

cf. DIN 250 (2002-04)

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | **0.2** | | | | 0.3 | | **0.4** | | 0.5 | | **0.6** | | 0.8 | |
| **1** | | 1.2 | | **1.6** | | 2 | | **2.5** | | 3 | | **4** | | 5 | | **6** | | 8 | |
| **10** | | 12 | | **16** | 18 | **20** | 22 | **25** | 28 | **32** | 36 | **40** | 45 | **50** | 56 | **63** | 70 | **80** | 90 |
| **100** | 110 | **125** | 140 | **160** | 180 | **200** | | | | | | | | | | | | | |

Values shown in bold font in the table are preferred values.

## Scale factors[2)]

cf. DIN ISO 5455 (1979-12)

| Actual size | Reduction factors | | | | Enlargement factors | | |
|---|---|---|---|---|---|---|---|
| 1 : 1 | 1 : 2 | 1 : 20 | 1 : 200 | 1 : 2000 | 2 : 1 | 5 : 1 | 10 : 1 |
| | 1 : 5 | 1 : 50 | 1 : 500 | 1 : 5000 | 20 : 1 | 50 : 1 | |
| | 1 : 10 | 1 : 100 | 1 : 1000 | 1 : 10000 | | | |

1) Preferred numbers, e. g. for length dimensions and radii. Their usage prevents arbitrary graduations. In the series of preferred numbers (base series R 5 to R 40), each number of the series is obtained by multiplying the previous number by a constant multiplier for that series. Series 5 (R 5) is preferred over R 10, R 10 over R 20 and R 20 over R 40. The numbers of each series can be multiplied by 10, 100, 1000, etc. or divided by 10, 100, 1000, etc.

2) For special applications the given enlargement and reduction factors can be expanded by multiplying by whole multiples of 10.

# Drawing layout

## Paper sizes (ISO)

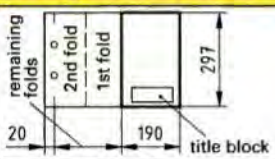
cf. DIN EN ISO 5457 (1999-07) and DIN EN ISO 216 (2002-03)

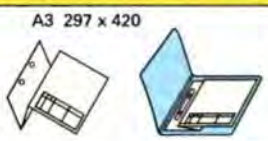
| Format | A0 | A1 | A2 | A3 | A4 | A5 | A6 |
|---|---|---|---|---|---|---|---|
| Format dimensions[1] in mm | 841 x 1189 | 594 x 841 | 420 x 594 | 297 x 420 | 210 x 297 | 148 x 210 | 105 x 148 |
| Drawing area dimensions in mm | 821 x 1159 | 574 x 811 | 400 x 564 | 277 x 390 | 180 x 277 | – | – |

[1] The height: width aspect ratio of the drawing papers are $1 : \sqrt{2}$ (= 1 : 1.414).

## Folding for DIN A4 format

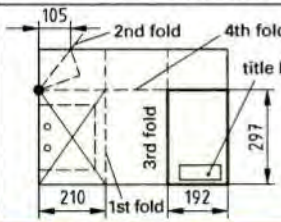
cf. DIN 824 (1981-03)

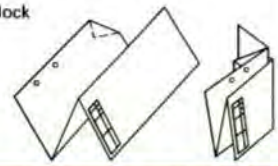



**1st fold:** Fold right side (190 mm wide) toward the back.

**2nd fold:** Fold the remainder of the sheet so that the edge of the 1st fold is 20 mm from the left edge of the paper.




**1st fold:** Fold the left side (210 mm wide) towards the right.

**2nd fold:** Fold a triangle of 297 mm height by 105 mm width towards the left.

**3rd fold:** Fold the right side (192 mm wide) towards the back.

**4th fold:** Fold the folded packet of 297 mm height toward the back.

## Title block

cf. DIN EN ISO 7200 (2004-05), Replacement for DIN 6771-1

The width of the title block is 180 mm. The sizes of the individual data fields (field widths and heights) are no longer stipulated, in contrast to the previous standard. The table at the bottom of this page has examples of possible field sizes.

**Example of a title block:**

| Resp. dept. | Technical reference | Created by | Approved by | |
|---|---|---|---|---|
| AB 131 11 | Susan Miller 12 | Kristin Brown 13 | John Davis 14 | 15 |

| | | |
|---|---|---|
| John Smith Co.[1] | Type of document: Assembly drawing 9 | Document status: released 10 |
| | Title, additional title: Circular saw shaft 2 / complete with bearing 3 | A225-03300-012 4 |

| Changes | Release date | L. | Sheet |
|---|---|---|---|
| 5 | 6 | 7 | 8 |
| A | 2008-01-15 | de | 1/3 |

Drawing specific callouts, such as scale, projection symbol, tolerances and surface specifications should be indicated on the drawing outside of the title block.

## Data fields in the title block

| Field no. | Field name | Max. no. of characters | Field name required | Field name optional | Field size (mm) width | Field size (mm) height |
|---|---|---|---|---|---|---|
| 1 | Owner of the drawing | not specified | yes | – | 69 | 27 |
| 2 | Title (drawing name) | 25 | yes | – | 60 | 18 |
| 3 | Additional title | 25 | – | yes | 60 | |
| 4 | Drawing number | 16 | yes | – | 51 | 9 |
| 5 | Change symbol (drawing version) | 2 | – | yes | 7 | |
| 6 | Issue date of the drawing | 10 | yes | – | 25 | |
| 7 | Language identifier (de = German) | 4 | – | yes | 10 | |
| 8 | Page number and number of pages | 4 | – | yes | 9 | |
| 9 | Type of document | 30 | yes | – | 60 | |
| 10 | Document status | 20 | – | yes | 51 | |
| 11 | Responsible department | 10 | – | yes | 26 | |
| 12 | Technical reference | 20 | – | yes | 43 | |
| 13 | Drawing originator | 20 | yes | – | 44 | |
| 14 | Authorizing person | 20 | yes | – | 43 | |
| 15 | Classification/key words | not specified | – | yes | 24 | |

# Line types

## Lines in mechanical engineering drawings

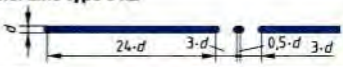
cf. DIN ISO 128-24 (1999-12)

| No. | Name, representation | Examples of application |
|---|---|---|
| 01.1 | Solid line, thin | • dimension and extension lines<br>• leader and reference lines<br>• root of thread<br>• hatching<br>• position direction of layers (e.g. lamination)<br>• outline of hinged section<br>• short center lines<br>• imaginary intersections from penetrations<br>• origin circles and dimension line terminators<br>• diagonal crosses to mark plane surfaces<br>• framing details<br>• projection and grid lines<br>• deflection lines on rough and machined parts<br>• marking for repeated details (e.g. root diameter of toothed gear) |
| | Free-hand line, thin[1] | • preferably hand-drawn representing border of partial or broken views and sections, provided that the border is not a line of symmetry or a center line |
| | Break line, thin[1] | • preferably automated drawing representing border of partial or broken views and sections, provided that the border is not a line of symmetry or a center line |
| 01.2 | Solid line, thick | • visible edges and outlines<br>• crests of threads<br>• limit of the usable thread length<br>• cross-section arrow lines<br>• surface structures (e.g. knurls)<br>• main representations in graphs, edges and flow charts<br>• system lines (steel construction)<br>• mold parting lines in views |
| 02.1 | Dashed line, thin | • hidden edges<br>• hidden contours |
| 02.2 | Dashed line, thick | • identifies allowable areas for surface treatment (e.g. heat treatment) |
| 04.1 | Dot-dash line (long dash), thin | • center lines<br>• lines of symmetry<br>• partial circle in gears<br>• hole circle |
| 04.2 | Dot-dash line (long dash), thick | • marking areas of (delimited) required surface treatment (e.g. heat treatment)<br>• marking section planes |
| 05.1 | Two-dot dash-dot line (long dash), thin | • outlines of adjacent parts<br>• final position of movable parts<br>• centroidal axes<br>• contours of the shape<br>• portions in front of the cutting plane<br>• outlines of alternative designs<br>• contours of finished parts within rough parts<br>• framing special areas or fields<br>• projected tolerance zone |

[1] Free-hand and break line types should not be used together in the same drawing.

## Lengths of line elements

cf. DIN EN ISO 128-20 (2002-12)

| Line element | Line type no. | Length | Line element | Line type no. | Length |
|---|---|---|---|---|---|
| long dashes | 04.1 and 05.1 | 24 · *d* | gaps | 02.1, 02.2, 04.1, 04.2 and 05.1 | 3 · *d* |
| short dashes | 02.1 and 02.2 | 12 · *d* | **Example: Line type 04.2** | | |
| points | 04.1, 04.2 and 05.1 | < 0.5 · *d* |  | | |

# Line types

## Line thicknesses and line groups

cf. DIN ISO 128-24 (1999-12)

**Line widths.** Normally two line types are used in drawings. They are in a ratio of 1 : 2.

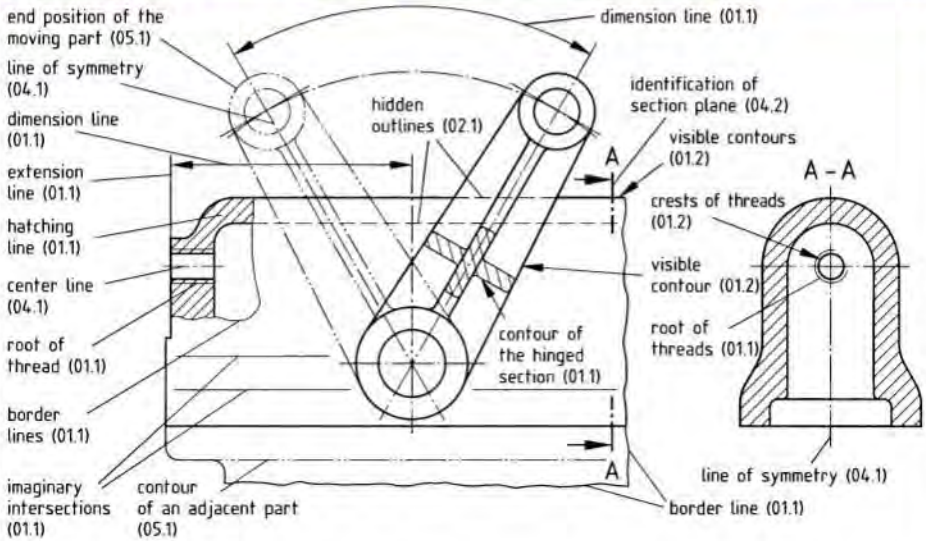
**Line groups.** The line groups are ordered in a ratio of 1 : $\sqrt{2}$ (≈ 1 : 1.4).

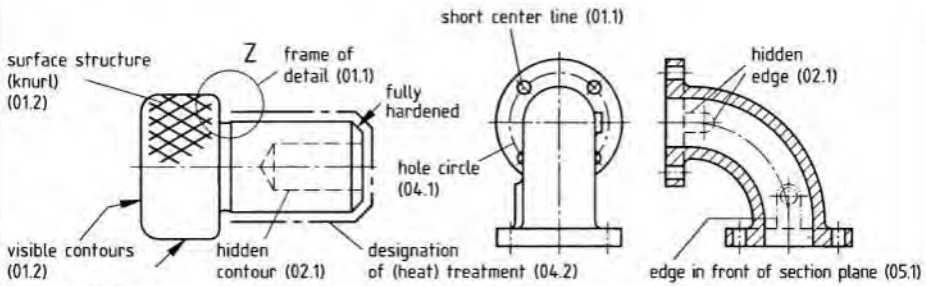
**Selection.** Line thicknesses and line groups are selected corresponding to the type and size of drawing, as well as to the drawing scale and the requirements of microfilming and/or method of reproduction.

| Line group | Associated line thicknesses (dimension in mm) for | | |
|---|---|---|---|
| | Thick lines | Thin lines | Dimension and tolerance callouts, graphical symbols |
| 0.25 | 0.25 | 0.13 | 0.18 |
| 0.35 | 0.35 | 0.18 | 0.25 |
| 0.5 | 0.5 | 0.25 | 0.35 |
| 0.7 | 0.7 | 0.35 | 0.5 |
| 1 | 1 | 0.5 | 0.7 |
| 1.4 | 1.4 | 0.7 | 1 |
| 2 | 2 | 1 | 1.4 |

## Examples of lines in technical drawings

cf. DIN ISO 128-24 (1999-12)



# General principles of presentation, Projection methods

## General principles of presentation

cf. DIN ISO 128-30 (2002-05) and DIN ISO 5456-2 (1998-04)

**Selection of the front view.** The view that is selected for the front view is the one which provides the most information regarding shape and dimensions.

**Other views.** If other views are necessary for clear representation or for complete dimensioning of a workpiece, the following should be observed:

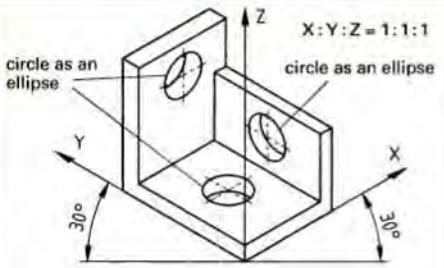
- The selection of the views should be limited to those most necessary.
- Additional views should contain as few hidden edges and contours as possible.

**Position of other views.** The position of other views is dependent upon the method of projection. For drawings based on the first- and the third-angle projection methods (page 70) the symbol for the projection method must be given in the title block.

## Axonometric representation[1]

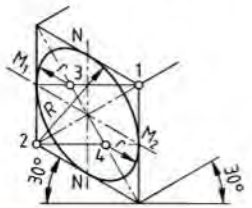
cf. DIN ISO 5456-3 (1998-04)

### Isometric projection

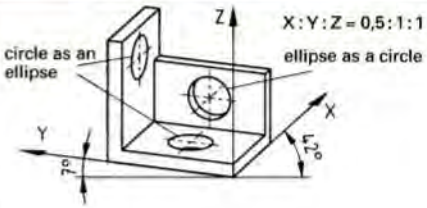



Approximate construction of the ellipse:

1. Construct a rhombus tangential to the hole. Bisect the sides of the rhombus to yield the intersecting points $M_1$, $M_2$ and N.
2. Draw connecting lines from $M_1$ to 1 and from $M_2$ to 2 to yield the intersecting points 3 and 4.
3. Construct circular arcs with radius *R* about 1 and 2 and with radius *r* about 3 and 4.

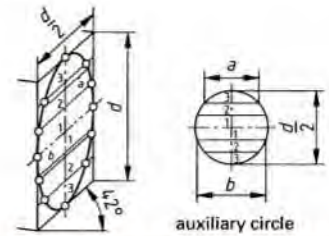



### Diametric projection

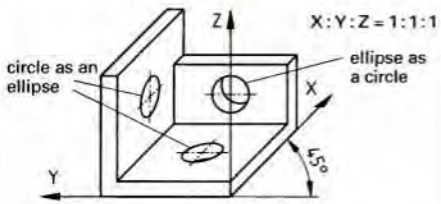



Construction of ellipses:

1. Construct an auxiliary circle with radius $r = d/2$.
2. Subdivide height *d* into any desired number of equal segments and construct grids (1 to 3).
3. Subdivide the diameter of the auxiliary circle into the same number of grids.
4. Transfer the segment lengths *a*, *b* etc. from the auxiliary circle to the rhombus.

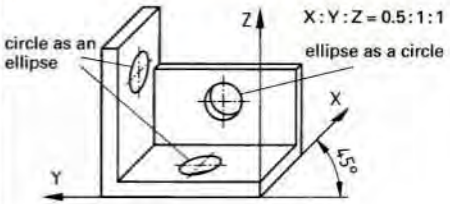



### Cavalier projection




Ellipse construction identical to that on page 60 (ellipse construction in a parallelogram).

### Cabinet projection



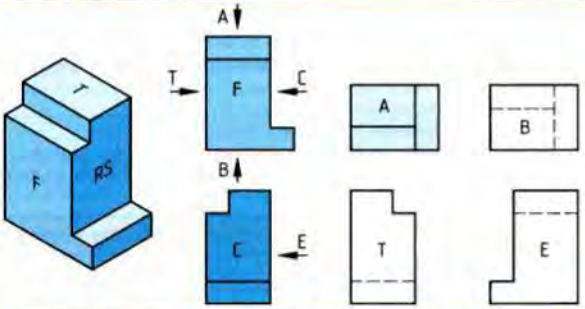

Ellipse construction identical to that of the diametric projection (above).

[1] Axonometric representations: simple, graphical representations.

# Projection methods

cf. DIN ISO 128-30 (2002-05) and DIN ISO 5456-2 (1998-04)

## Arrow projection method



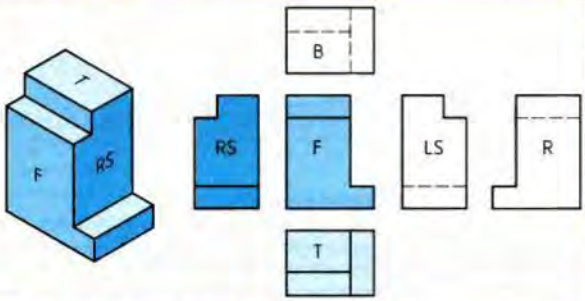

**Marking the direction of observation:**
- with arrow lines and upper case letters

**Marking the views:**
- with upper case letters

**Locations of the views:**
- any location with respect to front view

**Layout of upper case letters:**
- above the views
- vertical in reading direction
- above or to the right of the arrow lines

## First-angle projection



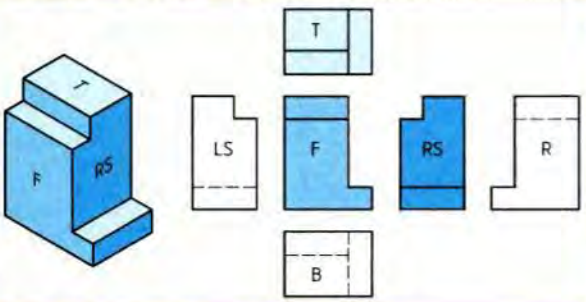

Locations with respect to front view F:

| | | |
|---|---|---|
| T | top view | below F |
| LS | view from the left side | right of F |
| RS | view from the right side | left of F |
| B | bottom view | above F |
| R | rear view | left or right of F |

**Symbol**



## Third-angle projection [1]




Locations with respect to front view F:

| | | |
|---|---|---|
| T | top view | above F |
| LS | view from the left side | left of F |
| RS | view from the right side | right of F |
| B | bottom view | below F |
| R | rear view | left or right of F |

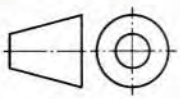
**Symbol**



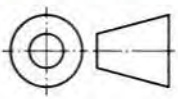
## Symbols for projection methods

Symbol[2] for

first-angle projection



third-angle projection

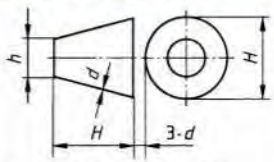


Application in

Germany and most European countries

English speaking countries, e.g. USA/Canada

**Symbol for first-angle projection**



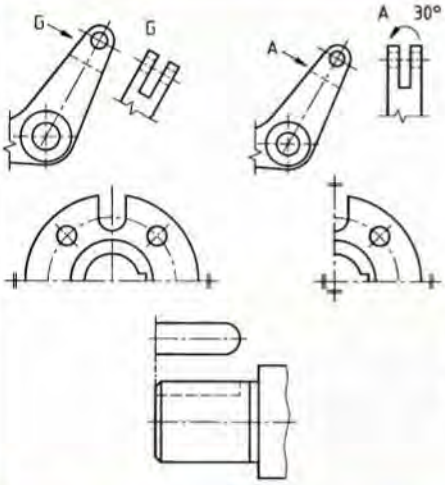

$h$ font height in mm (page 64)
$H = 2h$
$d = 0.1h$

[1] Second-angle projection is not provided.
[2] The symbol for projection method is included in the drawing layout (page 66).

# Views

cf. DIN ISO 128-30 and -34 (2002-05)

## Partial views




**Application.** Partial views are used to avoid unfavorable projections or shortened representations.

**Position.** The partial view is shown in the direction of the arrow or rotated. The angle of rotation must be given.

**Boundary.** This is identified with a break line.

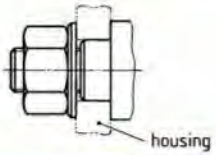
**Application.** It is sufficient to represent just a portion of the whole workpiece, for example if space is limited.

**Marking.** With two short parallel solid lines through the line of symmetry on the outside of the view.

**Application.** If the representation is clear, a partial view is sufficient instead of a full view.

**Representation.** The partial view (third-angle projection) is connected with the main view by a thin dot-dash line.

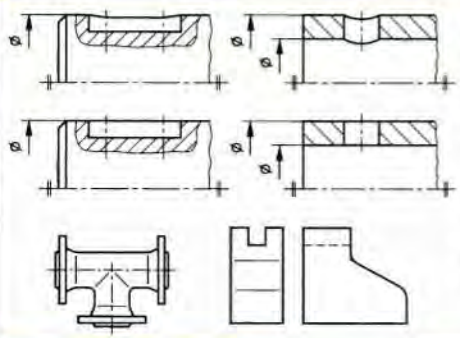
## Adjacent parts




**Application.** Adjacent parts are drawn if it aids in understanding the drawing.

**Representation.** This is done with thin two-dot dash-dot lines. Sectioned adjacent parts are not hatched.

## Simplified penetrations

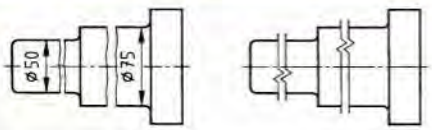


**Application.** If the drawing remains clearly understandable, rounded penetrating lines may be replaced by straight lines.

**Representation.** Rounded penetrating lines are drawn with thick solid lines for grooves in shafts and penetrating holes whose diameters significantly differ.

Implied penetrating lines of imaginary intersections and rounded edges are drawn with thin solid lines at the location at which the (circumferential) edge would have been with a sharp edged transition. The thin solid lines do not contact the outline.

## Broken views



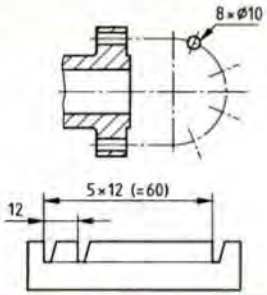

**Application.** To save space only the important areas of long workpieces need to be represented.

**Representation.** The boundary of the remaining parts is shown by free-hand lines or break lines. The parts must be drawn close to each other.

# Views

cf. DIN ISO 128-30 and -34 (2002-05)

## Repeating geometrical elements



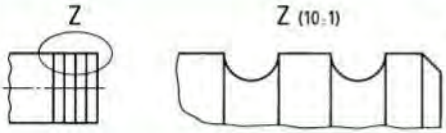

**Application.** For geometric elements which repeat regularly, the individual element only needs to be drawn once.

**Representation.** For geometric elements which are not drawn,

- the positions of symmetrical geometric elements are shown with thin dot-dash lines.
- asymmetrical geometric elements of the area in which they are found are drawn with thin solid lines.

The number of repeated elements must be given in the dimensioning.

## Parts at a larger scale (details)

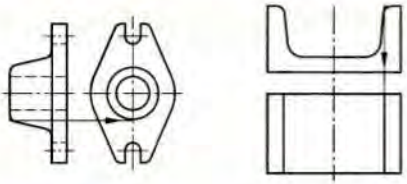



**Application.** Partial areas of a workpiece which can not be clearly represented may be drawn at a larger scale.

**Representation.** The partial area is framed with a thin solid line or encircled and marked with a capital letter.

The partial area is represented in an enlarged detail view and is identified with the same capital letter. The enlarged scale is additionally given.

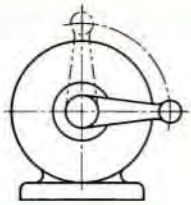
## Minimal inclines



**Application.** Minimal inclines on slopes, cones or pyramids which cannot be shown clearly, do not have to be drawn in the corresponding projection.

**Representation.** The edge representing the projection of the smaller dimension is drawn with a thick solid line.

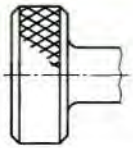
## Moving parts



**Application.** Depicting alternative positions and limits of movement of parts in assembly drawings.

**Representation.** Parts in alternate positions and limits of movement are drawn with two-dot dash-dot lines.

## Surface structures

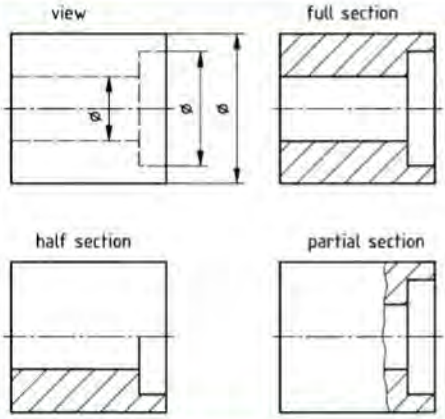


**Representation.** Structures such as knurls and embossing are represented with thick solid lines. Partial representation of the structure is preferable.

# Sectional views

cf. DIN ISO 128-40, -44 and -50 (2002-05)

## Section types




**Section.** The interior of a workpiece can be shown with a section. The front part of the workpiece, which hides the view to the interior, is perceived to be cut out.

In a section it is possible to represent:

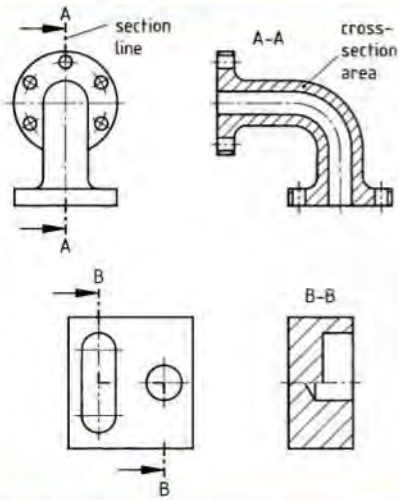
- the cutting plane and additional workpiece outlines lying behind the cutting plane or
- only the cutting plane.

**Full section.** The full section shows the conceptualized workpiece sectioned in a plane.

**Half section.** In a symmetrical workpiece one half is represented as a view, the other half as a section.

**Partial section.** A partial section shows only part of the workpiece in section.

## Definitions




**Cutting plane.** The cutting plane is the imaginary plane with which the workpiece is sectioned. Complicated workpieces can also be represented in two or more cutting planes.

**Cross-section area.** It is formed by the theoretical sectioning of the workpiece. The cross-section area is marked with hatch lines (see below and page 75).

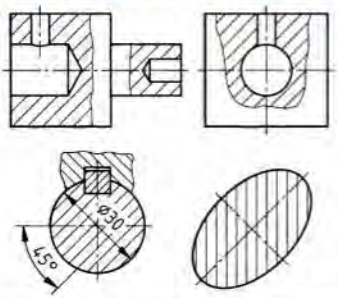
**Section line.** It marks the position of the cutting plane; for two or more cutting planes it marks the cutting path. The section line is drawn with a thick dot-dash line.

For two or more cutting planes the path of the section line is emphasized on the ends of the corresponding plane using short thick solid lines.

**Marking the section line.** It is done with the same upper case letters. Arrows drawn with thick solid lines indicate the direction for viewing the cutting plane.

**Marking the section.** The sectional view is marked with the same upper case reference letters as the section lines.

## Hatching of sections




**Hatching.** The hatching is drawn with parallel solid lines, preferably at an angle of 45° to the centerline or to the main outlines. The hatching is interrupted for lettering.

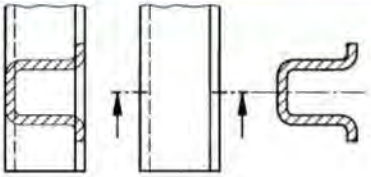
**Hatching is used** for

- individual parts – all hatch lines for cross-section areas should be in the same direction and at the same spacing.
- parts adjacent to each other – hatch lines for the different parts should be in different directions or at different spacing.
- large cross-section areas – hatching preferably only near boundaries or edges.

# Sectional views

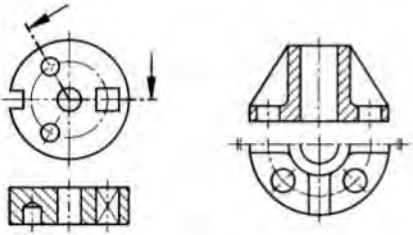
cf. DIN ISO 128-40, -44 and -50 (2002-05)

## Special sections



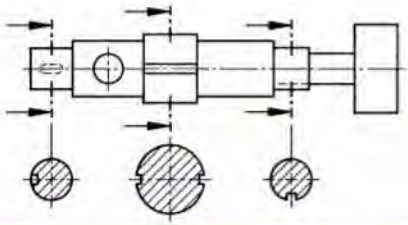
**Profile sections.** They may be

- drawn rotated in a view (revolved section).
  The contour lines of the section are represented with thin solid lines and are drawn within the interior of the part.
- taken out of a view (removed section).
  The section must be connected with the view by a thin dot-dash line.



**Sections with intersecting planes.** If two planes intersect, one cutting plane may be rotated in the projection plane.

**Details of rotated parts.** Uniformly arranged details outside of the cross-section area, e.g. holes, may be rotated in the cutting plane.



**Outlines and edges.** Contours and edges lying behind the cutting plane are only drawn if they add clarity to the drawing.

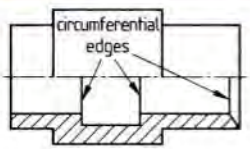
## Parts that are not sectioned

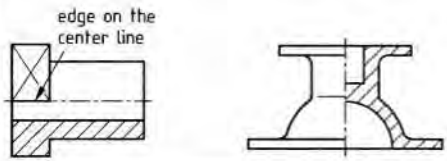


**Not sectioned in the lengthwise direction:**

- parts that are not hollow, e.g. screws, bolts, pins, shafts
- areas of an individual part which should protrude from the base body, e.g. ribs.

## Notes on drawing




**Tool edges**

- **Circumferential edges.** Edges exposed by sectioning must be represented.
- **Hidden edges.** In sections the hidden edges are not represented.
- **Edges on the center line.** If an edge falls on a center-line by sectioning, it is represented.

**Half-sections in symmetrical workpieces**

Section halves of symmetrical workpieces are preferably drawn in relation to the center line,

- below, with horizontal center lines
- to the right, for vertical center lines.

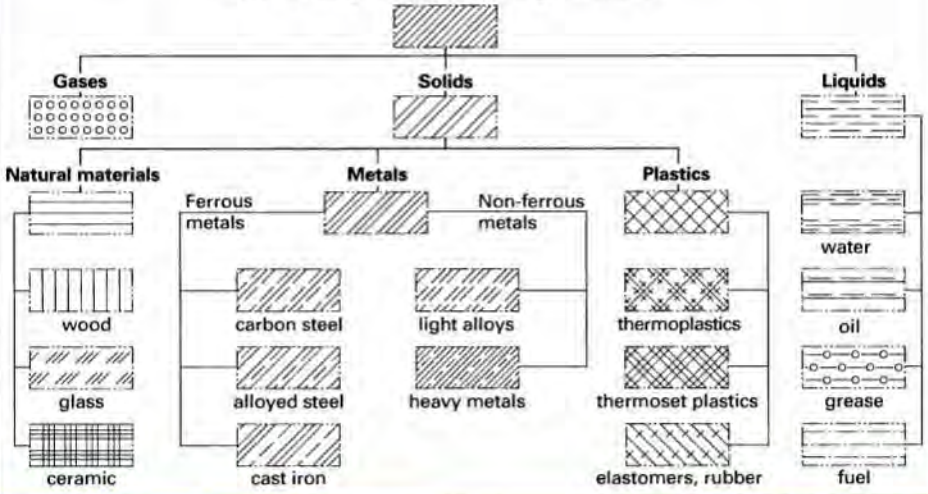
# Hatching, Systems for entering dimensions

## Hatching

cf. DIN ISO 128-50 (2002-05)

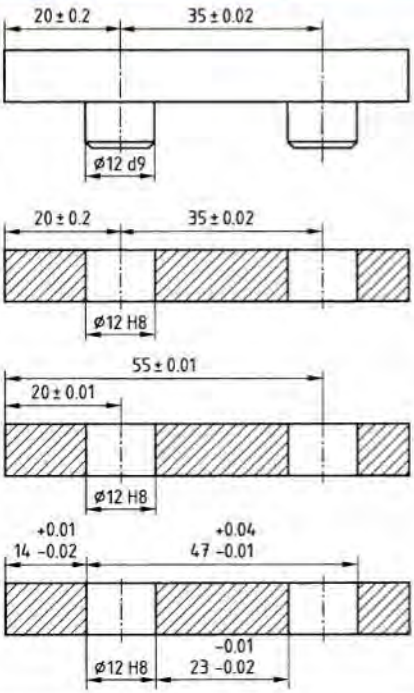
**Section areas** are generally marked with basic hatching without consideration of the material.
Parts whose material should be emphasized can be identified using specific section lining.

**Basic hatching** (without considering the material)




## Systems for entering dimensions

cf. DIN 406-10 (1992-12)




The **dimensioning and tolerancing of workpieces** can be based on

- function,
- manufacturing or
- testing.

Several systems of dimensioning may be used within a single drawing.

**Dimensioning based on function**

**Characteristic.** Selection, entry and tolerancing of the dimensions is done according to design requirements.

**Dimensioning based on fabrication**

**Characteristic.** Dimensions which are necessary for fabrication are calculated from functional dimensions.

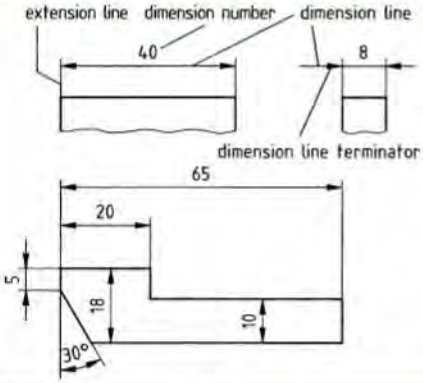
**Dimensioning based on testing**

**Characteristic.** Dimensions and tolerances are entered in the drawing according to the planned testing.

# Dimensioning drawings

## Dimension lines, dimension line terminators, extension lines, dimension numbers cf. DIN 406-11 (1992-12)

### Dimension lines



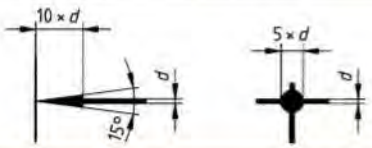

**Design.** Dimension lines are drawn as thin solid lines.

**Entry.** Dimension lines are used for:
- length dimensions parallel to the length to be dimensioned
- angle and arc dimensions as a circular arc about the center of the angle or arc.

**Limited space.** If space is limited, dimension lines may be
- extended to the outside using extension lines
- entered within the workpiece
- drawn to the edges of the part body.

**Spacing.** Dimension lines should have a minimum distance of
- 10 mm from the edge of bodies and
- 7 mm between each other.

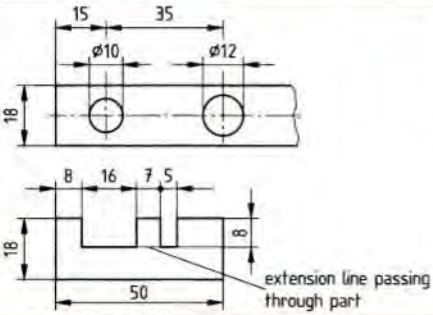
### Dimension line terminator




**Dimension arrowheads.** Generally arrowheads are used to delimit the boundaries of dimension lines.
- arrowhead length: 10 x dimension line width
- angle of lateral side: 15°

**Dots.** Used if space is limited.
- diameter: 5 x dimension line width

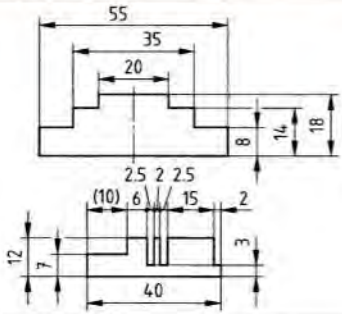
### Extension lines




**Design.** Extension lines are drawn perpendicular to the length to be dimensioned with thin solid lines.

**Special features**
- **Symmetrical elements.** Centerlines may be used as extension lines within symmetrical elements.
- **Breaks** in extension lines may be used e.g. for entering dimensions.
- **Within a view** the extension lines may be drawn to spatially separate elements of the same or similar shape.
- Extension lines may not be extended **from one view to another view.**

### Dimension numbers




**Entry.** Dimension numbers are entered
- in standard lettering according to DIN EN ISO 3098
- with a minimum font size of 3.5 mm
- above the dimension line
- so that they are legible from below and from the right
- for multiple parallel dimension lines – separated from each other.

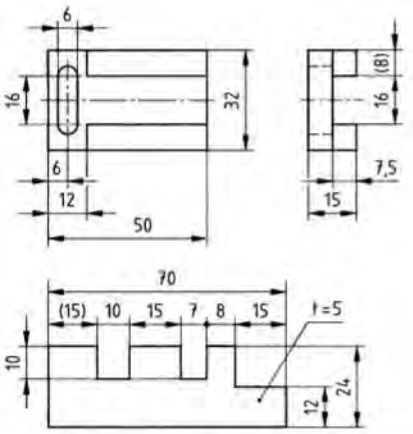
**Limited space.** If there is limited space, the dimensioning numbers may be entered
- on a leader line
- over the extension of the dimension line.

# Dimensioning drawings

## Dimensioning rules, leader and reference lines, angle dimensions, square and width across flats

cf. DIN 406-11 (1992-12) and DIN ISO 128-22 (1999-11)

### Dimensioning rules




**Entering dimensions**

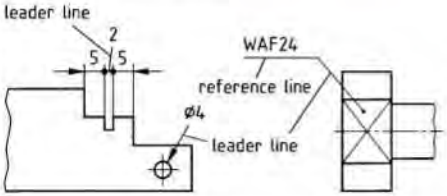
- Each dimension is only entered once. If two elements have identical dimensions but different shapes, they must be dimensioned separately.
- If multiple views are drawn, the dimensions should be entered where the shape of the workpiece is best recognized.
- Symmetrical workpieces. The position of the center line is not dimensioned.

**Chained dimensions.** Series of chained dimensions should be avoided. If chained dimensions are required for reasons related to manufacturing, one dimension of the chain must be in parentheses.

**Flat workpieces.** For flat workpieces that are only drawn in one view, the thickness dimension may be entered with the reference letter t

- in the view or
- near the view.

### Leader and reference lines

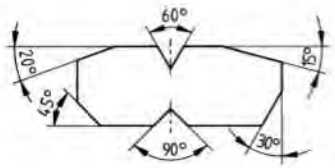



**Leader lines.** Leader lines are drawn as thin solid lines. They end

- with an arrowhead, if they point to solid body edges or holes.
- with a dot, if they point to a surface.
- without marking, if they point to other lines.

**Reference lines.** Reference lines are drawn in the reading direction with thin solid lines. They may be connected to leader lines.

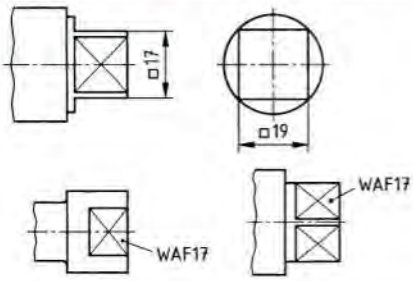
### Angular dimensions




**Extension lines.** The extension lines point toward the vertex of the angle.

**Dimension numbers.** Normally these are entered tangentially to the dimensioning line so that their lower edge points to the vertex of the angle if they are above the horizontal center line and with their upper edge if they are below it.

### Square, width across flats




**Square**

**Symbol.** For square shaped elements the symbol is set in front of the dimensioning number. The size of the symbol corresponds to the size of the small letters.

**Dimensioning.** Square shapes should preferably be dimensioned in the view in which their shape is recognizable. Only the length of one side of the square should be entered.

**Width across flats**

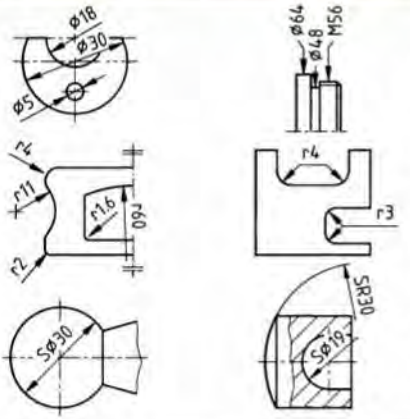
**Symbol.** For widths across flats the upper case letters WAF are placed in front of the dimensioning number, if the width between flats cannot be dimensioned.

# Dimensioning drawings

## Diameters, radii, spheres, chamfers, inclines, tapers, arc dimensions

cf. DIN 406-11 (1992-12)

### Diameter, radius, sphere




**Diameter**

**Symbol.** For all diameters the symbol ∅ is placed before the dimension number. Its overall height corresponds to the height of the dimensioning number.

**Limited space.** In the case of limited space the dimension references the workpiece feature from the outside.

**Radius**

**Symbol.** For radii the lower case letter r is placed before the dimensioning number.

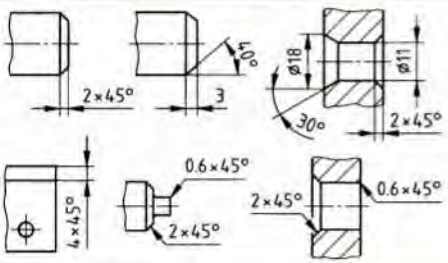
**Dimension lines.** Dimension lines should be drawn

- from the center of the radius or
- from the direction of the midpoint.

**Sphere**

**Symbol.** For spherical shape workpiece features the capital letter S is placed before the diameter or radius symbol.

### Chamfers, countersinks



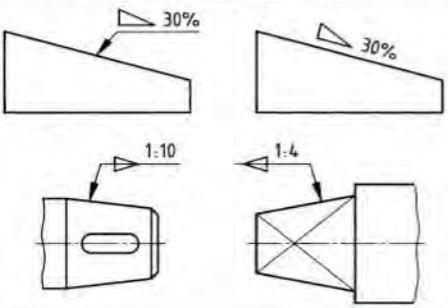

**45° chamfers and countersinks of 90°** can be simply dimensioned by indicating the angle and the chamfer width. Both drawn and undrawn chamfers may be dimensioned using an extension line.

**Other chamfer angles.** For chamfers with an angle deviating from 45° the

- angle and the chamfer width or
- the angle and the chamfer diameter

are to be entered.

### Inclines, tapers




**Incline**

**Symbol.** The symbol ◺ is entered before the dimension numbers.

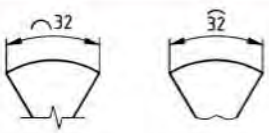
**Orientation of the symbol.** The symbol is oriented so that its incline matches the incline of the workpiece. Preferably the symbol is connected to the inclined surface with a reference line or a leader line.

**Taper**

**Symbol.** The symbol ▷ is entered before the dimension numbers on a reference line.

**Orientation of the symbol.** The orientation of the symbol must match the direction of the workpiece taper. The reference line of the symbol is connected to the outline of the taper with a leader line.

### Arc dimensions



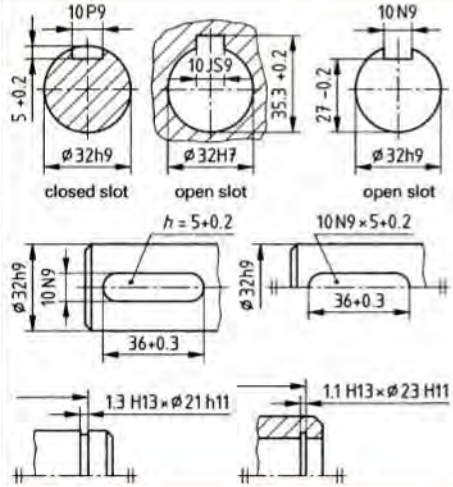

**Symbol.** The symbol ⌒ is entered before the dimension numbers. For manual drawing the arc may be labeled with a similar symbol over the dimension number.

# Dimensioning drawings

## Slots, threads, patterns

cf. DIN 406-11 (1992-12) and DIN ISO 6410-1 (1993-12)

### Slots




**Slot depth.** The slot depth is measured

- from the slot side for closed slots
- from the opposing side for open slots.

**Simplified dimensioning.** For slots represented only in the top view, the slot depth is dimensioned

- with the letter *h* or
- in combination with the slot width.

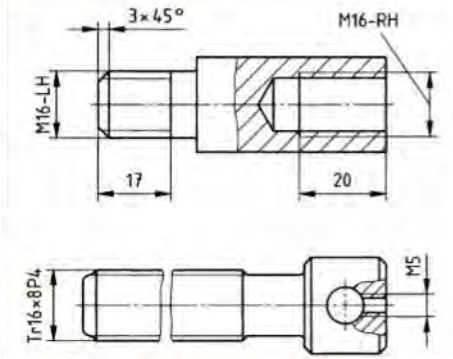
With **slots for retaining rings** the slot depth may also be entered in combination with the slot width.

Limit deviations for tolerance classes JS9, N9, P9 and H11: page 109

Slot dimensions

- for wedges see page 239
- for fitted keys see page 240
- for retaining rings see page 269

### Threads




**Code designation.** Code designators are used for standard threads.

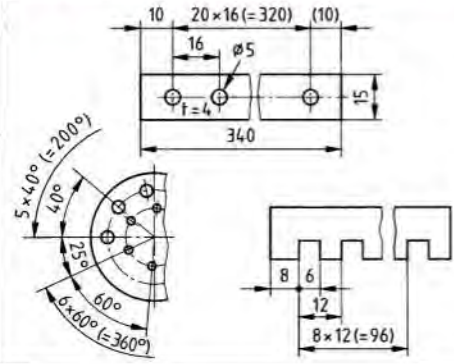
**Left hand threads.** Left hand threads are marked with LH. If both left hand and right hand threads are found on a workpiece, the right hand threads get the addition RH.

**Multiple screw threads.** For multiple screw threads the pitch and the spacing are entered behind the nominal diameter.

**Length specifications.** These give the usable thread length. The depth of the basic hole (page 211) is normally not dimensioned.

**Chamfers.** Chamfers on threads are only dimensioned if their diameters do not correspond to the thread core or the thread outside diameter.

### Radial and linear patterns




**Identical design elements.** The following data is given for spacing of identical design elements having the same distance or angle between them

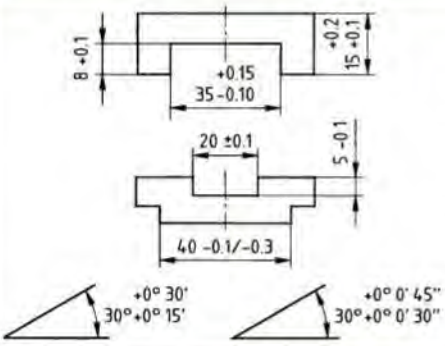
- the number of elements
- the distance between the elements
- the overall length or overall angle (in parentheses).

# Dimensioning drawings

## Tolerance specifications

cf. DIN 406-12 (1992-12), DIN ISO 2768-1 (1991-06) and DIN ISO 2768-2 (1991-04)

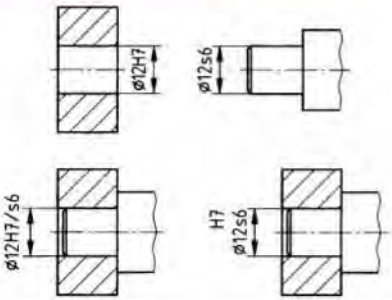
### Tolerance specifications using deviations




**Entry.** The deviations are entered

- after the nominal size
- if there are two deviations, the upper deviation is shown above the lower deviation
- for equally large upper and lower deviations by a ± mark before the number value, which is only entered once
- for angle dimensioning with units specified.

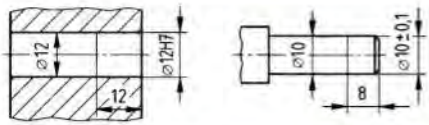
### Tolerance specifications using tolerance classes




**Entry.** Tolerance classes are entered for

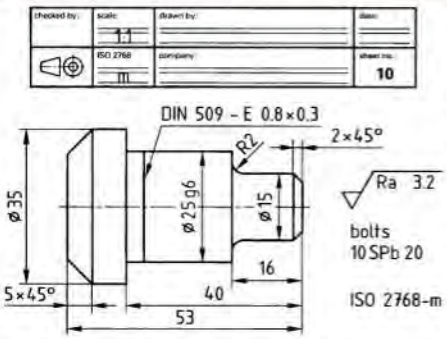
- single nominal sizes: after the nominal size
- parts shown inserted: the tolerance class of the interior dimension (hole) is before or over the tolerance class of the outer dimension (shaft).

### Tolerance specifications for specific areas




**Area of application.** The area to which the tolerance applies is bounded by a thin solid line.

### Tolerance specifications using general tolerances




**Application.** General tolerances are used for

- linear and angular dimensions
- form and position.

They apply to dimensions without individual tolerance entry.

**Drawing entry.** The note for general tolerances (page 110) can be located:

- near the individual part drawings
- for title blocks according to DIN 6771 (retracted): in the title block.

**Entries.** Given are:

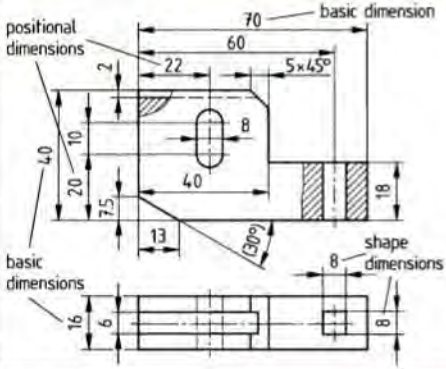
- the sheet number of the standard
- the tolerance class for linear and angular dimensions
- the tolerance class for form and positional tolerances, as needed.

# Dimensioning in drawings

## Dimensions

cf. DIN 406-10 and -11 (1992-12)

### Types of dimensioning




**Basic Dimensions.** The basic dimensions of a workpiece are the

- total length
- total width
- total height.

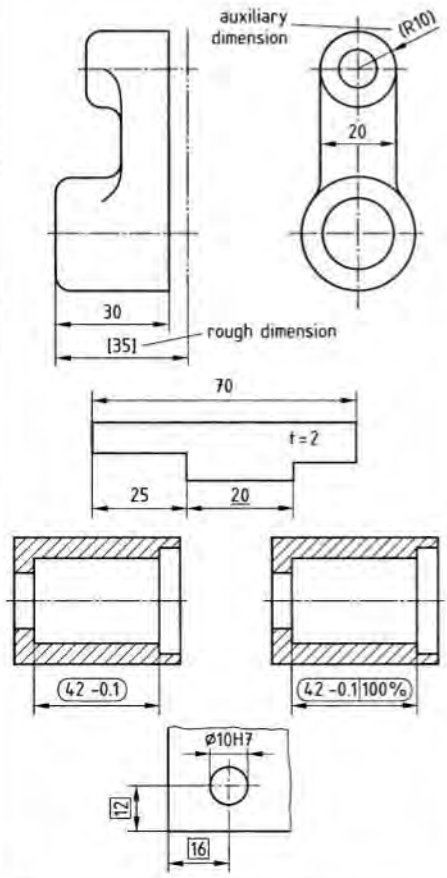
**Shape dimensions.** Shape dimensions establish, e.g. the

- dimensions of slots
- dimensions of shoulders.

**Positional dimensions.** These are used to specify the location of

- holes
- slots
- elongated holes, etc.

### Special dimensions




#### Rough dimensions

**Function.** Rough dimensions might be used to give information about, for example, the dimensions of cast or forged workpieces before machining.

**Labeling.** Rough dimensions are put in brackets.

#### Auxiliary dimensions

**Function.** Auxiliary dimensions give additional information. They are not necessary to geometrically define the workpiece.

**Labeling.** Auxiliary dimensions are

- put in parentheses
- entered without tolerances.

#### Dimensions not drawn to scale

**Labeling.** Dimensions not drawn to scale might be used for drawing changes, for example, and they are marked by underlining.

**Prohibited** are underlined dimensions in computer aided (CAD) drawings.

#### Control dimensions

**Function.** It should be noted that these dimensions are especially checked by the purchaser. If necessary a 100% check will be performed.

**Labeling.** Control dimensions are set in frames with rounded ends.

#### Theoretically precise dimensions

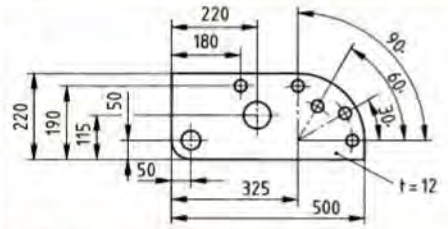
**Function.** These dimensions give the geometrically ideal (theoretically precise) position of the shape of a design feature.

**Labeling.** The dimensions are placed in a frame without tolerance specifications and correspond with geometric tolerancing.

# Types of dimensioning

## Parallel dimensioning, running dimensioning, coordinate dimensioning[1] cf. DIN 406-11 (1992-12)

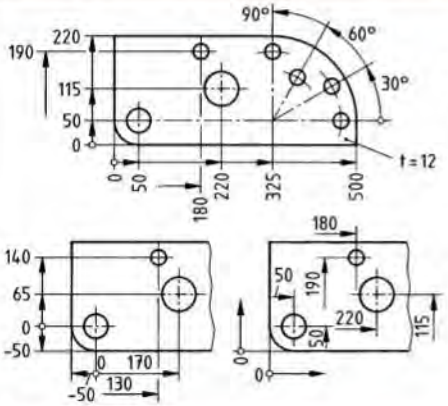
### Stack dimensioning




**Dimension lines**. Several dimension lines are entered together for

- stacked linear dimensions
- concentric angular dimensions.

### Running dimensioning




**Origin**. The dimensions are entered outwards from the origin in each of the three possible directions. The origin is indicated by a small circle.

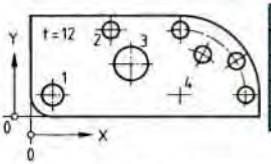
**Dimension lines**. The following applies for the entries:

- As a rule only one dimension line is used for each direction.
- If there is limited space two or more dimension lines may be used. The dimension lines may also be shown broken.

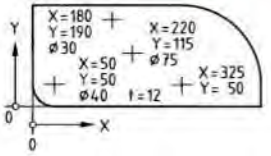
**Dimensions**

- must be provided with a minus sign if they are entered from the origin in the opposite direction.
- may also be entered in the reading direction.

### Coordinate dimensioning




| Item | X | Y | d |
|---|---|---|---|
| 1 | 50 | 50 | ø40 |
| 2 | 180 | 190 | ø30 |
| 3 | 220 | 115 | ø75 |
| 4 | 325 | 50 | – |




**Cartesian coordinates** (page 63)

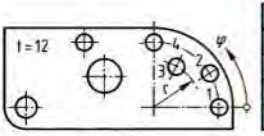
**Coordinate values**. These are

- entered in tables or
- entered near the coordinate points.

**Point of origin**. The point of origin

- is entered with a small circle
- can lie at any location of the drawing.

**Dimensions**. These must be provided with a minus sign if they are entered from the origin in the opposite direction to the positive direction.




| Item | r | φ | d |
|---|---|---|---|
| 1 | 140 | 0° | ø30 |
| 2 | 140 | 30° | ø30 |
| 3 | 100 | 60° | ø30 |
| 4 | 140 | 90° | ø30 |

**Polar coordinates** (page 63)

**Coordinate values**. The coordinate values are entered in tables.

[1] Parallel dimensioning, running dimensioning and coordinate dimensioning may be combined with each other.

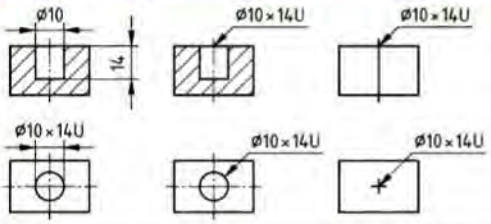
# Simplified presentation in drawings

## Simplified representation of holes

cf. DIN 6780 (2000-10)

### Hole base, line widths for simplified representation

| Full scale representation, full scale dimensioning | Full scale representation, simplified dimensioning | Simplified representation, simplified dimensioning |
|---|---|---|




**Hole base**

The shape of the hole base is given by a symbol if necessary.

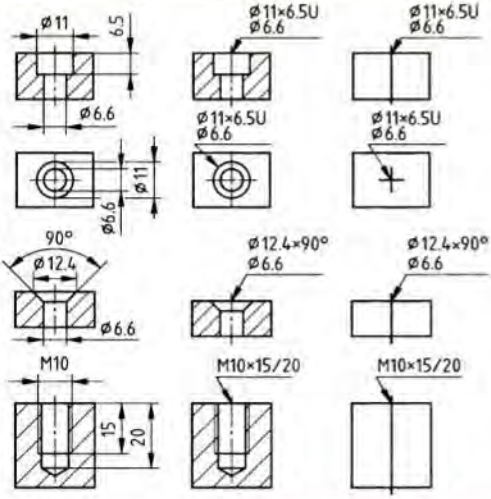
The **symbol U** for example means a **flat hole base** (cylindrical end bore).

**Line widths**

For holes depicted in simplified form, the positions of holes should be drawn as:

- simply the intersecting axes in the top view
- the position of the holes in thick solid lines in parallel axis representation.

### Stepped holes, countersinks and chamfers, internal threads




**Stepped holes**

For holes with two or more steps the dimensions are written under each other. Here the largest diameter is written on the first line.

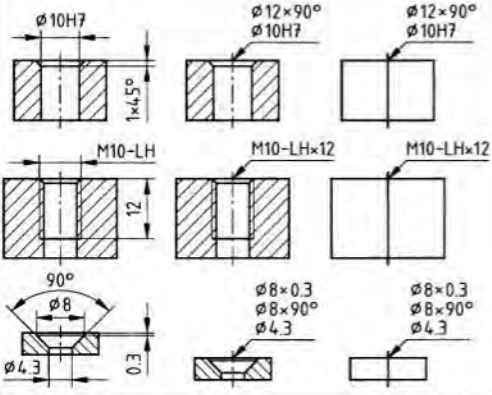
**Countersinks and chamfers**

For countersinks and hole chamfers the largest countersink diameter and the countersink angle are given.

**Internal threads**

The thread length and the hole depth are separated by a slash. Holes without depth specification are drilled through.

### Examples




Hole Ø 10H7
Through hole
Chamfer 1 x 45°

Left hand thread M10
Thread length 12 mm
Drilled through core hole

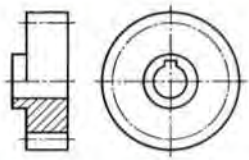
Cylindrical countersink Ø8
Bore depth 0.3 mm
Through hole Ø4.3 with
cone shaped counterbore 90°
Countersink diameter Ø8

# Gear types

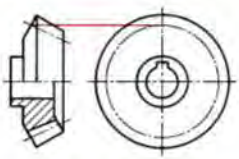
## Representation of gears

cf. DIN ISO 2203 (1976-06)

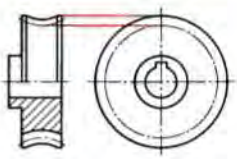
### Spur gear



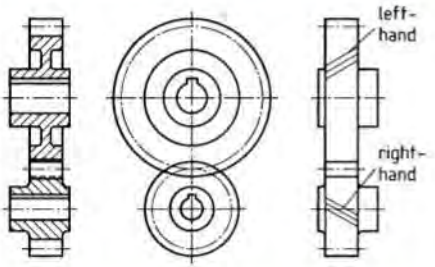
### Bevel gear



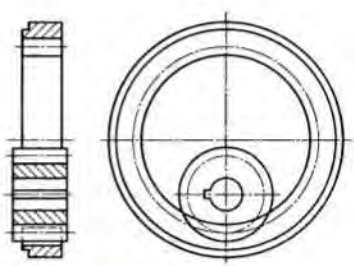
### Worm gear



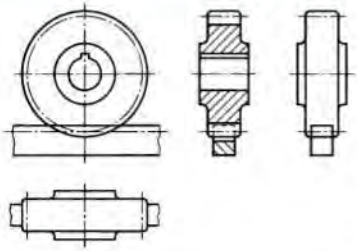
### External helical gear



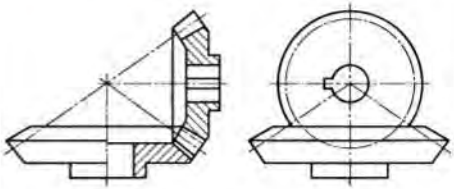

### Internal spur gear



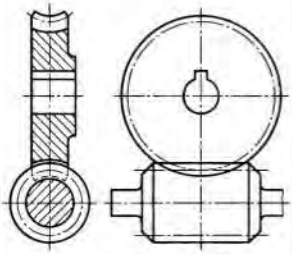
### Rack and Pinion



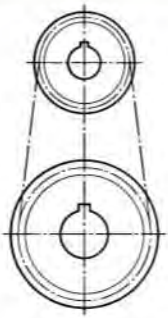
### Bevel gear set (shaft angle 90°)



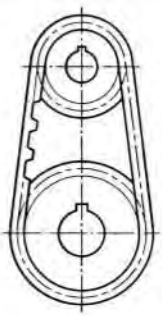
### Worm and worm gear



### Sprockets



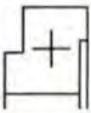
### Positive drive belts



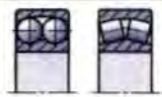
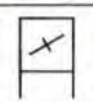
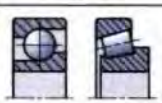
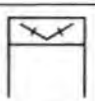
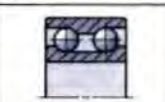
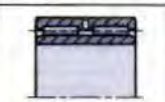
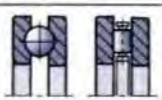
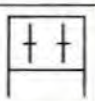
# Roller bearings

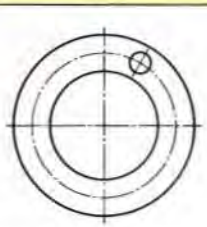
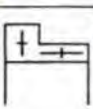
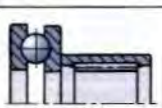
## Representation of roller bearings

cf. DIN ISO 8826-1 (1990-12) and DIN ISO 8826-2 (1995-10)

| Representation | | | Elements of a detailed simplified representation | |
|---|---|---|---|---|
| simplified | graphical | explanation | element | explanation, application |
|  |  | For general purposes a roller bearing is represented as square or rectangular with a free-standing upright cross. |  | Long, straight line; for representing the axis of the roller bearing elements for bearings that cannot be adjusted. |
| | | |  | Long, curved line; for representing the axis of the roller bearing elements for bearings that can be adjusted (self-aligning bearing). |
|  |  | If necessary, the roller bearing can be represented by its outline and a free-standing upright cross. |  | Short straight line; used to represent the position and number of rows of roller bearing elements. |
| | | |  | Circle; for the representation of roller bearing elements (balls, roller, needle rollers) which are drawn perpendicular to their axis. |

### Examples of detailed simplified representation of roller bearings

| Representation of single-row roller bearings | | | Representation of double row roller bearings | | |
|---|---|---|---|---|---|
| detailed simplified | graphical | designation | detailed simplified | graphical | designation |
|  |  | Radial-deep groove ball bearings, cylindrical roller bearings |  |  | Radial-deep groove ball bearings, cylindrical roller bearings |
|  |  | Radial spherical roller bearing (barrel-shaped bearing) |  |  | Spherical roller bearing, radial-spherical roller bearing |
|  |  | Angular-contact ball bearing, tapered roller bearing |  |  | Angular-contact ball bearings |
|  |  | Needle bearing, needle roller assembly |  |  | Needle bearing, needle roller assembly |
|  |  | Axial-deep grooved ball bearing, axial-roller bearing |  |  | Axial-deep grooved ball bearing, dual action |
|  |  | Axial-spherical roller bearing |  |  | Axial-deep grooved ball bearing with spherical seating, dual action |

| Combined ball bearings | | | Representation perpendicular to the rolling element axis | |
|---|---|---|---|---|
|  |  | Combined radial-needle bearing with angular-contact ball bearing |  | Roller bearing with any desired type of roller element shape (balls, rollers, needles) |
|  |  | Combined axial-ball bearing with radial needle bearing | | |

# Representation of seals and roller bearings

## Simplified representation of seals

cf. DIN ISO 9222-1 (1990-12) and DIN ISO 9222-2 (1991-03)

| Representation | | | Elements of a detailed simplified representation | |
|---|---|---|---|---|
| simplified | graphical | explanation | element | explanation, application |
|  |  | For general purposes a seal is represented by a square or rectangle and a separate diagonal cross-mark. The sealing direction can be given by an arrow. |  | Long line parallel to the sealing surface; for the fixed (static) sealing element. |
| | | |  | Long diagonal line; for the dynamic sealing element; e.g. the sealing lip. The sealing direction can be given by an arrow. |
| | | |  | Short diagonal line; for dust lip seal, scraper rings. |
|  |  | If necessary, the seals can be represented by the outline and a free-standing diagonal cross-mark. |  | Short lines pointing to the middle of the symbol; for the static parts of U-rings und V-rings, packing. |
| | | |  | Short lines, which point to the middle of the symbol; for the sealing lips of U-rings und V-rings, packing. |
| | | |  | T and U; for non-contact seals. |

### Examples of detailed simplified representation of seals

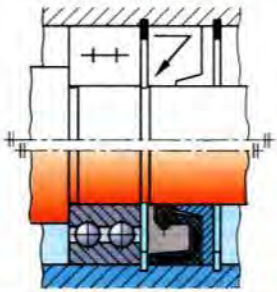
| Shaft seals and piston rod seals | | | | Profile gaskets, packing sets, labyrinth seals | | | |
|---|---|---|---|---|---|---|---|
| | | designation for | | | | | |
| detailed simplified | graphical | rotation | linear motion | detailed simplified | graphical | detailed simplified | graphical |
|  |  | Shaft seal without dust lip seal | Rod seal without stripper |  |  |  |  |
|  |  | Shaft seal with dust lip seal | Rod seal with stripper |  |  |  |  |
|  |  | Shaft seal, dual action | Rod seal, dual action |  |  |  |  |

### Examples of simplified representation of seals and roller bearings

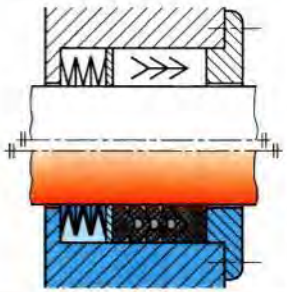
Deep grooved roller bearings and radial shaft seal with dust lip seal[1]



Dual row deep grooved roller bearings and radial shaft seal[2]



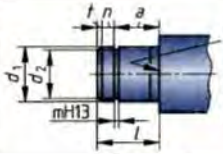
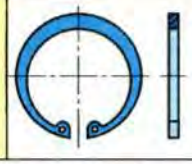
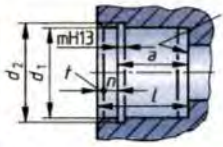
Packing set[2]



[1] Top half: simplified representation; bottom half: graphical representation.
[2] Top half: detailed simplified representation; bottom half: graphical representation.

# Representation of retaining rings, Slots for retaining rings, Springs, Splines and serrations

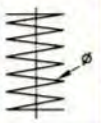
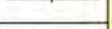
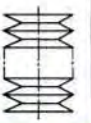
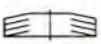
## Representation of retaining rings and slots for retaining rings

| | Representation | Assembly dimension | Deviations |
|---|---|---|---|
| Retaining rings for shafts (page 269) |  |   reference plane for dimensioning[1] $a$ = roller bearing width + retaining ring width | Deviations for $d_2$: upper deviation: 0 (zero) lower deviation: negative Deviations for $a$: upper deviation: positive lower deviation: 0 (zero) |
| Retaining rings for holes (page 269) |  |   reference plane for dimensioning[1] | Deviations for $d_2$: upper deviation: positive lower deviation: 0 (zero) Deviations for $a$: upper deviation: positive lower deviation: 0 (zero) |

[1] For functional reasons the reference plane for the dimensioning of slots is the locating face of the part to be secured.

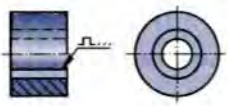
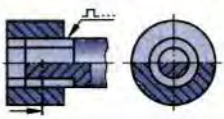
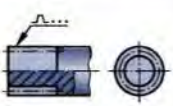
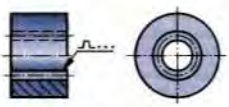
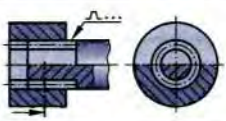
## Representation of springs

cf. DIN ISO 2162-1 (1994-08)

| Name | Representation view | Representation section | Symbol | Name | Representation view | Representation section | Symbol |
|---|---|---|---|---|---|---|---|
| Cylindrical helical compression spring (round wire) |  |  |  | Cylindrical helical tension spring |  |  |  |
| Cylindrical helical tension spring |  |  |  | Cylindrical helical compression spring (square wire) |  |  |  |
| Disk spring (simple) |  |  |  | Disk spring assembly (disks layered in alternating directions) |  |  |  |
| Disk spring assembly (disks layered in the same direction) |  |  |  | | | | |

## Representation of splines and serrations

cf. DIN ISO 6413 (1990-03)

| | Shaft | Hub | Joint |
|---|---|---|---|
| Splines or spline hubs with straight flanks. Symbol:  |  |  |  |
| Toothed shafts or toothed hubs with involute splines or serrations. Symbol:  |  |  |  |

⇒ **Splines ISO 14-6 x 26 f7 x 30:** Spline profile with straight flanks according to ISO 14, number of splines N = 6, inner diameter $d$ = 26f7, outer diameter $D$ = 30 (page 241)

# Bosses on turned parts, Workpiece corners and edges

## Bosses on turned parts

cf. DIN 6785 (1991-11)

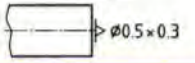
**Boss dimensions**




**Example**



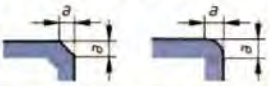
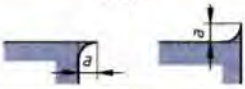

**Drawing entry**

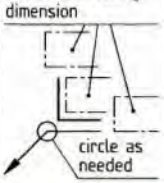



| Boss dimensions | Largest diameter of the finished part in mm | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | up to 3 | over 3 to 5 | over 5 to 8 | over 8 to 12 | over 12 to 18 | over 18 to 26 | over 26 to 40 | over 40 to 60 |
| $d_{2max}$ in mm | 0.3 | 0.5 | 0.8 | 1.0 | 1.5 | 2.0 | 2.5 | 3.5 |
| $l_{max}$ in mm | 0.2 | 0.3 | 0.5 | 0.6 | 0.9 | 1.2 | 2.0 | 3.0 |

## Workpiece corners and edges

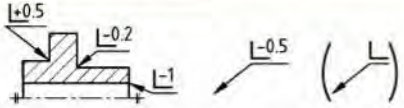
cf. DIN ISO 13715 (2000-12), replacement for DIN 6784

| Edge or corner | Workpiece edge/corner lies in reference to the ideal geometrical form | | |
|---|---|---|---|
| | inside | outside | in area |
| outer edge  | material removal  | burr  | sharp edged  |
| inner edge  | material removal  | transition  | sharp edged  |
| Dim. $a$ (mm) | −0.1; −0.3; −0.5; −1.0; −2.5 | +0.1; +0.3; +0.5; +1.0; +2.5 | −0.05; −0.02; +0.02; +0.05 |

| Symbol for labeling workpiece edges/corners | Symbol element | Meaning for outer edge | Meaning for inner edge | Burr and material removal direction | outer edge | inner edge |
|---|---|---|---|---|---|---|
| field for entering dimension   | + | Burr allowed, material removal not allowed | Transition allowed, material removal not allowed | Specification allowed for | Burr | Material removal |
| | − | Removal required, burr not allowed | Removal required, transition not allowed | Example   | | |
| | ± [1] | Burr or transition allowed | Material removal or transition allowed | Meaning   | | |
| [1] only allowed with a dimension callout | | | | | | |

### Labeling of workpiece corners and edges

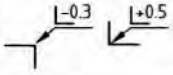
**Collective indications**




**Collective indications** apply to all edges for which an edge condition is not given.

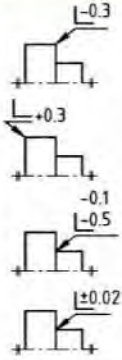
**Edges for which the collective indication does not apply** must be marked in the drawing.

The exceptions are placed after the collective indication in parentheses or indicated by the base symbol.




**Collective indications** which **are only valid for outside or inside edges** are given by the corresponding symbols.

**Examples**




Outside edge without burr. The allowable material removal is between 0 and 0.3 mm.

Outside edge with allowable burr of 0 to 0.3 mm (burr direction specified).

Inside edge with allowable material removal between 0.1 and 0.5 mm (material removal direction not specified).

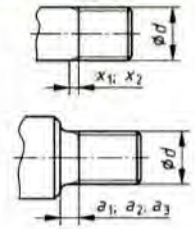
Inside edge with allowable material removal between 0 and 0.02 mm or allowable transition up to 0.02 mm (sharp edged).

# Thread runouts, Thread undercuts

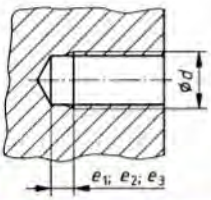
## Thread runouts for metric ISO threads

cf. DIN 76-1 (2004-06)

**External thread**




**Internal thread**




| Pitch [1] P | ISO standard thread d | Thread runout [2] $x_1$ max. | $a_1$ max. | $e_1$ | Pitch [1] P | ISO standard thread d | Thread runout [2] $x_1$ max. | $a_1$ max. | $e_1$ |
|---|---|---|---|---|---|---|---|---|---|
| 0.2 | – | 0.5 | 0.6 | 1.3 | 1.25 | M8 | 3.2 | 3.75 | 6.2 |
| 0.25 | M1 | 0.6 | 0.75 | 1.5 | 1.5 | M10 | 3.8 | 4.5 | 7.3 |
| 0.3 | – | 0.75 | 0.9 | 1.8 | 1.75 | M12 | 4.3 | 5.25 | 8.3 |
| 0.35 | M1.6 | 0.9 | 1.05 | 2.1 | 2 | M16 | 5 | 6 | 9.3 |
| 0.4 | M2 | 1 | 1.2 | 2.3 | 2.5 | M20 | 6.3 | 7.5 | 11.2 |
| 0.45 | M2.5 | 1.1 | 1.35 | 2.6 | 3 | M24 | 7.5 | 9 | 13.1 |
| 0.5 | M3 | 1.25 | 1.5 | 2.8 | 3.5 | M30 | 9 | 10.5 | 15.2 |
| 0.6 | – | 1.5 | 1.8 | 3.4 | 4 | M36 | 10 | 12 | 16.8 |
| 0.7 | M4 | 1.75 | 2.1 | 3.8 | 4.5 | M42 | 11 | 13.5 | 18.4 |
| 0.75 | – | 1.9 | 2.25 | 4 | 5 | M48 | 12.5 | 15 | 20.8 |
| 0.8 | M5 | 2 | 2.4 | 4.2 | 5.5 | M56 | 14 | 16.5 | 22.4 |
| 1 | M6 | 2.5 | 3 | 5.1 | 6 | M64 | 15 | 18 | 24 |

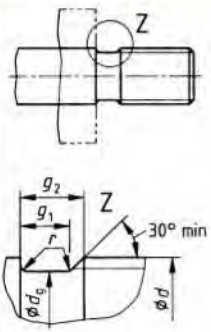
[1] For fine threads the dimension of the thread runout is chosen according to the pitch *P*.

[2] As a rule; applies if no other entries are given.
If a shorter thread runout is necessary, this applies:
$x_2 \approx 0.5 \cdot x_1$; $a_2 \approx 0.67 \cdot a_1$; $e_2 \approx 0.625 \cdot e_1$
If a longer thread runout is necessary, this applies:
$a_3 \approx 1.3 \cdot a_1$; $e_3 \approx 1.6 \cdot e_1$

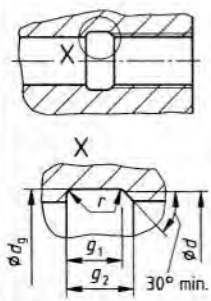
## Screw thread undercuts for metric ISO threads

cf. DIN 76-1 (2004-06)

**External thread**
form A and form B




**Internal thread**
form C and form D




| Pitch [1] P | ISO standard thread d | r | External threads: $d_3$ h13 | Form A [2]: $g_1$ min. | Form A [2]: $g_2$ max. | Form B [3]: $g_1$ min. | Form B [3]: $g_2$ max. | Internal threads: $d_3$ H13 | Form C [2]: $g_1$ min. | Form C [2]: $g_2$ max. | Form D [3]: $g_1$ min. | Form D [3]: $g_2$ max. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.2 | – | 0.1 | d – 0.3 | 0.45 | 0.7 | 0.25 | 0.5 | d + 0.1 | 0.8 | 1.2 | 0.5 | 0.9 |
| 0.25 | M1 | 0.12 | d – 0.4 | 0.55 | 0.9 | 0.25 | 0.6 | d + 0.1 | 1 | 1.4 | 0.6 | 1 |
| 0.3 | – | 0.16 | d – 0.5 | 0.6 | 1.05 | 0.3 | 0.75 | d + 0.1 | 1.2 | 1.6 | 0.75 | 1.25 |
| 0.35 | M1.6 | 0.16 | d – 0.6 | 0.7 | 1.2 | 0.4 | 0.9 | d + 0.2 | 1.4 | 1.9 | 0.9 | 1.4 |
| 0.4 | M2 | 0.2 | d – 0.7 | 0.8 | 1.4 | 0.5 | 1 | d + 0.2 | 1.6 | 2.2 | 1 | 1.6 |
| 0.45 | M2.5 | 0.2 | d – 0.7 | 1 | 1.6 | 0.5 | 1.1 | d + 0.2 | 1.8 | 2.4 | 1.1 | 1.7 |
| 0.5 | M3 | 0.2 | d – 0.8 | 1.1 | 1.75 | 0.5 | 1.25 | d + 0.3 | 2 | 2.7 | 1.25 | 2 |
| 0.6 | – | 0.4 | d – 1 | 1.2 | 2.1 | 0.6 | 1.5 | d + 0.3 | 2.4 | 3.3 | 1.5 | 2.4 |
| 0.7 | M4 | 0.4 | d – 1.1 | 1.5 | 2.45 | 0.8 | 1.75 | d + 0.3 | 2.8 | 3.8 | 1.75 | 2.75 |
| 0.75 | – | 0.4 | d – 1.2 | 1.6 | 2.6 | 0.9 | 1.9 | d + 0.3 | 3 | 4 | 1.9 | 2.9 |
| 0.8 | M5 | 0.4 | d – 1.3 | 1.7 | 2.8 | 0.9 | 2 | d + 0.3 | 3.2 | 4.2 | 2 | 3 |
| 1 | M6 | 0.6 | d – 1.6 | 2.1 | 3.5 | 1.1 | 2.5 | d + 0.5 | 4 | 5.2 | 2.5 | 3.7 |
| 1.25 | M8 | 0.6 | d – 2 | 2.7 | 4.4 | 1.5 | 3.2 | d + 0.5 | 5 | 6.7 | 3.2 | 4.9 |
| 1.5 | M10 | 0.8 | d – 2.3 | 3.2 | 5.2 | 1.8 | 3.8 | d + 0.5 | 6 | 7.8 | 3.8 | 5.6 |
| 1.75 | M12 | 1 | d – 2.6 | 3.9 | 6.1 | 2.1 | 4.3 | d + 0.5 | 7 | 9.1 | 4.3 | 6.4 |
| 2 | M16 | 1 | d – 3 | 4.5 | 7 | 2.5 | 5 | d + 0.5 | 8 | 10.3 | 5 | 7.3 |
| 2.5 | M20 | 1.2 | d – 3.6 | 5.6 | 8.7 | 3.2 | 6.3 | d + 0.5 | 10 | 13 | 6.3 | 9.3 |
| 3 | M24 | 1.6 | d – 4.4 | 6.7 | 10.5 | 3.7 | 7.5 | d + 0.5 | 12 | 15.2 | 7.5 | 10.7 |
| 3.5 | M30 | 1.6 | d – 5 | 7.7 | 12 | 4.7 | 9 | d + 0.5 | 14 | 17.7 | 9 | 12.7 |
| 4 | M36 | 2 | d – 5.7 | 9 | 14 | 5 | 10 | d + 0.5 | 16 | 20 | 10 | 14 |
| 4.5 | M42 | 2 | d – 6.4 | 10.5 | 16 | 5.5 | 11 | d + 0.5 | 18 | 23 | 11 | 16 |
| 5 | M48 | 2.5 | d – 7 | 11.5 | 17.5 | 6.5 | 12.5 | d + 0.5 | 20 | 26 | 12.5 | 18.5 |
| 5.5 | M56 | 3.2 | d – 7.7 | 12.5 | 19 | 7.5 | 14 | d + 0.5 | 22 | 28 | 14 | 20 |
| 6 | M64 | 3.2 | d – 8.3 | 14 | 21 | 8 | 15 | d + 0.5 | 24 | 30 | 15 | 21 |

⇒ **DIN 76-C:** Screw thread undercut shape C

[1] For fine thread screws the dimension of the thread undercut is chosen according to the pitch *P*.

[2] as a rule; always applies if no other entries are made

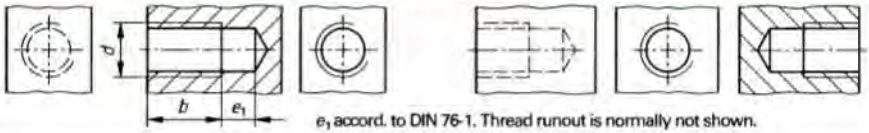
[3] Only in cases where a shorter thread undercut is required.

# Representation of threads and screw joints

## Representation of threads

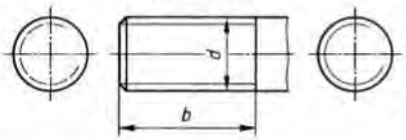
cf. DIN ISO 6410-1 (1993-12)

### Internal thread

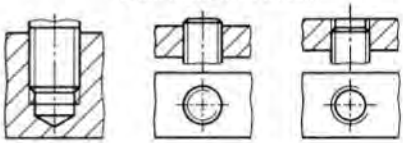



$e_1$ accord. to DIN 76-1. Thread runout is normally not shown.

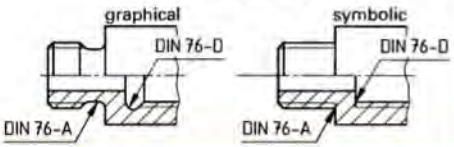
### Bolt thread



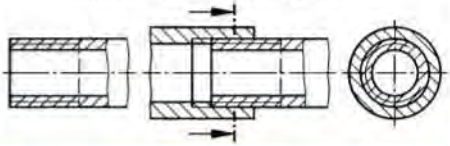

### Bolts in internal thread



### Thread undercut



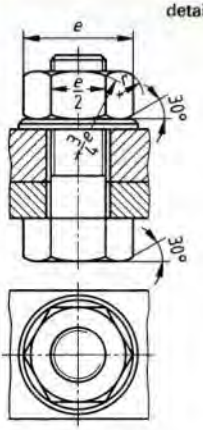

### Pipe threads and pipe screw joints

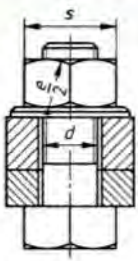


## Representation of screw joints

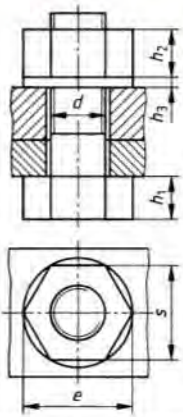
### Hexagonal bolt and nut

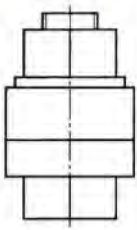
detailed




simplified

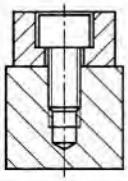


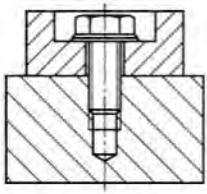
$h_1$ bolt head hight
$h_2$ nut height
$h_3$ washer thickness
$e$ diagonal between corners
$s$ width across flats
$d$ thread nominal ø

$h_1 \approx 0.7 \cdot d$
$h_2 \approx 0.8 \cdot d$
$h_3 \approx 0.2 \cdot d$
$e \approx 2 \cdot d$
$s \approx 0.87 \cdot e$

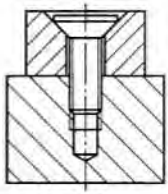
### Screw joint with cap screw



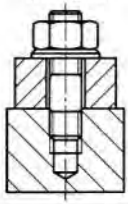
### Screw joint with hexagonal screw



### Screw joint with countersunk head screw



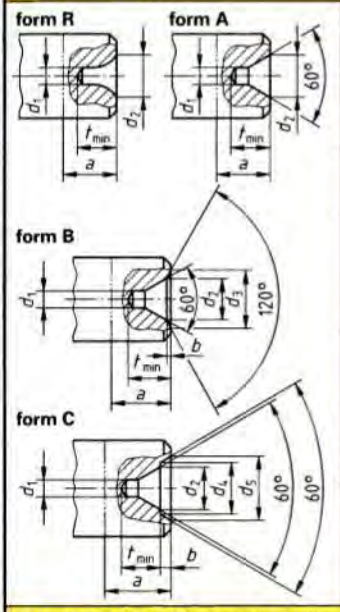
### Screw joint with stud



# Center holes, Knurls

## Center holes

cf. DIN 332-1 (1986-04)




| Form | | Nominal sizes | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $d_1$ | 1 | 1.25 | 1.6 | 2 | 2.5 | 3.15 | 4 | 5 | 6.3 | 8 |
| | $d_2$ | 2.12 | 2.65 | 3.35 | 4.25 | 5.3 | 6.7 | 8.5 | 10.6 | 13.2 | 17 |
| R | $t_{min}$ | 1.9 | 2.3 | 2.9 | 3.7 | 4.6 | 5.8 | 7.4 | 9.2 | 11.4 | 14.7 |
| | $a$ | 3 | 4 | 5 | 6 | 7 | 9 | 11 | 14 | 18 | 22 |
| A | $t_{min}$ | 1.9 | 2.3 | 2.9 | 3.7 | 4.6 | 5.9 | 7.4 | 9.2 | 11.5 | 14.8 |
| | $a$ | 3 | 4 | 5 | 6 | 7 | 9 | 11 | 14 | 18 | 22 |
| B | $t_{min}$ | 2.2 | 2.7 | 3.4 | 4.3 | 5.4 | 6.8 | 8.6 | 10.8 | 12.9 | 16.4 |
| | $a$ | 3.5 | 4.5 | 5.5 | 6.6 | 8.3 | 10 | 12.7 | 15.6 | 20 | 25 |
| | $b$ | 0.3 | 0.4 | 0.5 | 0.6 | 0.8 | 0.9 | 1.2 | 1.6 | 1.4 | 1.6 |
| | $d_3$ | 3.15 | 4 | 5 | 6.3 | 8 | 10 | 12.5 | 16 | 18 | 22.4 |
| C | $t_{min}$ | 1.9 | 2.3 | 2.9 | 3.7 | 4.6 | 5.9 | 7.4 | 9.2 | 11.5 | 14.8 |
| | $a$ | 3.5 | 4.5 | 5.5 | 6.6 | 8.3 | 10 | 12.7 | 15.6 | 20 | 25 |
| | $b$ | 0.4 | 0.6 | 0.7 | 0.9 | 0.9 | 1.1 | 1.7 | 1.7 | 2.3 | 3 |
| | $d_4$ | 4.5 | 5.3 | 6.3 | 7.5 | 9 | 11.2 | 14 | 18 | 22.4 | 28 |
| | $d_5$ | 5 | 6 | 7.1 | 8.5 | 10 | 12.5 | 16 | 20 | 25 | 31.5 |

Form
- **R:** curved bearing surface, without protective countersink
- **A:** straight bearing surface, without protective countersink
- **B:** straight bearing surface, conical protective countersink
- **C:** straight bearing surface, truncated conical protective countersink

## Drawing callout for center holes

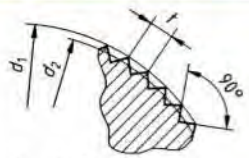
cf. DIN ISO 6411 (1997-11)

| A center hole **is** required on the finished part | A center hole **is allowed** on the finished part | A center hole **may not** be present on the finished part |
|---|---|---|
| ISO 6411-A4/8.5 | ISO 6411-A4/8.5 | ISO 6411-A4/8.5 |

⇒ **< ISO 6411 – A4/8.5:** center hole ISO 6411: a center hole is required on the finished part.
Form and dimensions of the center hole according to DIN 332: form A; $d_1 = 4$ mm; $d_2 = 8.5$ mm.

## Knurls

cf. DIN 82 (1973-01)

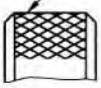


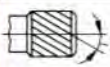
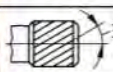
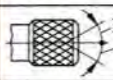

$d_1$ nominal diameter
$d_2$ initial diameter
$t$ spacing

Standard spacing values
$t$: 0.5; 0.6; 0.8; 1.0; 1.2; 1.6 mm

**Drawing entry** (example):

DIN 82-RGE 0.8



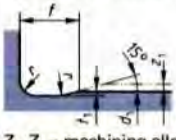
| Letter symbol | Representation | Name | Point shape | Initial diameter $d_2$ |
|---|---|---|---|---|
| RAA |  | Knurls with axially parallel grooves | – | $d_2 = d_1 - 0.5 \cdot t$ |
| RBR |  | Right-hand knurl | – | $d_2 = d_1 - 0.5 \cdot t$ |
| RBL |  | Left-hand knurl | – | $d_2 = d_1 - 0.5 \cdot t$ |
| RGE |  | Left-hand/right-hand knurls | raised | $d_2 = d_1 - 0.67 \cdot t$ |
| RGV | | | recessed | $d_2 = d_1 - 0.33 \cdot t$ |
| RKE |  | Axial and circumferential knurl | raised | $d_2 = d_1 - 0.67 \cdot t$ |
| RKV | | | recessed | $d_2 = d_1 - 0.33 \cdot t$ |
| ⇒ | **DIN 82-RGE 0.8:** Left-hand/right-hand knurls, raised points, $t = 0.8$ mm | | | |

# Undercuts

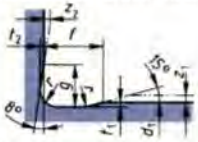
## Undercuts[1]

cf. DIN 509 (2006-12)

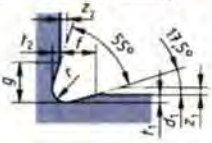
**form E**
for cylindrical surface to be further machined



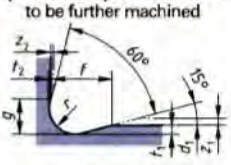
**form F**
for shoulders and cylindrical surfaces to be further machined



**form G**
for small transition (for low loading)



**form H**
for planar and cylindrical surfaces to be further machined



$Z_1$, $Z_2$ = machining allowances

⇒ **Undercut DIN 509 – E 0.8 x 0.3:** form E, radius $r$ = 0.8 mm, undercut depth $t_1$ = 0.3 mm

### Undercut dimensions and countersink dimensions

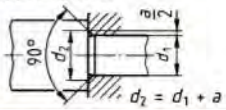
| Form | $r$[2] ± 0.1 Series 1 | $r$[2] ± 0.1 Series 2 | $t_1$ + 0.1 0 | $t_2$ + 0.05 0 | $f$ + 0.2 0 | $g$ | Correlation to diameter $d_1$[3] for workpieces with normal loading | Correlation to diameter $d_1$[3] for workpieces with increased fatigue strength | Minimum dimension $a$ for countersink on the opposing piece[4] Undercut $r \times t_1$ | Form E | Form F | Form G | Form H |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| E and F | – | R0.2 | 0.1 | 0.1 | 1 | (0.9) | > Ø 1.6–Ø 3 | – | 0.2 x 0.1 | 0.2 | 0 | – | – |
| | R0.4 | – | 0.2 | 0.1 | 2 | (1.1) | > Ø 3–Ø 18 | – | 0.4 x 0.2 | 0.3 | 0 | – | – |
| | – | R0.6 | 0.2 | 0.1 | 2 | (1.4) | > Ø 10–Ø 18 | – | 0.6 x 0.2 | 0.5 | 0.15 | – | – |
| | – | R0.6 | 0.3 | 0.2 | 2.5 | (2.1) | > Ø 18–Ø 80 | – | 0.6 x 0.3 | 0.4 | 0 | – | – |
| | R0.8 | – | 0.3 | 0.2 | 2.5 | (2.3) | > Ø 18–Ø 80 | – | 0.8 x 0.3 | 0.6 | 0.05 | – | – |
| | – | R1 | 0.2 | 0.1 | 2.5 | (1.8) | – | > Ø 18–Ø 50 | 1.0 x 0.2 | 0.9 | 0.45 | – | – |
| | – | R1 | 0.4 | 0.3 | 4 | (3.2) | > Ø 80 | – | 1.0 x 0.4 | 0.7 | 0 | – | – |
| | R1.2 | – | 0.2 | 0.1 | 2.5 | (2) | – | > Ø 18–Ø 50 | 1.2 x 0.2 | 1.1 | 0.6 | – | – |
| | R1.2 | – | 0.4 | 0.3 | 4 | (3.4) | > Ø 80 | – | 1.2 x 0.4 | 0.9 | 0.1 | – | – |
| | R1.6 | – | 0.3 | 0.2 | 4 | (3.1) | – | > Ø 50–Ø 80 | 1.6 x 0.3 | 1.4 | 0.6 | – | – |
| | R2.5 | – | 0.4 | 0.3 | 5 | (4.8) | – | > Ø 80–Ø 125 | 2.5 x 0.4 | 2.2 | 1.0 | – | – |
| | R4 | – | 0.5 | 0.3 | 7 | (6.4) | – | > Ø 125 | 4.0 x 0.5 | 3.6 | 2.1 | – | – |
| G | R0.4 | – | 0.2 | 0.2 | (0.9) | (1.1) | > Ø 3–Ø 18 | – | 0.4 x 0.2 | – | – | 0 | – |
| H | R0.8 | – | 0.3 | 0.05 | (2.0) | (1.1) | > Ø 18–Ø 80 | – | 0.8 x 0.3 | – | – | – | 0.35 |
| | R1.2 | – | 0.3 | 0.05 | (2.4) | (1.5) | – | > Ø 18–Ø 50 | 1.2 x 0.3 | – | – | – | 0.65 |

[1] All forms of undercut apply to both shafts and holes.

[2] Undercuts with Series 1 radii are preferred.

[3] The correlation to the diameter area does not apply with curved shoulders and thin walled parts. For workpieces with differing diameters it may be advisable to design all undercuts for all diameters in the same form and size.

[4] Countersink dimension $a$ on opposing piece

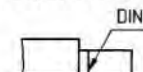



### Drawing entry for undercuts

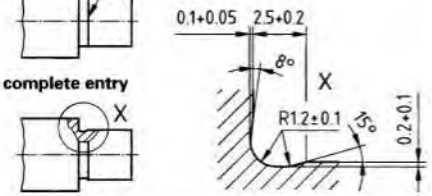
Normally undercuts are represented in drawings as a simplified entry with the designator. However they can also be completely drawn and dimensioned.

**Example:** Shaft with undercut DIN 509 – F1.2 x 0.2

**simplified entry**

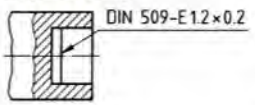



**complete entry**

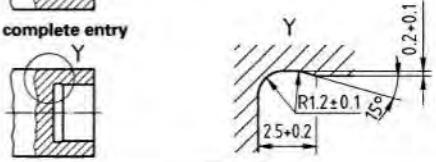



**Example:** Hole with undercut- DIN 509 – E1.2 x 0.2

**simplified entry**




**complete entry**

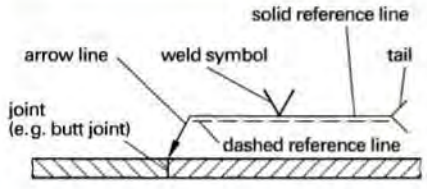


# Symbols for Welding and Soldering

## Positioning of symbols for welding and soldering in drawings

cf. DIN EN 22553 (1997-03)

### Basic terms




**Reference line.** This consists of the solid reference line and the dashed reference line. The dashed reference line runs parallel to the solid reference line and above or below it. The dashed reference line is omitted for symmetrical welds.

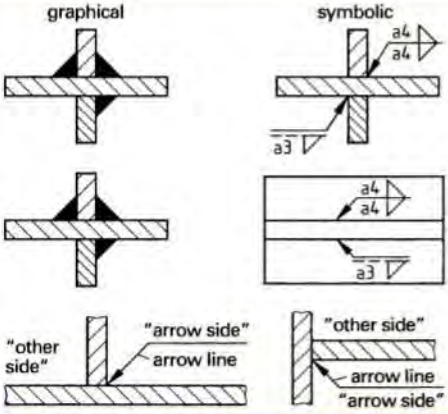
**Arrow line.** It connects the solid reference line with the joint.

**Tail.** Additional entries can be given here as needed for:

- method, process
- working position
- evaluation group
- additional material

**Joint.** Orientation of the parts to be joined to each other.

### Weld information




**Symbol.** The symbol identifies the form of the weld. It is preferably placed normal to the solid reference line, or if necessary on the dashed reference line.

| Arrangement of the weld symbol | |
|---|---|
| position of the weld symbol | position of the weld (weld surface) |
| solid reference line | "arrow side" |
| dashed reference line | "other side" |

For welds represented in section or view, the position of the symbol must agree with the weld cross section.

**Arrow side.** The arrow side is that side of the joint to which the arrow line refers.

**Other side.** The other side of the joint that is opposite the arrow side.

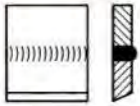
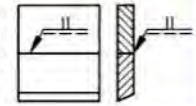
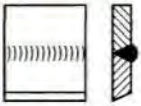
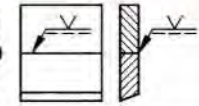
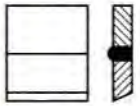
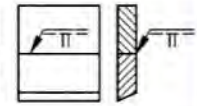
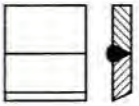
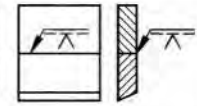
## Supplemental and auxiliary symbols

cf. DIN EN 22553 (1997-03)

| | | | |
|---|---|---|---|
|  | Weld all around |  | Weld surface hollow (concave) |
|  | Field weld (weld is made on the construction site) |  | Weld surface flat (planar) |
|  | Entry of the welding process in the tail |  | Weld surface curved (convex) |
| | |  | Weld surface notch free |

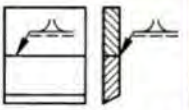
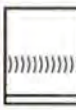
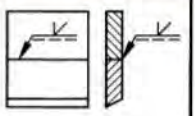
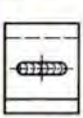
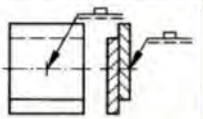
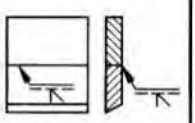
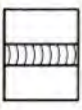
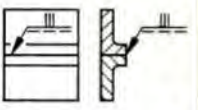
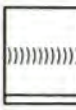
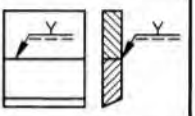
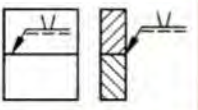
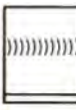
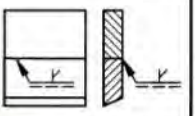
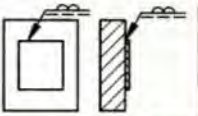
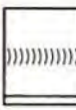
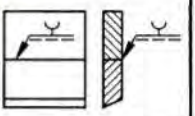
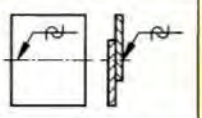
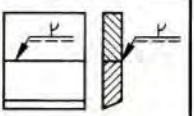
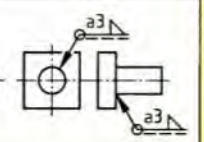
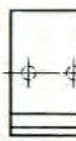
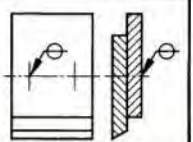
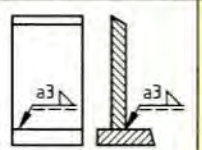
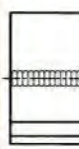
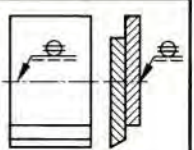
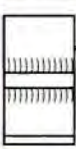
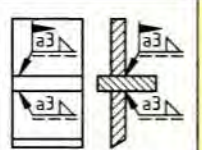
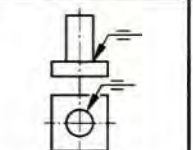
## Representation in drawings (basic symbols)

cf. DIN EN 22553 (1997-03)

| Weld type/ symbol | Representation graphical | Representation symbolic | Weld type/ symbol | Representation graphical | Representation symbolic |
|---|---|---|---|---|---|
| Butt weld ‖ |  |  | V groove weld V |  |  |
| |  |  | |  |  |

# Symbols for Welding and Soldering

**Representation in drawings (basic symbols)** cf. DIN EN 22553 (1997-03)

| Weld type/ symbol | Representation graphical | Representation symbolic | Weld type/ symbol | Representation graphical | Representation symbolic |
|---|---|---|---|---|---|
| Flare-V groove weld |  |  | Bevel groove weld |  |  |
| Plug welding |  |  | |  |  |
| Frontal flush weld |  |  | Y-butt weld |  |  |
| Steep-flanked weld |  |  | HY-weld |  |  |
| Build-up weld |  |  | U-groove weld |  |  |
| Fold weld |  |  | J-groove weld |  |  |
| Weld all around |  |  | Spot weld |  |  |
| Fillet weld |  |  | Line weld |  |  |
| Field weld with 3 mm seam thickness |  |  | Surface weld |  |  |

# Symbols for Welding and Soldering

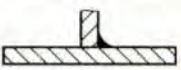
## Composite symbols for symmetrical welds[1] (examples)

cf. DIN EN 22553 (1997-03)

| Weld type | Symbol | Representation | Weld type | Symbol | Representation |
|---|---|---|---|---|---|
| D(ouble)-V-weld (X-weld) |  |  | D(ouble)-HY-weld |  |  |
| D(ouble)-bevel weld |  |  | D(ouble)-U-weld |  |  |
| D(ouble)-Y-weld |  |  | [1] The symbols are located symmetrical to the reference line. Example: | graphical  | symbolic  |

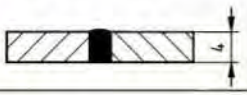
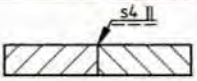
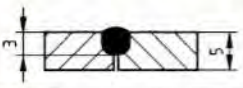
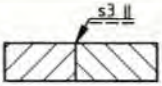
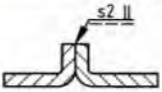
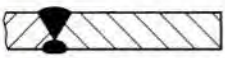
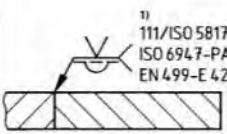
## Application examples for auxiliary symbols

cf. DIN EN 22553 (1997-03)

| Weld type | Symbol | Representation | Weld type | Symbol | Representation |
|---|---|---|---|---|---|
| Flat V-weld |  |  | Flat reworked V-weld |  |  |
| Convex double V-weld |  |  | Flat V-weld with flat backing run |  |  |
| Y-weld with backing run |  |  | Hollow fillet weld, weld transfer unnotched |  |  |

## Dimensioning examples

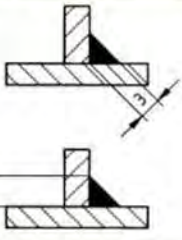
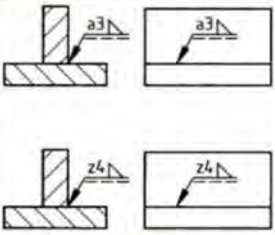
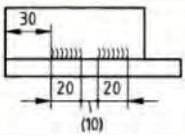
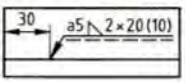
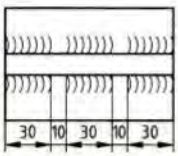
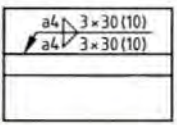
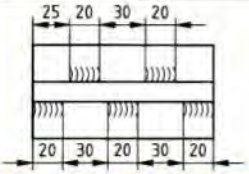
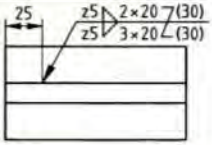
cf. DIN EN 22553 (1997-03)

| Weld type | Representation and dimensioning graphical | Representation and dimensioning symbolic | Meaning of the symbolic dimension entry |
|---|---|---|---|
| I-weld (penetrating) |   |   | Butt weld, penetrating, weld seam thickness $s$ = 4 mm |
| I-weld (non-penetrating) |   |   | Butt weld, non-penetrating, weld seam thickness $s$ = 3 mm, running over the entire workpiece |
| Flare-V groove weld |   |   | Flare-V groove weld, not completely melted down, weld seam thickness $s$ = 2 mm |
| V-weld (penetrating weld) with backing run |  |   | V-weld (penetrating weld) with backing run, fabricated by manual arc welding (code 111 accord. to DIN EN ISO 4063), required evaluation group C accord. to ISO 5817; flat welding position PA accord. to ISO 6947; electrode E 42 0 RR 12 accord. to DIN EN 499 |

[1] Supplementary requirements can be entered in a tail at the end of a reference line.

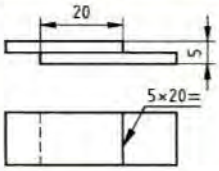
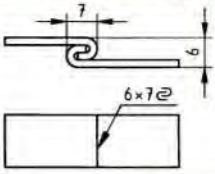
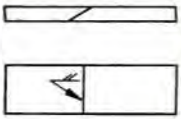
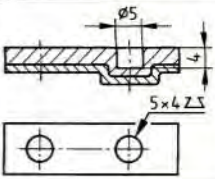
# Symbols for Welding and Soldering, Representation of adhesive, folded and pressed joints

## Dimensioning examples (continued)

| Weld type | Representation and dimensioning graphical | Representation and dimensioning symbolic | Meaning of the symbolic dimension entry |
|---|---|---|---|
| Fillet weld (continuous) |   |   | Fillet weld, weld leg thickness $a = 3$ mm (height of the isosceles triangle)<br>Fillet weld, weld leg thickness $z = 4$ mm (side length of the isosceles triangle) |
| Fillet weld (interrupted) |   |   | Fillet weld (interrupted), weld leg thickness $a = 5$ mm; 2 single welds each with $l = 20$ mm length; weld spacing $e = 10$ mm, end distance $v = 30$ mm |
| Double fillet weld (interrupted) |   |   | Double fillet weld (interrupted, symmetrical), weld leg thickness $a = 4$ mm; single weld length $l = 30$ mm, weld spacing $e = 10$ mm, without end distance |
| Double fillet weld (interrupted, staggered) |   |   | Double fillet weld (interrupted, staggered), weld leg thickness $z = 5$ mm; single weld length $l = 20$ mm, weld spacing $e = 30$ mm, end distance $v = 25$ mm |

## Symbolic representation of adhesive, folded and pressed joints (examples)

cf. DIN EN ISO 15785 (2002-12)

| Type of joint | Weld type/ symbol | Meaning/ drawing entry | Type of joint | Weld type/ symbol | Meaning/ drawing entry |
|---|---|---|---|---|---|
| Adhesive bonded-seams | Surface seam[1] |   | Folded seam | Folded seam |   |
| | Slant seam[1] |  | Pressed seam | Pressed seam |   |

[1] The adhesive media is not shown for adhesive seams.

# Heat treated parts – Hardness specifications

## Presentation and indication of heat treated parts on drawings

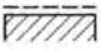
cf. DIN 6773 (2001-04)

### Heat treatment specifications

| Term(s) for material condition | Measurable parameters of the material condition | | | Possible additions |
|---|---|---|---|---|
| **Examples:**<br>quenched and tempered<br>hardened<br>hardened and tempered<br>annealed<br>nitrided | hardness value | HRC<br>HV<br>HB | rockwell hardness<br>vickers hardness<br>brinell hardness | **Measuring points.** Entering and dimensioning in the drawing with symbol (⏚).<br>**Heat treatment diagram.** Simplified, usually reduced scale representation of the part near the title block.<br>**Minimum tensile strength or microstructure.** If it is possible to test a part treated in the same batch. |
| | hardness indentation | Eht<br>Nht<br>Rht | case hardening thickness<br>nitriding depth<br>effective hardening depth | |
| | HTA<br>WL | | carburizing depth<br>nitride white layer thickness | |
| | All entries are made with plus tolerances. | | | |

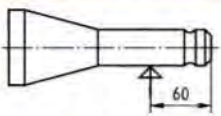
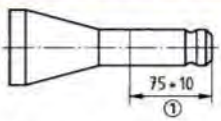
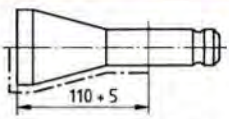
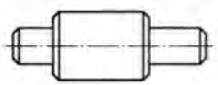
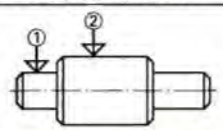
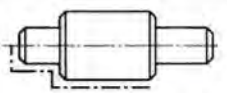
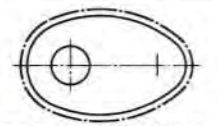
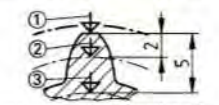
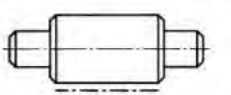
### Identifying areas of the surface to undergo localized heat treatment


Area must be heat treated.


Area may be heat treated.


Intermediate area may not be heat treated.

### Heat treatment specifications in drawings (examples)

| Method | Heat treatment of the entire part<br>same requirements | Heat treatment of the entire part<br>different requirements | Heat treatment localized |
|---|---|---|---|
| Quenching and tempering,<br>Hardening,<br>Hardening and tempering |  <br>quenched and tempered<br>350 + 50 HB 2.5/187.5 |  <br>hardened and tempered<br>58 + 4 HRC ① 40 + 5 HRC |  <br>—·— hardened and entire part tempered 60 + 3 HRC |
| Nitriding,<br>Case hardening |  <br>nitrided<br>≥ 900 HV 10<br>Nht = 0.3 + 0.1 |  <br>case-hardened and tempered<br>① 60 + 4 HRC Eht = 0.5 + 0.3<br>② ≤ 52 HRC |  <br>—·— case-hardened and tempered 700 + 100 HV 10<br>Eht = 1.2 + 0.5 |
| Surfaced hardening |  <br>—·— surface hardened<br>620 + 120 HV 50<br>Rht 500 = 0.8 + 0.8 |  <br>—·— surface hardened and entire part tempered<br>① 54 + 6 HRC ② ≤ 35 HRC<br>③ ≤ 30 HRC |  <br>—·— surface hardened and tempered<br>61 + 4 HRC Rht 600 = 0.8 + 0.8 |

### Hardening depths and tolerances in mm

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Case-hardening depth Eht | 0.05+0.03 | 0.1+0.1 | 0.3+0.2 | 0.5+0.3 | 0.8+0.4 | 1.2+0.5 | 1.6+0.6 |
| Nitriding depth Nht | 0.05+0.02 | 0.1+0.05 | 0.15+0.02 | 0.2+0.1 | 0.25+0.1 | 0.3+0.1 | 0.35+0.15 |
| Induction hardening depth Rht | 0.2+0.2 | 0.4+0.4 | 0.6+0.6 | 0.8+0.8 | 1.0+1.0 | 1.3+1.1 | 1.6+1.3 |
| Laser/electr. beam hardening depth Rht | 0.2+0.1 | 0.4+0.2 | 0.6+0.3 | 0.8+0.4 | 1.0+0.5 | 1.3+0.6 | 1.6+0.8 |

### Control limit hardnesses at the specified hardening depths

| | |
|---|---|
| Case-hardening depth Eht | 550 HV 1 |
| Nitriding depth Nht | core hardness + 50 HV 0.5 |
| Effective hardening depth Rht | 0.8 · minimum surface hardness, calculated in HV |

# Form deviations and roughness parameters

## Form deviations

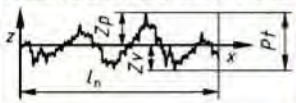
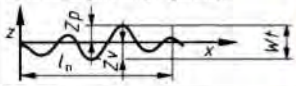
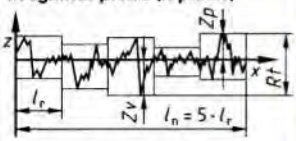
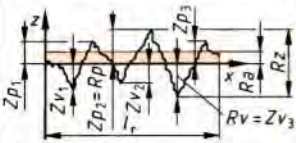
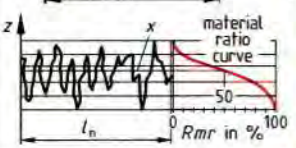
cf. DIN 4760 (1982-06)

Form deviations are deviations of the actual surface (surfaces ascertainable by measurement) from the geometrically ideal surface, whose standard shape is defined by the drawing.

| **Degrees of form deviation** (Profile section repres. with vertical exaggeration) | **Examples** | **Possible causes** |
|---|---|---|
| **1st degree: form deviation**  | deviation in straightness, roundness | Deflection of the workpiece or the machine during fabrication of the part, malfunction or wear in the guides of the machine tool. |
| **2nd degree: waviness**  | waves | Vibrations of the machine, runout or shape deviation of a milling machine during fabrication of the part. |
| **3rd degree: roughness**  | grooves | Geometry of the cutting tool, feed or depth of cut of the tool during fabrication of the part. |
| **4th degree: roughness**  | scoring, scales, bumps | Sequence of chip formation (e.g. tearing chip), surface deformation due to blasting during fabrication of the part. |
| **5th and 6th degree: roughness** Cannot be represented as a simple profile section | matrix structure, lattice structure | Crystallization cycles, matrix changes due to welding or hot working, changes due to chemical effects, e.g. corrosion, etching. |

## Surface texture profiles and parameters

cf. DIN EN ISO 4287 (1998-10) and DIN EN ISO 4288 (1998-04)

| **Surface profile** | **Parameters** | **Explanations** |
|---|---|---|
| **Primary profile (act. profile , P profile)**   | **Total height of the profile *Pt*** | The **primary profile** represents the foundation for calculating the parameters of the primary profile and forms the basis for the waviness and roughness profiles.<br>The **total height of the profile *Pt*** is the sum of the height of the highest profile peak *Zp* and the depth of the lowest profile trough *Zv* within the evaluation length $l_n$. |
| **Waviness profile (W-profile)**   | **Total height of the profile *Wt*** | The **waviness profile** is obtained by low-pass filtering, i.e. by suppressing the short wavelength components of the profile.<br>The **total height of the profile *Wt*** is the sum of the height of the highest profile peak *Zp* and the depth of the lowest profile trough *Zv* within the evaluation length $l_n$. |
| **Roughness profile (R-profile)**   | **Total height of the profile *Rt*** | The **roughness profile** is obtained by high-pass filtering, i.e. by suppressing the long wavelength components of the profile.<br>The **total height of the profile *Rt*** is the sum of the height of the highest profile peak *Zp* and the depth of the lowest profile trough *Zv* within the evaluation length $l_n$. |
| | ***Rp, Rv*** | **Height of the highest profile peak *Zp*, depth of the lowest profile trough *Zv*** within the single evaluation length $l_r$. |
|   | **Highest peak of the profile *Rz*[1)]** | The **highest peak of the profile *Rz*** is the sum of the height of the highest profile peak *Zp* and the depth of the lowest profile trough *Zv* within the single evaluation length $l_r$. |
| | **Arithmetic mean of the profile ordinates *Ra*[1)]** | The **arithmetic mean of the profile ordinates *Ra*** is the arithmetic mean of all ordinate values *Z(x)* within the single evaluation length $l_r$. |
|   | **Material ratio of the profile *Rmr*** | The **material ratio of the profile expressed as a percentage, *Rmr,*** is the ratio of the sum of the contributing material lengths at a specified section height to the total evaluation length $l_n$. |
| | **Center line (x-axis) *x*** | The **center line (x-axis) *x*** is the line corresponding to the long wavelength profile component which is suppressed by profile filtering. |

*Z(x)* height of the profile at any position x; ordinate value

$l_n$ evaluation length

$l_r$ single evaluation length

1) For parameters defined over a single evaluation length, the arithmetic mean of 5 single evaluation lengths to DIN EN ISO 4288 is used for determining the parameters.

# Surface testing, Surface indications

## Measuring sections for roughness

cf. DIN EN ISO 4288 (1998-04)

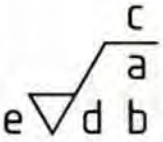
| Periodic profiles (e.g. turning profiles) | Non-periodic profiles (e.g. grinding and lapping profiles) | | Limit wave-length | Single / total evaluation length | Periodic profiles (e.g. turning profiles) | Non-periodic profiles (e.g. grinding and lapping profiles) | | Limit wave-length | Single / total evaluation length |
|---|---|---|---|---|---|---|---|---|---|
| Groove width *RSm* mm | *Rz* µm | *Ra* µm | µm | $l_r$, $l_n$ mm | groove width *RSm* mm | *Rz* µm | *Ra* µm | µm | $l_r$, $l_n$ mm |
| > 0.01–0.04 | up to 0.1 | up to 0.02 | 0.08 | 0.08/0.4 | > 0.13–0.4 | > 0.5–10 | > 0.1–2 | 0.8 | 0.8/4 |
| > 0.04–0.13 | > 0.1–0.5 | > 0.02–0.1 | 0.25 | 0.25/1.25 | > 0.4–1.3 | > 10–50 | > 2–10 | 2.5 | 2.5/12.5 |

## Indication of surface finish

cf. DIN EN ISO 1302 (2002-06)

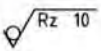
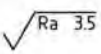
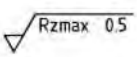
| Symbol | Meaning |
|---|---|
|  | All manufacturing processes are allowed. |
|  | Material removal specified, e.g. turning, milling. |
|  | Material removal not allowed or the surface remains in delivered condition. |
|  | All surfaces around the contour must have the same surface-finish. |

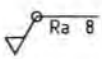
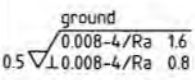
**Additional marks**




a surface parameter[1] with numerical value in µm, transfer characteristic[2]/individual evaluation length in mm
b secondary surface finish requirement (as described for a)
c manufacturing process
d symbol for the required groove direction (table page 100)
e machining deviation in mm

### Examples

| Symbol | Meaning |
|---|---|
|   | • material removing machining not allowed<br>• *Rz* = 10 µm (upper limit)<br>• standard transfer characteristic[3]<br>• standard evaluation length[4]<br>• "16% rule"[5] |
|   | • Machining can be done as desired<br>• standard transfer characteristic[3]<br>• *Ra* = 3.5 µm (upper limit)<br>• standard evaluation length[4]<br>• "16% rule"[5] |
|   | • material removal machining<br>• *Rz* = 0.5 µm (upper limit)<br>• standard transfer characteristic[3]<br>• standard evaluation length[4]<br>• "max. rule"[6] |

| Symbol | Meaning |
|---|---|
|   | • material removal machining<br>• *Ra* = 8 µm (upper limit)<br>• standard transfer characteristic[3]<br>• standard evaluation length[4]<br>• "16% rule"[5]<br>• applies all around the contour |
|   | • material removal machining<br>• manufacturing process grinding<br>• *Ra* = 1.6 µm (upper limit)<br>• *Ra* = 0.8 µm (lower limit)<br>• for both *Ra* values: „16% rule"[5]<br>• transfer characteristic each 0.008 to 4 mm<br>• standard evaluation length[4]<br>• machining deviation 0.5 mm<br>• surface grooves vertical |

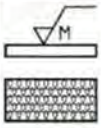
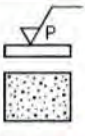
[1] **surface parameter,** e.g. *Rz*, consists of the profile (here the roughness profile *R*) and the parameters (here: *z*).
[2] **transfer characteristic:** wavelength range between the short wavelength filter $\lambda_s$ and the long wavelength filter $\lambda_c$. The wavelength of the long wavelength filter corresponds to the single evaluation length $l_r$. If no transfer characteristic is entered, then the standard transfer characteristic applies[3].
[3] **standard transfer characteristic:** the limit wavelength for measurement of the roughness parameters is dependent upon the roughness profile and is taken from tables.
[4] **standard evaluation length** $l_n = 5 \times$ single evaluation length $l_r$.
[5] **"16% rule":** only 16% of all measured values may exceed the chosen parameter.
[6] **"max. rule"** ("highest value rule"): no measured value may exceed the specified highest value.

# Surface finish symbols

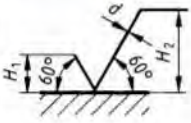
## Indication of surface finish

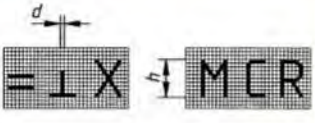
cf. DIN EN ISO 1302 (2002-06)

### Symbols for groove direction

| Representation of groove direction |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|
| Symbol | = | ⊥ | X | M | C | R | P |
| Groove direction | parallel to the projection plane | perpendicular to the projection plane | crossed in two angular directions | multi-directional | approximately concentric to the center | approximately radial to the center | non-grooved surface, non-directional or troughs |

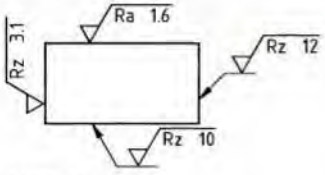
### Sizes of the symbols



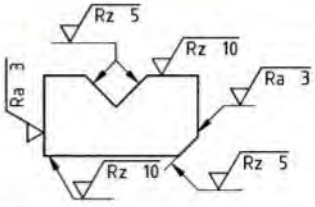




| | Letter height $h$ in mm | | | | | | |
|---|---|---|---|---|---|---|---|
| | 2.5 | 3.5 | 5 | 7 | 10 | 14 | 20 |
| $d$ | 0.25 | 0.35 | 0.5 | 0.7 | 1.0 | 1.4 | 2.0 |
| $H_1$ | 3.5 | 5 | 7 | 10 | 14 | 20 | 28 |
| $H_2$ | 8 | 11 | 15 | 21 | 30 | 42 | 60 |

### Layout of symbols in drawings

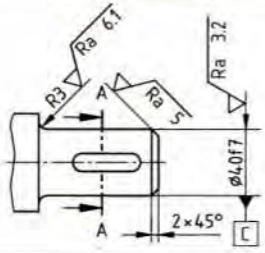


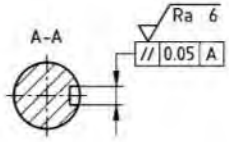

**Legibility**
from below or from the right

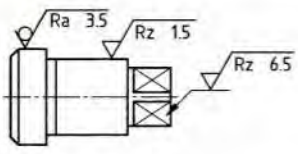


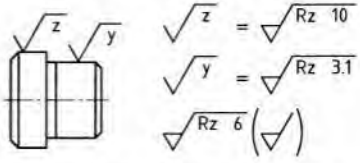

**Layout**
directly on the surface or with reference and leader lines

### Examples of drawing entries



# Roughness of surfaces

## Recommended assignment of roughness values to ISO tolerance specifications[1)]

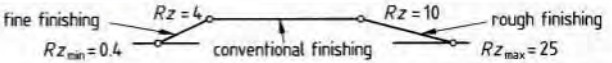
| Nominal size range from–to mm | Recommended values of *Rz* and *Ra* µm | ISO tolerance grade 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|
| 1–6 | *Rz* | 2.5 | 4 | 6.3 | 6.3 | 10 | 16 | 25 |
| | *Ra* | 0.4 | 0.8 | 0.8 | 1.6 | 1.6 | 3.2 | 6.3 |
| 6–10 | *Rz* | 2.5 | 4 | 6.3 | 10 | 16 | 25 | 40 |
| | *Ra* | 0.4 | 0.8 | 0.8 | 1.6 | 3.2 | 6.3 | 12.5 |
| 10–18 | *Rz* | 4 | 4 | 6.3 | 10 | 16 | 25 | 40 |
| | *Ra* | 0.8 | 0.8 | 0.8 | 1.6 | 3.2 | 6.3 | 12.5 |
| 18–80 | *Rz* | 4 | 6.3 | 10 | 16 | 16 | 40 | 63 |
| | *Ra* | 0.8 | 0.8 | 1.6 | 3.2 | 3.2 | 6.3 | 12.5 |
| 80–250 | *Rz* | 6.3 | 10 | 16 | 25 | 25 | 40 | 63 |
| | *Ra* | 0.8 | 1.6 | 1.6 | 3.2 | 3.2 | 6.3 | 12.5 |
| 250–500 | *Rz* | 6.3 | 10 | 16 | 25 | 40 | 63 | 100 |
| | *Ra* | 0.8 | 1.6 | 1.6 | 3.2 | 6.3 | 12.5 | 25 |

## Achievable roughness of surfaces[1)]

| | Manufacturing process | | *Rz* in µm for type of manufacturing: fine min. | normal from–to | rough max. | *Ra* in µm for type of manufacturing: fine min. | normal from–to | rough max. |
|---|---|---|---|---|---|---|---|---|
| Primary forming | Casting: | Die casting | 4 | 10–100 | 160 | – | 0.8–30 | – |
| | | Permanent mold casting | 10 | 25–160 | 250 | – | 3.2–50 | – |
| | | Sand casting | 25 | 63–250 | 1000 | – | 12.5–50 | – |
| | Sintering: | Sinter smooth | – | 2.5–10 | – | – | 0.4–1.6 | – |
| | | Calibrated smooth | – | 1.6–7 | – | – | 0.3–0.8 | – |
| Forming | Extrusion | | 4 | 25–100 | 400 | 0.8 | 3.2–12.5 | 25 |
| | Closed-die forming | | 10 | 63–400 | 1000 | 0.8 | 2.5–12.5 | 25 |
| | Rod extrusion | | 4 | 25–100 | 400 | 0.8 | 3.2–12.5 | 25 |
| | Deep drawing sheet metal | | 0.4 | 4–10 | 16 | 0.2 | 1–3.2 | 6.3 |
| | Rolling: | Burnishing | 0.1 | 0.5–6.3 | 10 | 0.025 | 0.06–1.6 | 2 |
| Cutting operations | Material removal: | Wire EDM | 0.8 | 2.8–10 | 16 | 0.1 | 0.4–1 | 3.2 |
| | | Diesinking | 1.5 | 5–10 | 31 | 0.2 | 0.45 | 6.3 |
| | Cutting operations: | Oxyacetylene cutting | 16 | 40–100 | 1000 | 3.2 | 8–16 | 50 |
| | | Laser cutting | – | 10–100 | – | – | 1–10 | – |
| | | Plasma cutting | – | 6–280 | – | – | 1–10 | – |
| | | Shearing | – | 10–63 | – | – | 1.6–12.5 | – |
| | | Water jet cutting | 4 | 16–100 | 400 | 1.6 | 6.3–25 | 50 |
| | Machining operations: | Drilling: Drilling in solid | 16 | 40–160 | 250 | 1.6 | 6.3–12.5 | 25 |
| | | Boring | 0.1 | 2.5–25 | 40 | 0.05 | 0.4–3.2 | 12.5 |
| | | Countersinking | 6.3 | 10–25 | 40 | 0.8 | 1.6–6.3 | 12.5 |
| | | Routing | 0.4 | 4–10 | 25 | 0.2 | 0.8–2 | 6.3 |
| | | Turning: Longitudinal turning | 1 | 4–63 | 250 | 0.2 | 0.8–12.5 | 50 |
| | | Facing | 2.5 | 10–63 | 250 | 0.4 | 1.6–12.5 | 50 |
| | | Milling: Peripheral, face milling | 1.6 | 10–63 | 160 | 0.4 | 1.6–12.5 | 25 |
| | | Honing: Super finishing | 0.04 | 0.1–1 | 2.5 | 0.006 | 0.02–0.17 | 0.34 |
| | | Long-stroke honing | 0.04 | 1–11 | 15 | 0.006 | 0.13–0.65 | 1.6 |
| | | Lapping | 0.04 | 0.25–1.6 | 10 | 0.006 | 0.025–0.2 | 0.21 |
| | | Polishing | – | 0.04–0.25 | 0.4 | – | 0.005–0.035 | 0.05 |
| | | Grinding | 0.1 | 1.6–4 | 25 | 0.012 | 0.2–0.8 | 6.3 |

[1)] Roughness values, as long as they are not contained in DIN 4766-1 (cancelled) are according to specifications of the industry.

Read-out example:
reaming (for surface characteristic *Rz*)



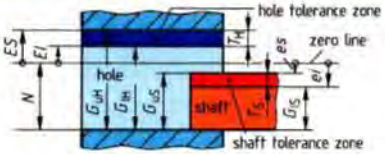
# ISO system of limits and fits

## Terms

cf. DIN ISO 286-1 (1990-11)

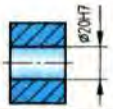
**Hole**

| | |
|---|---|
| $N$ | nominal size |
| $G_{uH}$ | hole max. dimension |
| $G_{lH}$ | hole min. dimension |
| $ES$ | hole upper deviation |
| $EI$ | hole lower deviation |
| $T_H$ | hole tolerance |

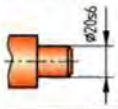



**shaft**

| | |
|---|---|
| $N$ | nominal dimension |
| $G_{uS}$ | shaft max. dimension |
| $G_{lS}$ | shaft min. dimension |
| $es$ | shaft upper deviation |
| $ei$ | shaft lower deviation |
| $T_S$ | shaft tolerance |




ø20H7
- nominal dimension
- tolerance class
- tolerance grade
- fundamental deviation



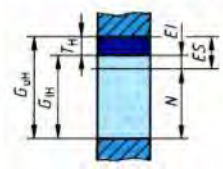

ø20s6
- nominal dimension
- tolerance class
- tolerance grade
- fundamental deviation

| Designation | Explanation | Designation | Explanation |
|---|---|---|---|
| **Zero line** | It represents the nominal dimension that is referenced by the deviations and tolerances. | **Fundament. tolerance grade** | A group of tolerances assigned to same level of precision, e.g IT7. |
| **Fundamental deviation** | The fund. deviation determin. the position of the tolerance zone with resp. to the zero line. | **Tolerance grade** | Number of the fundamental tol. grade, e.g. 7 for the fundamental tolerance grade IT7. |
| **Tolerance** | Difference between the max. and the min. dimension or between the upper and lower deviation. | **Tolerance class** | Name for a combination of a fundamental deviation and a tolerance grade, e.g. H7. |
| **Fundamental tolerance** | A tolerance assigned to a fundamental tolerance grade, e.g. IT7 and a nominal dimension range, e.g. 30 to 50 mm. | **Fit** | Planned joining condition between hole and shaft. |

## Limits, deviations and tolerances

cf. DIN ISO 286-1 (1990-11)

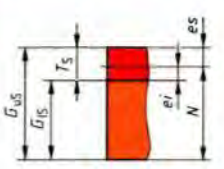
**Hole**




$$G_{uH} = N + ES$$
$$G_{lH} = N + EI$$
$$T_H = ES - EI$$
$$T_H = G_{uH} - G_{lH}$$

**Example:** Hole ∅50 + 0.3/+ 0.1; $G_{uH}$ = ?; $T_H$ = ?
$G_{uH} = N + ES = 50\ mm + 0.3\ mm = 50.30\ mm$
$T_H = ES - EI = 0.3\ mm - 0.1\ mm = 0.2\ mm$

**Shaft**



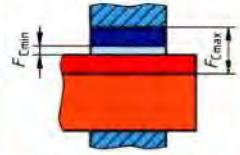

$$G_{uS} = N + es$$
$$G_{lS} = N + ei$$
$$T_S = es - ei$$
$$T_S = G_{uS} - G_{lS}$$

**Example:** Shaft ∅20e8; $G_{lS}$ = ?; $T_S$ = ?
For values for *ei* and *es* see page 107.
$ei = -73\ \mu m = -0.073\ mm$; $es = -40\ \mu m = -0.040\ mm$
$G_{lS} = N + ei = 20\ mm + (-0.073\ mm) = 19.927\ mm$
$T_S = es - ei = -40\ \mu m - (-73\ \mu m) = 33\ \mu m$

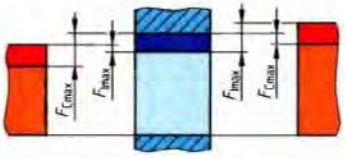
## Fits

cf. DIN ISO 286-1 (1990-11)

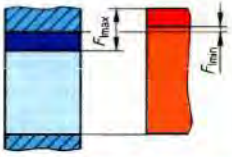
**Clearance fit**
$F_{Cmax}$ max. clearance
$F_{Cmin}$ min. clearance




**Transition fit**
$F_{Cmax}$ max. clearance
$F_{Imax}$ max. interference




**Interference fit**
$F_{Imax}$ max. interference
$F_{Imin}$ min. interference




$$F_{Cmin} = G_{lH} - G_{uS}$$
$$F_{Cmax} = G_{uH} - G_{lS}$$
$$F_{Imax} = G_{lH} - G_{uS}$$
$$F_{Imin} = G_{uH} - G_{lS}$$

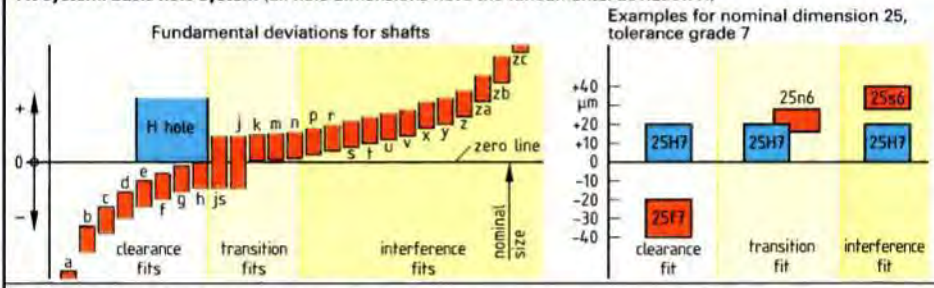
**Example:** Fit ∅30 H8/f7; $F_{Cmax}$ = ?; $F_{Cmin}$ = ?
For values for *ES, EI, es, ei* see page 107.
$G_{uH} = N + ES = 30\ mm + 0.033\ mm = 30.033\ mm$
$G_{lH} = N + EI = 30\ mm + 0\ mm = 30.000\ mm$
$G_{uH} = N + ES = 30\ mm + (-0.020\ mm) = 29.980\ mm$
$G_{lH} = N + ES = 30\ mm + (-0.041\ mm) = 29.959\ mm$
$F_{Cmax} = G_{uH} - G_{lS} = 30.033\ mm - 29.959\ mm = 0.074\ mm$
$F_{Cmin} = G_{lH} - G_{uS} = 30.000\ mm - 29.980\ mm = 0.02\ mm$

# ISO system of limits and fits

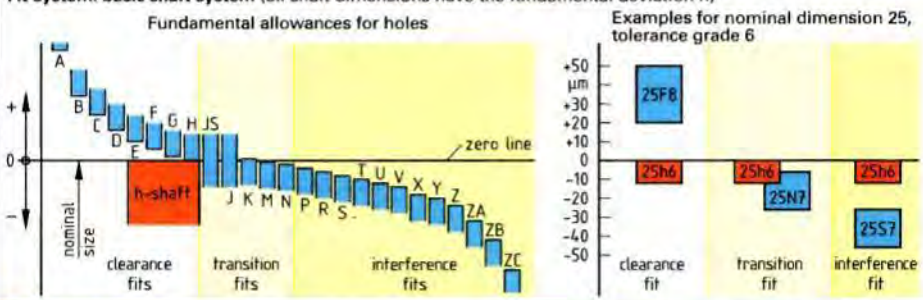
## Fit systems

cf. DIN ISO 286-1 (1990-11)

**Fit system: basic hole system** (all hole dimensions have the fundamental deviation H)




**Fit system: basic shaft system** (all shaft dimensions have the fundamental deviation h)




## Fundamental tolerances

cf. DIN ISO 286-1 (1990-11)

| Nominal dimension range over–to mm | Fundamental tolerance grade | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | IT1 | IT2 | IT3 | IT4 | IT5 | IT6 | IT7 | IT8 | IT9 | IT10 | IT11 | IT12 | IT13 | IT14 | IT15 | IT16 | IT17 | IT18 |
| | Fundamental tolerances | | | | | | | | | | | | | | | | | |
| | µm | | | | | | | | | | | mm | | | | | | |
| up to 3 | 0.8 | 1.2 | 2 | 3 | 4 | 6 | 10 | 14 | 25 | 40 | 60 | 0.1 | 0.14 | 0.25 | 0.4 | 0.6 | 1 | 1.4 |
| 3–6 | 1 | 1.5 | 2.5 | 4 | 5 | 8 | 12 | 18 | 30 | 48 | 75 | 0.12 | 0.18 | 0.3 | 0.48 | 0.75 | 1.2 | 1.8 |
| 6–10 | 1 | 1.5 | 2.5 | 4 | 6 | 9 | 15 | 22 | 36 | 58 | 90 | 0.15 | 0.22 | 0.36 | 0.58 | 0.9 | 1.5 | 2.2 |
| 10–18 | 1.2 | 2 | 3 | 5 | 8 | 11 | 18 | 27 | 43 | 70 | 110 | 0.18 | 0.27 | 0.43 | 0.7 | 1.1 | 1.8 | 2.7 |
| 18–30 | 1.5 | 2.5 | 4 | 6 | 9 | 13 | 21 | 33 | 52 | 84 | 130 | 0.21 | 0.33 | 0.52 | 0.84 | 1.3 | 2.1 | 3.3 |
| 30–50 | 1.5 | 2.5 | 4 | 7 | 11 | 16 | 25 | 39 | 62 | 100 | 160 | 0.25 | 0.39 | 0.62 | 1 | 1.6 | 2.5 | 3.9 |
| 50–80 | 2 | 3 | 5 | 8 | 13 | 19 | 30 | 46 | 74 | 120 | 190 | 0.3 | 0.46 | 0.74 | 1.2 | 1.9 | 3 | 4.6 |
| 80–120 | 2.5 | 4 | 6 | 10 | 15 | 22 | 35 | 54 | 87 | 140 | 220 | 0.35 | 0.54 | 0.87 | 1.4 | 2.2 | 3.5 | 5.4 |
| 120–180 | 3.5 | 5 | 8 | 12 | 18 | 25 | 40 | 63 | 100 | 160 | 250 | 0.4 | 0.63 | 1 | 1.6 | 2.5 | 4 | 6.3 |
| 180–250 | 4.5 | 7 | 10 | 14 | 20 | 29 | 46 | 72 | 115 | 185 | 290 | 0.46 | 0.72 | 1.15 | 1.85 | 2.9 | 4.6 | 7.2 |
| 250–315 | 6 | 8 | 12 | 16 | 23 | 32 | 52 | 81 | 130 | 210 | 320 | 0.52 | 0.81 | 1.3 | 2.1 | 3.2 | 5.2 | 8.1 |
| 315–400 | 7 | 9 | 13 | 18 | 25 | 36 | 57 | 89 | 140 | 230 | 360 | 0.57 | 0.89 | 1.4 | 2.3 | 3.6 | 5.7 | 8.9 |
| 400–500 | 8 | 10 | 15 | 20 | 27 | 40 | 63 | 97 | 155 | 250 | 400 | 0.63 | 0.97 | 1.55 | 2.5 | 4 | 6.3 | 9.7 |
| 500–630 | 9 | 11 | 16 | 22 | 32 | 44 | 70 | 110 | 175 | 280 | 440 | 0.7 | 1.1 | 1.75 | 2.8 | 4.4 | 7 | 11 |
| 630–800 | 10 | 13 | 18 | 25 | 36 | 50 | 80 | 125 | 200 | 320 | 500 | 0.8 | 1.25 | 2 | 3.2 | 5 | 8 | 12.5 |
| 800–1000 | 11 | 15 | 21 | 28 | 40 | 56 | 90 | 140 | 230 | 360 | 560 | 0.9 | 1.4 | 2.3 | 3.6 | 5.6 | 9 | 14 |
| 1000–1250 | 13 | 18 | 24 | 33 | 47 | 66 | 105 | 165 | 260 | 420 | 660 | 1.05 | 1.65 | 2.6 | 4.2 | 6.6 | 10.5 | 16.5 |
| 1250–1600 | 15 | 21 | 29 | 39 | 55 | 78 | 125 | 195 | 310 | 500 | 780 | 1.25 | 1.95 | 3.1 | 5 | 7.8 | 12.5 | 19.5 |
| 1600–2000 | 18 | 25 | 35 | 46 | 65 | 92 | 150 | 230 | 370 | 600 | 920 | 1.5 | 2.3 | 3.7 | 6 | 9.2 | 15 | 23 |
| 2000–2500 | 22 | 30 | 41 | 55 | 78 | 110 | 175 | 280 | 440 | 700 | 1100 | 1.75 | 2.8 | 4.4 | 7 | 11 | 17.5 | 28 |
| 2500–3150 | 26 | 36 | 50 | 68 | 96 | 135 | 210 | 330 | 540 | 860 | 1350 | 2.1 | 3.3 | 5.4 | 8.6 | 13.5 | 21 | 33 |

The limit deviations of the tolerance grade for the fundamental deviations h, js, H and JS can be derived from the fundamental tolerances: **h**: $es = 0$; $ei = -IT$ **js**: $es = +IT/2$; $ei = -IT/2$ **H**: $ES = +IT$; $EI = 0$ **JS**: $ES = +IT/2$; $EI = -IT/2$

# ISO fits

## Fundamental deviations for shafts (selection)

cf. DIN ISO 286-1 (1990-11)

| Fundamental deviations | a | c | d | e | f | g | h | j | k | | m | n | p | r | s |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fundamental tolerance grade | IT9 to IT13 | IT8 to IT12 | IT5 to IT13 | IT5 to IT10 | IT3 to IT10 | IT3 to IT10 | IT1 to IT18 | IT5 to IT8 | IT3 to IT13 | | IT3 to IT9 | IT3 to IT9 | IT3 to IT10 | | |
| Table applies to | all fundamental tolerance grades | | | | | | | IT7 | IT4 to IT7 | over IT7 | all fundamental tolerance grades | | | | |
| Nominal dimension over–to mm | Upper deviation *es* in µm | | | | | | | Lower deviation *ei* in µm | | | | | | | |
| up to 3 | −270 | −60 | −20 | −14 | −6 | −2 | 0 | −4 | 0 | 0 | +2 | +4 | +6 | +10 | +14 |
| 3–6 | | −70 | −30 | −20 | −10 | −4 | 0 | −4 | +1 | 0 | +4 | +8 | +12 | +15 | +19 |
| 6–10 | −280 | −80 | −40 | −25 | −13 | −5 | 0 | −5 | +1 | 0 | +6 | +10 | +15 | +19 | +23 |
| 10–18 | −290 | −95 | −50 | −32 | −16 | −6 | 0 | −6 | +1 | 0 | +7 | +12 | +18 | +23 | +28 |
| 18–30 | −300 | −110 | −65 | −40 | −20 | −7 | 0 | −8 | +2 | 0 | +8 | +15 | +22 | +28 | +35 |
| 30–40 | −310 | −120 | −80 | −50 | −25 | −9 | 0 | −10 | +2 | 0 | +9 | +17 | +26 | +34 | +43 |
| 40–50 | −320 | −130 | | | | | | | | | | | | | |
| 50–65 | −340 | −140 | −100 | −60 | −30 | −10 | 0 | −12 | +2 | 0 | +11 | +20 | +32 | +41 | +53 |
| 65–80 | −360 | −150 | | | | | | | | | | | | +43 | +59 |
| 80–100 | −380 | −170 | −120 | −72 | −36 | −12 | 0 | −15 | +3 | 0 | +13 | +23 | +37 | +51 | +71 |
| 100–120 | −410 | −180 | | | | | | | | | | | | +54 | +79 |
| 120–140 | −460 | −200 | −145 | −85 | −43 | −14 | 0 | −18 | +3 | 0 | +15 | +27 | +43 | +63 | +92 |
| 140–160 | −520 | −210 | | | | | | | | | | | | +65 | +100 |
| 160–180 | −580 | −230 | | | | | | | | | | | | +68 | +108 |
| 180–200 | −660 | −240 | −170 | −100 | −50 | −15 | 0 | −21 | +4 | 0 | +17 | +31 | +50 | +77 | +122 |
| 200–225 | −740 | −260 | | | | | | | | | | | | +80 | +130 |
| 225–250 | −820 | −280 | | | | | | | | | | | | +84 | +140 |
| 250–280 | −920 | −300 | −190 | −110 | −56 | −17 | 0 | −26 | +4 | 0 | +20 | +34 | +56 | +94 | +158 |
| 280–315 | −1050 | −330 | | | | | | | | | | | | +98 | +170 |
| 315–355 | −1200 | −360 | −210 | −125 | −62 | −18 | 0 | −28 | +4 | 0 | +21 | +37 | +62 | +108 | +190 |
| 355–400 | −1350 | −400 | | | | | | | | | | | | +114 | +208 |
| 400–450 | −1500 | −440 | −230 | −135 | −68 | −20 | 0 | −32 | +5 | 0 | +23 | +40 | +68 | +126 | +232 |
| 450–500 | −1650 | −480 | | | | | | | | | | | | +132 | +252 |

### Calculation of limit deviations

Limit deviations for fundamental tolerance grades given in the table row "Table applies to" (above and page 105) can be calculated using tables on this page and page 105 and the formulas below. The values necessary for the fundamental tolerances IT are found in the table on page 103.

**Formulas**

- for shaft deviations

$ei = es - IT$

$es = ei + IT$

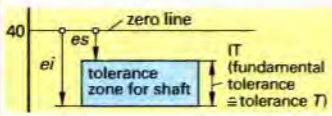
- for hole deviations

$EI = ES - IT$

$ES = EI + IT$

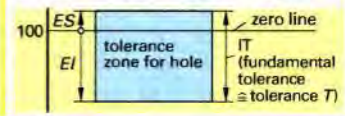
**Example 1:** Shaft (outside dimension)
∅ 40g5; *es* = ?; *ei* = ?

*es* (table above) = −9 µm
IT5 (table page 103) = 11 µm
*ei* = *es* − IT = −9 µm − 11 µm = −20 µm




**Example 2:** Hole (inside dimension)
∅ 100K6; *ES* = ?; *EI* = ?

*ES* (table page 105) = −3 µm + Δ
(Value Δ for fundamental tolerance grade IT6 acc. to table, bottom of page 105: 7 µm)
*ES* = −3 µm + 7 µm = 4 µm
IT6 (table page 103) = 22 µm
*EI* = *ES* − IT = 4 µm − 22 µm = −18 µm



# ISO fits

**Fundamental deviations for holes (selection)[1]** — cf. DIN ISO 286-1 (1990-11)

| Fundamental deviations | A | C | D | E | F | G | H | J | K | M | N | P, R, S | P | R | S |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fundamental tolerance grade | IT9 to IT13 | IT8 to IT13 | IT6 to IT13 | IT5 to IT10 | IT3 to IT10 | IT3 to IT10 | IT1 to IT18 | IT6 to IT8 | IT3 to IT10 | IT3 to IT10 | IT3 to IT11 | IT3 to IT10 | | | |
| Table applies to | all fundamental tolerance grades | | | | | | | IT8 | IT3 to IT8 | | | to IT7 | IT 8 to IT10 | | |
| Nominal dimension over–to; mm | Lower deviation *EI* in µm | | | | | | | Upper deviation *ES* in µm | | | | | | | |
| up to 3 | +270 | +60 | +20 | +14 | +6 | +2 | 0 | +6 | 0 | –2 | –4 | Values for the upper deviations *ES*: the same as fundamental tolerance grade IT8 to IT10, plus Δ | –6 | –10 | –14 |
| 3–6 | | +70 | +30 | +20 | +10 | +4 | 0 | +10 | –1 +Δ | –4 +Δ | –8 +Δ | | –12 | –15 | –19 |
| 6–10 | +280 | +80 | +40 | +25 | +13 | +5 | 0 | +12 | –1 +Δ | –6 +Δ | –10 +Δ | | –15 | –19 | –23 |
| 10–18 | +290 | +95 | +50 | +32 | +16 | +6 | 0 | +15 | –1 +Δ | –7 +Δ | –12 +Δ | | –18 | –23 | –28 |
| 18–30 | +300 | +110 | +65 | +40 | +20 | +7 | 0 | +20 | –2 +Δ | –8 +Δ | –15 +Δ | | –22 | –28 | –35 |
| 30–40 | +310 | +120 | +80 | +50 | +25 | +9 | 0 | +24 | –2 +Δ | –9 +Δ | –17 +Δ | | –26 | –34 | –43 |
| 40–50 | +320 | +130 | | | | | | | | | | | | | |
| 50–65 | +340 | +140 | +100 | +60 | +30 | +10 | 0 | +28 | –2 +Δ | –11 +Δ | –20 +Δ | | –32 | –41 | –53 |
| 65–80 | +360 | +150 | | | | | | | | | | | | –43 | –59 |
| 80–100 | +380 | +170 | +120 | +72 | +36 | +12 | 0 | +34 | –3 +Δ | –13 +Δ | –23 +Δ | | –37 | –51 | –71 |
| 100–120 | +410 | +180 | | | | | | | | | | | | –54 | –79 |
| 120–140 | +460 | +200 | +145 | +85 | +43 | +14 | 0 | +41 | –3 +Δ | –15 +Δ | –27 +Δ | | –43 | –63 | –92 |
| 140–160 | +520 | +210 | | | | | | | | | | | | –65 | –100 |
| 160–180 | +580 | +230 | | | | | | | | | | | | –68 | –108 |
| 180–200 | +660 | +240 | +170 | +100 | +50 | +15 | 0 | +47 | –4 +Δ | –17 +Δ | –31 +Δ | | –50 | –77 | –122 |
| 200–225 | +740 | +260 | | | | | | | | | | | | –80 | –130 |
| 225–250 | +820 | +280 | | | | | | | | | | | | –84 | –140 |
| 250–280 | +920 | +300 | +190 | +110 | +56 | +17 | 0 | +55 | –4 +Δ | –20 +Δ | –34 +Δ | | –56 | –94 | –158 |
| 280–315 | +1050 | +330 | | | | | | | | | | | | –98 | –170 |
| 315–355 | +1200 | +360 | +210 | +125 | +62 | +18 | 0 | +60 | –4 +Δ | –21 +Δ | –37 +Δ | | –62 | –108 | –190 |
| 355–400 | +1350 | +400 | | | | | | | | | | | | –114 | –208 |
| 400–450 | +1500 | +440 | +230 | +135 | +68 | +20 | 0 | +66 | –5 +Δ | –23 +Δ | –40 +Δ | | –68 | –126 | –232 |
| 450–500 | +1650 | +480 | | | | | | | | | | | | –132 | –252 |

**Values for Δ[1] in µm**

| Fundamental tolerance grade | Nominal dimension over–to in mm | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 3 to 6 | 6 to 10 | 10 to 18 | 18 to 30 | 30 to 50 | 50 to 80 | 80 to 120 | 120 to 180 | 180 to 250 | 250 to 315 | 315 to 400 | 400 to 500 |
| IT3 | 1 | 1 | 1 | 1.5 | 1.5 | 2 | 2 | 3 | 3 | 4 | 4 | 5 |
| IT4 | 1.5 | 1.5 | 2 | 2 | 3 | 3 | 4 | 4 | 4 | 4 | 5 | 5 |
| IT5 | 1 | 2 | 3 | 3 | 4 | 5 | 5 | 6 | 6 | 7 | 7 | 7 |
| IT6 | 3 | 3 | 3 | 4 | 5 | 6 | 7 | 7 | 9 | 9 | 11 | 13 |
| IT7 | 4 | 6 | 7 | 8 | 9 | 11 | 13 | 15 | 17 | 20 | 21 | 23 |
| IT8 | 6 | 7 | 9 | 12 | 14 | 16 | 19 | 23 | 26 | 29 | 32 | 34 |

[1] For examples of calculations see page 104.

# ISO fits

## Basic hole system

cf. DIN ISO 286-2 (1990-11)

Limit deviations in µm for tolerance classes[1)]

| Nominal dimension range over–to mm | for hole | for shafts Paired with an H6 hole results in a clearance, transition, interference fit | | | | | for hole | for shafts Paired with an H7 hole results in a | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | clearance fit | | | transition fit | | | | interference fit | |
| | H6 | h5 | j5 | k6 | n5 | r5 | H7 | f7 | g6 | h6 | j6 | k6 | m6 | n6 | r6 | s6 |
| up to 3 | +6 | 0 | ±2 | +6 | +8 | +14 | +10 | –6 | –2 | 0 | +4 | +6 | +8 | +10 | +16 | +20 |
| | 0 | –4 | | 0 | +4 | +10 | 0 | –16 | –8 | –6 | –2 | 0 | +2 | +4 | +10 | +14 |
| 3–6 | +8 | 0 | +3 | +9 | +13 | +20 | +12 | –10 | –4 | 0 | +6 | +9 | +12 | +16 | +23 | +27 |
| | 0 | –5 | –2 | +1 | +8 | +15 | 0 | –22 | –12 | –8 | –2 | +1 | +4 | + 8 | +15 | +19 |
| 6–10 | +9 | 0 | +4 | +10 | +16 | +25 | +15 | –13 | –5 | 0 | +7 | +10 | +15 | +19 | +28 | +32 |
| | 0 | –6 | –2 | +1 | +10 | +19 | 0 | –28 | –14 | –9 | –2 | +1 | +6 | +10 | +19 | +23 |
| 10–14 | +11 | 0 | +5 | +12 | +20 | +31 | +18 | –16 | –6 | 0 | +8 | +12 | +18 | +23 | +34 | +39 |
| 14–18 | 0 | –8 | –3 | +1 | +12 | +23 | 0 | –34 | –17 | –11 | –3 | +1 | +7 | +12 | +23 | +28 |
| 18–24 | +13 | 0 | +5 | +15 | +24 | +37 | +21 | –20 | –7 | 0 | +9 | +15 | +21 | +28 | +41 | +48 |
| 24–30 | 0 | –9 | –4 | +2 | +15 | +28 | 0 | –41 | –20 | –13 | –4 | +2 | +8 | +15 | +28 | +35 |
| 30–40 | +16 | 0 | +6 | +18 | +28 | +45 | +25 | –25 | –9 | 0 | +11 | +18 | +25 | +33 | +50 | +59 |
| 40–50 | 0 | –11 | –5 | +2 | +17 | +34 | 0 | –50 | –25 | –16 | –5 | +2 | +9 | +17 | +34 | +43 |
| 50–65 | | | | | | +54 | | | | | | | | | +60 | +72 |
| | +19 | 0 | +6 | +21 | +33 | +41 | +30 | –30 | –10 | 0 | +12 | +21 | +30 | +39 | +41 | +53 |
| 65–80 | 0 | –13 | –7 | +2 | +20 | +56 | 0 | –60 | –29 | –19 | –7 | +2 | +11 | +20 | +62 | +78 |
| | | | | | | +43 | | | | | | | | | +43 | +59 |
| 80–100 | | | | | | +66 | | | | | | | | | +73 | +93 |
| | +22 | 0 | +6 | +25 | +38 | +51 | +35 | –36 | –12 | 0 | +13 | +25 | +35 | +45 | +51 | +71 |
| 100–120 | 0 | –15 | –9 | +3 | +23 | +69 | 0 | –71 | –34 | –22 | –9 | +3 | +13 | +23 | +76 | +101 |
| | | | | | | +54 | | | | | | | | | +54 | +79 |
| 120–140 | | | | | | +81 | | | | | | | | | +88 | +117 |
| | | | | | | +63 | | | | | | | | | +63 | +92 |
| 140–160 | +25 | 0 | +7 | +28 | +45 | +83 | +40 | –43 | –14 | 0 | +14 | +28 | +40 | +52 | +90 | +125 |
| | 0 | –18 | –11 | +3 | +27 | +65 | 0 | –83 | –39 | –25 | –11 | +3 | +15 | +27 | +65 | +100 |
| 160–180 | | | | | | +86 | | | | | | | | | +93 | +133 |
| | | | | | | +68 | | | | | | | | | +68 | +108 |
| 180–200 | | | | | | +97 | | | | | | | | | +106 | +151 |
| | | | | | | +77 | | | | | | | | | +77 | +122 |
| 200–225 | +29 | 0 | + 7 | +33 | +51 | +100 | +46 | –50 | –15 | 0 | +16 | +33 | +46 | +60 | +109 | +159 |
| | 0 | –20 | –13 | +4 | +31 | +80 | 0 | –96 | –44 | –29 | –13 | +4 | +17 | +31 | +80 | +130 |
| 225–250 | | | | | | +104 | | | | | | | | | +113 | +169 |
| | | | | | | +84 | | | | | | | | | +84 | +140 |
| 250–280 | | | | | | +117 | | | | | | | | | +126 | +190 |
| | +32 | 0 | +7 | +36 | +57 | +94 | +52 | –56 | –17 | 0 | +16 | +36 | +52 | +66 | +94 | +158 |
| 280–315 | 0 | –23 | –16 | +4 | +34 | +121 | 0 | –108 | –49 | –32 | –16 | +4 | +20 | +34 | +130 | +202 |
| | | | | | | +98 | | | | | | | | | +98 | +170 |
| 315–355 | | | | | | +133 | | | | | | | | | +144 | +226 |
| | +36 | 0 | +7 | +40 | +62 | +108 | +57 | –62 | –18 | 0 | +18 | +40 | +57 | +73 | +108 | +190 |
| 355–400 | 0 | –25 | –18 | +4 | +37 | +139 | 0 | –119 | –54 | –36 | –18 | +4 | +21 | +37 | +150 | +244 |
| | | | | | | +114 | | | | | | | | | +114 | +208 |
| 400–450 | | | | | | +153 | | | | | | | | | +166 | +272 |
| | +40 | 0 | +7 | +45 | +67 | +126 | +63 | –68 | –20 | 0 | +20 | +45 | +63 | +80 | +126 | +232 |
| 450–500 | 0 | –27 | –20 | +5 | +40 | +159 | 0 | –131 | –60 | –40 | –20 | +5 | +23 | +40 | +172 | +292 |
| | | | | | | +132 | | | | | | | | | +132 | +252 |

[1)] The tolerance classes in **bold** print correspond to row 1 in DIN 7157; their use is preferable.

# ISO fits

## Basic hole system

cf. DIN ISO 286-2 (1990-11)

Limit deviations in µm for tolerance classes[1]

| Nominal dimension range over–to mm | for hole | for shafts Paired with an H8 hole results in a clearance fit | | | | interference fit | | for hole | for shafts Paired with an H11 hole results in a clearance fit | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **H8** | d9 | e8 | f7 | h9 | u8[2] | x8[2] | **H11** | a11 | c11 | d9 | d11 | h9 | h11 |
| up to 3 | +14 | –20 | –14 | –6 | 0 | +32 | +34 | +60 | –270 | –60 | –20 | –20 | 0 | 0 |
| | 0 | –45 | –28 | –16 | –25 | +18 | +20 | 0 | –330 | –120 | –45 | –80 | –25 | –60 |
| 3–6 | +18 | –30 | –20 | –10 | 0 | +41 | +46 | +75 | –270 | –70 | –30 | –30 | 0 | 0 |
| | 0 | –60 | –38 | –22 | –30 | +23 | +28 | 0 | –345 | –145 | –60 | –105 | –30 | –75 |
| 6–10 | +22 | –40 | –25 | –13 | 0 | +50 | +56 | +90 | –280 | –80 | –40 | –40 | 0 | 0 |
| | 0 | –76 | –47 | –28 | –36 | +28 | +34 | 0 | –370 | –170 | –76 | –130 | –36 | –90 |
| 10–14 | +27 | –50 | –32 | –16 | 0 | +60 | +67 +40 | +110 | –290 | –95 | –50 | –50 | 0 | 0 |
| 14–18 | 0 | –93 | –59 | –34 | –43 | +33 | +72 +45 | 0 | –400 | –205 | –93 | –160 | –43 | –110 |
| 18–24 | +33 | –65 | –40 | –20 | 0 | +74 +41 | +87 +54 | +130 | –300 | –110 | –65 | –65 | 0 | 0 |
| 24–30 | 0 | –117 | –73 | –41 | –52 | +81 +48 | +97 +64 | 0 | –430 | –240 | –117 | –195 | –52 | –130 |
| 30–40 | +39 | –80 | –50 | –25 | 0 | +99 +60 | +119 +80 | +160 | –310 –470 | –120 –280 | –80 | –80 | 0 | 0 |
| 40–50 | 0 | –142 | –89 | –50 | –62 | +109 +70 | +136 +97 | 0 | –320 –480 | –130 –290 | –142 | –240 | –62 | –160 |
| 50–65 | +46 | –100 | –60 | –30 | 0 | +133 +87 | +168 +122 | +190 | –340 –530 | –140 –330 | –100 | –100 | 0 | 0 |
| 65–80 | 0 | –174 | –106 | –60 | –74 | +148 +102 | +192 +146 | 0 | –360 –550 | –150 –340 | –174 | –290 | –74 | –190 |
| 80–100 | +54 | –120 | –72 | –36 | 0 | +178 +124 | +232 +178 | +220 | –380 –600 | –170 –390 | –120 | –120 | 0 | 0 |
| 100–120 | 0 | –207 | –126 | –71 | –87 | +198 +144 | +264 +210 | 0 | –410 –630 | –180 –400 | –207 | –340 | –87 | –220 |
| 120–140 | +63 | –145 | –85 | –43 | 0 | +233 +170 | +311 +248 | +250 | –460 –710 | –200 –450 | –145 | –145 | 0 | 0 |
| 140–160 | 0 | –245 | –148 | –83 | –100 | +253 +190 | +343 +280 | 0 | –520 –770 | –210 –460 | –245 | –395 | –100 | –250 |
| 160–180 | | | | | | +273 +210 | +373 +310 | | –580 –830 | –230 –480 | | | | |
| 180–200 | +72 | –170 | –100 | –50 | 0 | +308 +236 | +422 +350 | +290 | –660 –950 | –240 –530 | –170 | –170 | 0 | 0 |
| 200–225 | 0 | –285 | –172 | –96 | –115 | +330 +258 | +457 +385 | 0 | –740 –1030 | –260 –550 | –285 | –460 | –115 | –290 |
| 225–250 | | | | | | +356 +284 | +497 +425 | | –820 –1110 | –280 –570 | | | | |
| 250–280 | +81 | –190 | –110 | –56 | 0 | +396 +315 | +556 +475 | +320 | –920 –1240 | –300 –620 | –190 | –190 | 0 | 0 |
| 280–315 | 0 | –320 | –191 | –108 | –130 | +431 +350 | +606 +525 | 0 | –1050 –1370 | –330 –650 | –320 | –510 | –130 | –320 |
| 315–355 | +89 | –210 | –125 | –62 | 0 | +479 +390 | +679 +590 | +360 | –1200 –1560 | –360 –720 | –210 | –210 | 0 | 0 |
| 355–400 | 0 | –350 | –214 | –119 | –140 | +524 +435 | +749 +660 | 0 | –1350 –1710 | –400 –760 | –350 | –570 | –140 | –360 |
| 400–450 | +97 | –230 | –135 | –68 | 0 | +587 +490 | +837 +740 | +400 | –1500 –1900 | –440 –840 | –230 | –230 | 0 | 0 |
| 450–500 | 0 | –385 | –232 | –131 | –155 | +637 +540 | +917 +820 | 0 | –1650 –2050 | –480 –880 | –385 | –630 | –155 | –400 |

[1] The tolerance classes in **bold** print correspond to row 1 in DIN 7157; their use is preferable.

[2] DIN 7157 recommends: nominal dimensions up to 24 mm: H8/x8; nominal dimensions over 24 mm: H8/u8.

# ISO fits

## Basic shaft system

cf. DIN ISO 286-2 (1990-11)

Limit deviations in µm for tolerance classes[1]

| Nominal dimension range over–to mm | for shafts | for holes Paired with an h5 shaft results in a | | | | | for shafts | for holes Paired with an h6 shaft results in a | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | clearance fit | transition fit | | interference fit | | | clearance fit | | | transition fit | | | | interference fit | |
| | **h5** | H6 | J6 | M6 | N6 | P6 | **h6** | F8 | G7 | H7 | J7 | K7 | M7 | N7 | R7 | S7 |
| up to 3 | 0 | +6 | +2 | –2 | –4 | –6 | 0 | +20 | +12 | +10 | +4 | 0 | –2 | –4 | –10 | –14 |
| | –4 | 0 | –4 | –8 | –10 | –12 | –6 | +6 | +2 | 0 | –6 | –10 | –12 | –14 | –20 | –24 |
| 3–6 | 0 | +8 | +5 | –1 | –5 | –9 | 0 | +28 | +16 | +12 | +6 | +3 | 0 | –4 | –11 | –15 |
| | –5 | 0 | –3 | –9 | –13 | –17 | –8 | +10 | +4 | 0 | –6 | –9 | –12 | –16 | –23 | –27 |
| 6–10 | 0 | +9 | +5 | –3 | –7 | –12 | 0 | +35 | +20 | +15 | +8 | +5 | 0 | –4 | –13 | –17 |
| | –6 | 0 | –4 | –12 | –16 | –21 | –9 | +13 | +5 | 0 | –7 | –10 | –15 | –19 | –28 | –32 |
| 10–18 | 0 | +11 | +6 | –4 | –9 | –15 | 0 | +43 | +24 | +18 | +10 | +6 | 0 | –5 | –16 | –21 |
| | –8 | 0 | –5 | –15 | –20 | –26 | –11 | +16 | +6 | 0 | –8 | –12 | –18 | –23 | –34 | –39 |
| 18–30 | 0 | +13 | +8 | –4 | –11 | –18 | 0 | +53 | +28 | +21 | +12 | +6 | 0 | –7 | –20 | –27 |
| | –9 | 0 | –5 | –17 | –24 | –31 | –13 | +20 | +7 | 0 | –9 | –15 | –21 | –28 | –41 | –48 |
| 30–40 | 0 | +16 | +10 | –4 | –12 | –21 | 0 | +64 | +34 | +25 | +14 | +7 | 0 | –8 | –25 | –34 |
| 40–50 | –11 | 0 | –6 | –20 | –28 | –37 | –16 | +25 | +9 | 0 | –11 | –18 | –25 | –33 | –50 | –59 |
| 50–65 | 0 | +19 | +13 | –5 | –14 | –26 | 0 | +76 | +40 | +30 | +18 | +9 | 0 | –9 | –30<br>–60 | –42<br>–72 |
| 65–80 | –13 | 0 | –6 | –24 | –33 | –45 | –19 | +30 | +10 | 0 | –12 | –21 | –30 | –39 | –32<br>–62 | –48<br>–78 |
| 80–100 | 0 | +22 | +16 | –6 | –16 | –30 | 0 | +90 | +47 | +35 | +22 | +10 | 0 | –10 | –38<br>–73 | –58<br>–93 |
| 100–120 | –15 | 0 | –6 | –28 | –38 | –52 | –22 | +36 | +12 | 0 | –13 | –25 | –35 | –45 | –41<br>–76 | –66<br>–101 |
| 120–140 | | | | | | | | | | | | | | | –48<br>–88 | –77<br>–117 |
| 140–160 | 0 | +25 | +18 | –8 | –20 | –36 | 0 | +106 | +54 | +40 | +26 | +12 | 0 | –12 | –50 | –85 |
| | –18 | 0 | –7 | –33 | –45 | –61 | –25 | +43 | +14 | 0 | –14 | –28 | –40 | –52 | –90 | –125 |
| 160–180 | | | | | | | | | | | | | | | –53<br>–93 | –93<br>–133 |
| 180–200 | | | | | | | | | | | | | | | –60<br>–106 | –105<br>–151 |
| 200–225 | 0 | +29 | +22 | –8 | –22 | –41 | 0 | +122 | +61 | +46 | +30 | +13 | 0 | –14 | –63 | –113 |
| | –20 | 0 | –7 | –37 | –51 | –70 | –29 | +50 | +15 | 0 | –16 | –33 | –46 | –60 | –109 | –159 |
| 225–250 | | | | | | | | | | | | | | | –67<br>–113 | –123<br>–169 |
| 250–280 | 0 | +32 | +25 | –9 | –25 | –47 | 0 | +137 | +69 | +52 | +36 | +16 | 0 | –14 | –74<br>–126 | –138<br>–190 |
| 280–315 | –23 | 0 | –7 | –41 | –57 | –79 | –32 | +56 | +17 | 0 | –16 | –36 | –52 | –66 | –78<br>–130 | –150<br>–202 |
| 315–355 | 0 | +36 | +29 | –10 | –26 | –51 | 0 | +151 | +75 | +57 | +39 | +17 | 0 | –16 | –87<br>–144 | –169<br>–226 |
| 355–400 | –25 | 0 | –7 | –46 | –62 | –87 | –36 | +62 | +18 | 0 | –18 | –40 | –57 | –73 | –93<br>–150 | –187<br>–244 |
| 400–450 | 0 | +40 | +33 | –10 | –27 | –55 | 0 | +165 | +83 | +63 | +43 | +18 | 0 | –17 | –103<br>–166 | –209<br>–272 |
| 450–500 | –27 | 0 | –7 | –50 | –67 | –95 | –40 | +68 | +20 | 0 | –20 | –45 | –63 | –80 | –109<br>–172 | –229<br>–292 |

[1] The tolerance classes in **bold** print correspond to row 1 in DIN 7157; their use is preferable.

# ISO fits

## Basic shaft system

cf. DIN ISO 286-2 (1990-11)

Limit deviations in µm for tolerance classes[1]

| Nominal dimension range over–to mm | for shafts | for holes | | | | | | | | for shafts | for holes | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Pairing with an h9 shaft results in a | | | | | | | | | Pairing with an h11 shaft results in a | | | |
| | | clearance fit | | | | | transition fit | | | | clearance fit | | | |
| | h9 | C11 | D10 | E9 | F8 | H8 | J9/JS9[2] | N9[3] | P9 | h11 | A11 | C11 | D10 | H11 |
| bis 3 | 0 | +120 | +60 | +39 | +20 | +14 | +12,5 | −4 | −6 | 0 | +330 | +120 | +60 | +60 |
| | −25 | +60 | +20 | +14 | +06 | 0 | −12,5 | −29 | −31 | −60 | +270 | +60 | +20 | 0 |
| 3–6 | 0 | +145 | +78 | +50 | +28 | +18 | +15 | 0 | −12 | 0 | +345 | +145 | +78 | +75 |
| | −30 | +70 | +30 | +20 | +10 | 0 | −15 | −30 | −42 | −75 | +270 | +70 | +30 | 0 |
| 6–10 | 0 | +170 | +98 | +61 | +35 | +22 | +18 | 0 | −15 | 0 | +370 | +170 | +98 | +90 |
| | −36 | +80 | +40 | +25 | +13 | 0 | −18 | −36 | −51 | −90 | +280 | +80 | +40 | 0 |
| 10–18 | 0 | +205 | +120 | +75 | +43 | +27 | +21,5 | 0 | −18 | 0 | +400 | +205 | +120 | +110 |
| | −43 | +95 | +50 | +32 | +16 | 0 | −21,5 | −43 | −61 | −110 | +290 | +95 | +50 | 0 |
| 18–30 | 0 | +240 | +149 | +92 | +53 | +33 | +26 | 0 | −22 | 0 | +430 | +240 | +149 | +130 |
| | −52 | +110 | +65 | +40 | +20 | 0 | −26 | −52 | −74 | −130 | +300 | +110 | +65 | 0 |
| 30–40 | | +280 | | | | | | | | | +470 | +280 | | |
| | 0 | +120 | +180 | +112 | +64 | +39 | +31 | 0 | −26 | 0 | +310 | +120 | +180 | +160 |
| 40–50 | −62 | +290 | +80 | +50 | +25 | 0 | −31 | −62 | −88 | −160 | +480 | +290 | +80 | 0 |
| | | +130 | | | | | | | | | +320 | +130 | | |
| 50–65 | | +330 | | | | | | | | | +530 | +330 | | |
| | 0 | +140 | +220 | +134 | +76 | +46 | +37 | 0 | −32 | 0 | +340 | +140 | +220 | +190 |
| 65–80 | −74 | +340 | +100 | +60 | +30 | 0 | −37 | −74 | −106 | −190 | +550 | +340 | +100 | 0 |
| | | +150 | | | | | | | | | +360 | +150 | | |
| 80–100 | | +390 | | | | | | | | | +600 | +390 | | |
| | 0 | +170 | +260 | +159 | +90 | +54 | +43,5 | 0 | −37 | 0 | +380 | +170 | +260 | +220 |
| 100–120 | −87 | +400 | +120 | +72 | +36 | 0 | −43,5 | −87 | −124 | −220 | +630 | +400 | +120 | 0 |
| | | +180 | | | | | | | | | +410 | +180 | | |
| 120–140 | | +450 | | | | | | | | | +710 | +450 | | |
| | | +200 | | | | | | | | | +460 | +200 | | |
| 140–160 | 0 | +460 | +305 | +185 | +106 | +63 | +50 | 0 | −43 | 0 | +770 | +460 | +305 | +250 |
| | −100 | +210 | +145 | +85 | +43 | 0 | −50 | −100 | −143 | −250 | +520 | +210 | +145 | 0 |
| 160–180 | | +480 | | | | | | | | | +820 | +480 | | |
| | | +230 | | | | | | | | | +580 | +230 | | |
| 180–200 | | +530 | | | | | | | | | +950 | +530 | | |
| | | +240 | | | | | | | | | +660 | +240 | | |
| 200–225 | 0 | +550 | +355 | +215 | +122 | +72 | +57,5 | 0 | −50 | 0 | +1030 | +550 | +355 | +290 |
| | −115 | +260 | +170 | +100 | +50 | 0 | −57,5 | −115 | −165 | −290 | +740 | +260 | +170 | 0 |
| 225–250 | | +570 | | | | | | | | | +1110 | +570 | | |
| | | +280 | | | | | | | | | +820 | +280 | | |
| 250–280 | | +620 | | | | | | | | | +1240 | +620 | | |
| | 0 | +300 | +400 | +240 | +137 | +81 | +65 | 0 | −56 | 0 | +920 | +300 | +400 | +320 |
| 280–315 | −130 | +650 | +190 | +110 | +56 | 0 | −65 | −130 | −186 | −320 | +1370 | +650 | +190 | 0 |
| | | +330 | | | | | | | | | +1050 | +330 | | |
| 315–355 | | +720 | | | | | | | | | +1560 | +720 | | |
| | 0 | +360 | +440 | +265 | +151 | +89 | +70 | 0 | −62 | 0 | +1200 | +360 | +440 | +360 |
| 355–400 | −140 | +760 | +210 | +125 | +62 | 0 | −70 | −140 | −202 | −360 | +1710 | +760 | +210 | 0 |
| | | +400 | | | | | | | | | +1350 | +400 | | |
| 400–450 | | +840 | | | | | | | | | +1900 | +840 | | |
| | 0 | +440 | +480 | +290 | +165 | +97 | +77,5 | 0 | −68 | 0 | +1500 | +440 | +480 | +400 |
| 450–500 | −155 | +880 | +230 | +135 | +68 | 0 | −77,5 | −155 | −223 | −400 | +2050 | +880 | +230 | 0 |
| | | +480 | | | | | | | | | +1650 | +480 | | |

[1] The tolerance classes in **bold** print correspond to row 1 in DIN 7157; their use is preferable.
[2] The tolerance zones J9/JS9, J10/JS10 etc. are all identical in size and are symmetrical to the zero line.
[3] Tolerance class N9 may not be used for nominal dimensions ≤ 1mm.

# General tolerances, Roller bearing fits

## General tolerances[1] for linear and angular dimensions

cf. DIN ISO 2768-1 (1991-06)

| Tolerance class | Linear dimensions<br>Limit deviations in mm for nominal dimension ranges | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0.5 to 3 | over 3 to 6 | over 6 to 30 | over 30 to 120 | over 120 to 400 | over 400 to 1000 | over 1000 to 2000 | over 2000 to 4000 |
| f (fine) | ± 0.05 | ± 0.05 | ± 0.1 | ± 0.15 | ± 0.2 | ± 0.3 | ± 0.5 | – |
| m (medium) | ± 0.1 | ± 0.1 | ± 0.2 | ± 0.3 | ± 0.5 | ± 0.8 | ± 1.2 | ± 2 |
| c (coarse) | ± 0.2 | ± 0.3 | ± 0.5 | ± 0.8 | ± 1.2 | ± 2 | ± 3 | ± 4 |
| v (very coarse) | – | ± 0.5 | ± 1 | ± 1.5 | ± 2.5 | ± 4 | ± 6 | ± 8 |

| Tolerance class | Radii and chamfers<br>Limit deviations in mm for nominal dimension ranges | | | Angular dimensions<br>Limit deviations in degrees and minutes for nominal dimension ranges (shorter angle leg) | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0.5 to 3 | over 3 to 6 | 6 | to 10 | over 10 to 50 | over 50 to 120 | over 120 to 400 | 400 |
| f (fine) | ± 0.2 | ± 0.5 | ± 1 | ± 1° | ± 0° 30′ | ± 0° 20′ | ± 0° 10′ | ± 0° 5′ |
| m (medium) | | | | | | | | |
| c (coarse) | ± 0.4 | ± 1 | ± 2 | ± 1° 30′ | ± 1° | ± 0° 30′ | ± 0° 15′ | ± 0° 10′ |
| v (very coarse) | | | | ± 3° | ± 2° | ± 1° | ± 0° 30′ | ± 0° 20′ |

## General tolerances[1] for form and position

cf. DIN ISO 2768-2 (1991-04)

| Tolerance class | Tolerances in mm for straightness and flatness<br>nominal dimension ranges in mm | | | | | | perpendicularity<br>nominal dim. ranges in mm (shorter angle leg) | | | | symmetry<br>nominal dim. ranges in mm (shorter feature) | | | | run |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | up to 10 | over 10 to 30 | over 30 to 100 | over 100 to 300 | over 300 to 1000 | over 1000 to 3000 | up to 100 | over 100 to 300 | over 300 to 1000 | over 1000 to 3000 | up to 100 | over 100 to 300 | over 300 to 1000 | over 1000 to 3000 | |
| H | 0.02 | 0.05 | 0.1 | 0.2 | 0.3 | 0.4 | 0.2 | 0.3 | 0.4 | 0.5 | 0.5 | | | | 0.1 |
| K | 0.05 | 0.1 | 0.2 | 0.4 | 0.6 | 0.8 | 0.4 | 0.6 | 0.8 | 1 | 0.6 | | 0.8 | 1 | 0.2 |
| L | 0.1 | 0.2 | 0.4 | 0.8 | 1.2 | 1.6 | 0.6 | 1 | 1.5 | 2 | 0.6 | 1 | 1.5 | 2 | 0.5 |

[1] General tolerances apply to dimensions without individual tolerance entry. Drawing entry page 80.

## Tolerances for the installation of roller bearings

cf. DIN 5425-1 (1984-11)

### Radial bearing

| Inner ring (shaft) | | | | | Outer ring (housing) | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Load case | Fit | Load | Fundamental deviations for shafts[1] with ball bearing | roller bearing | Load case | Fit | Load | Fundamental deviations for housings[1] with ball bearing | roller bearing |
| circumferential load  | transition or interference fit required | low | h, k | k, m | point load  | clearance fit allowed | arbitrarily large | J, H, G, F | |
| | | medium | j, k, m | k, m, n, p | | | | | |
| | | high | m, n | n, p, r | | | | | |
| point load  | clearance fit allowed | arbitrarily large | j, h, g, f | | circumferential load  | transition or interference fit required | low | J | K |
| | | | | | | | medium | K, M | M, N |
| | | | | | | | high | – | N, P |

### Thrust bearing

| Load type | Bearing construction | Shaft washer (shaft) Load case | Fundamental deviat. for shafts[1] | Housing plate (housing) Load case | Fundamental deviations for housing[1] |
|---|---|---|---|---|---|
| Combined radial/axial load | angular contact ball bearing<br>spherical roller bearing<br>tapered roller bearing | circumfer. load | j, k, m | point load | H, J |
| | | point load | j | circumfer. load | K, M |
| Pure axial load | ball bearing<br>roller bearing | – | h, j, k | – | H, G, E |

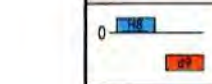
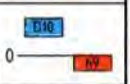
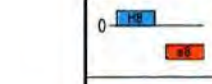
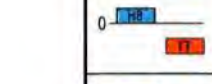
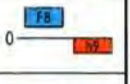
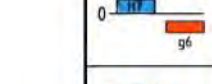
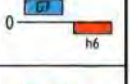
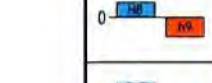
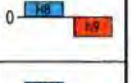
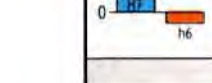
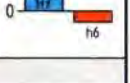
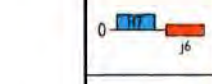
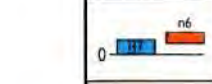
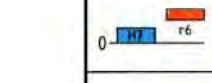
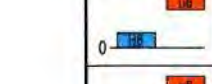
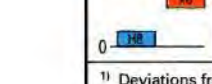
[1] Fundamental tolerance grades: for shafts typically IT6, for bores typically IT7. If the smoothness and accuracy of running must satisfy increased requirements, also smaller tolerance grades are specified.

# Fit recommendations, possible fits

**Fit recommendations**[1] cf. DIN 7157 (1966-01)

| | |
|---|---|
| From row 1 | C11/h9, D10/h9, E9/h9, F8/h9, H8/f7, F8/h6, H7/f7, H8/h9, H7/h6, H7/n6, H7/r6, H8/x8 or u8 |
| From row 2 | C11/h11, D10/h11, H8/d9, H8/e8, H7/g6, G7/h6, H11/h9, H7/j6, H7/k6, H7/s6 |

**Possible fits** (examples) cf. DIN 7157 (1966-01)

| Basic hole[2] | | Characteristic/application examples | Basic shaft[2] | |
|---|---|---|---|---|
| **Clearance fits** | | | | |
|  | H8/d9 | **Loose running fit**<br>Clearance allows for loose fit of mating parts.<br>(i.e. spacer sleeves on shafts) | **D10/h9** |  |
|  | H8/e8 | **Free running fit (Medium running fit):** Sufficient clearance is allowed for ease of assembly.<br>(i.e. collar on shaft) | **E9/h9** |  |
|  | **H8/f7** | **Close running fit:** Clearance allows for parts to be easily assembled by hand while maintaining location accuracy.<br>(i.e. plain bearing of shaft) | **F8/h9** |  |
|  | **H7/f7** | **Sliding fit – free:** Clearance allows accurate location and free movement, including turning.<br>(i.e. piston valves in cylinders) | **F8/h6** |  |
|  | H7/g6 | **Sliding fit – constrained:** Clearance allows better locational accuracy while still allowing sliding or turning movement.<br>(i.e. transmission gear on shaft) | G7/h6 |  |
|  | **H8/h9** | **Minimal clearance fit:** Allows locational accuracy and hand force assembly without being a snug fit.<br>(i.e. spacer sleeves) | **H8/h9** |  |
|  | **H7/h6** | **Locational clearance fit:** Allows snug fit of stationary parts that may be assembled by hand force.<br>(i.e. punch in punch holder) | **H7/h6** |  |
| **Transition fits** | | | | |
|  | H7/j6 | **Locational transition fit – clearance:** For accurate location allowing more clearance than interference.<br>(i.e. gears on shafts) | not specified | |
|  | **H7/n6** | **Locational transition fit – interference:** For accurate location where interference is permissible.<br>(i.e. drill bushing in jigs) | | |
| **Interference fits** | | | | |
|  | **H7/r6** | **Locational interference fit:** For rigidity and alignment/accurate location without special bore requirements.<br>(i.e. bushings in housings) | not specified | |
|  | H7/s6 | **Medium drive fit:** For ordinary steel parts or shrink fits of light sections. Tightest fit possible for cast iron.<br>(i.e. plain bearing bushings) | | |
|  | **H8/u8** | **Force fit:** For parts fitting that can withstand high mechanical pressing force or shrink fitting.<br>(i.e. wheel on axle) | | |
|  | **H8/x8** | **Extreme force fit:** For parts that can only be assembled by stretching or shrinking.<br>(i.e. turbine blade on shaft) | | |

[1] Deviations from these fit recommendations should only be made in exceptional cases, e.g. installation of roller bearings.
[2] The fits in **bold** print are tolerance combinations according to row 1. Their use is preferred.

# Geometric tolerancing

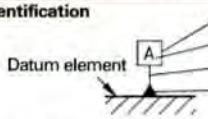
## Tolerances of geometry, orientation, location and run-out

cf. DIN EN ISO 1101 (2006-02)

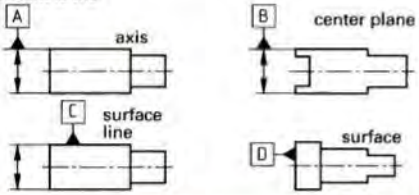
### Structure of tolerance specifications

**Datum**

- **Identification**

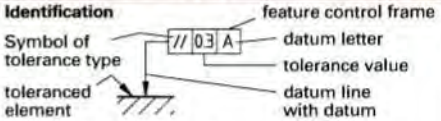



- **Datum** is the

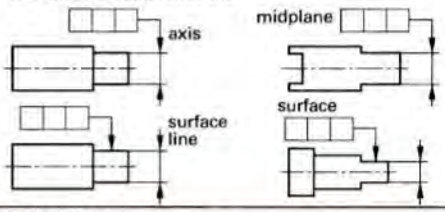



**Toleranced element**

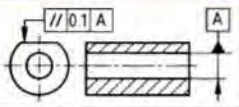
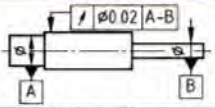
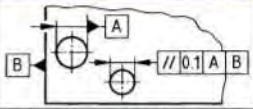
- **Identification**



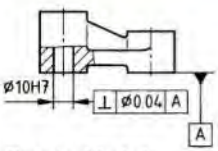

- **The tolerance** applies to the



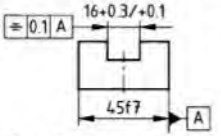

**Indications in drawings of datum specifications and toleranced elements**

| Datum | Simple datum | Common datum | Multiple datum (two or three elements) |
|---|---|---|---|
| Example |   |   |   |
| Datum in feature control frame | Individual datum letter | Datum letters separated with hyphens | Order of datum letters according to their importance |

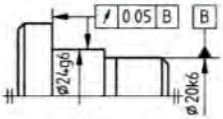
**Examples**



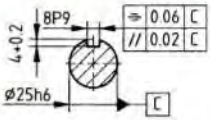

The axis of the hole must run perpendicular (tolerance value 0.04 mm) to the datum surface.




The center plane of the slot must run symmetrically to the center plane of the exterior surface (tolerance value 0.1 mm).



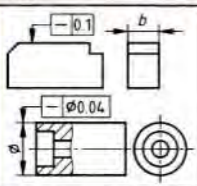
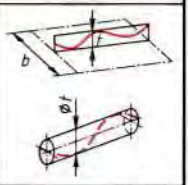

The cylindrical surface ⌀24g6 must run true to the axis ⌀20k6 and the flat surface must be planar (tolerance value 0.05 mm).




The slot must lie symmetrical (tolerance value 0.06 mm) and parallel (tolerance value 0.02 mm) to the axis ⌀25h6.

## Indication in drawings

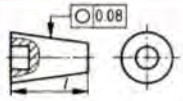
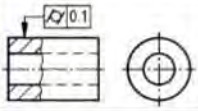
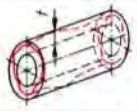
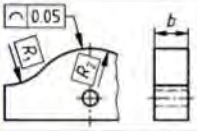
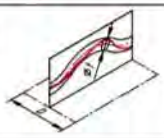
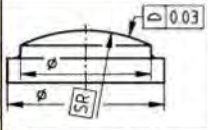
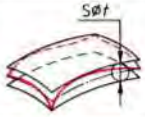
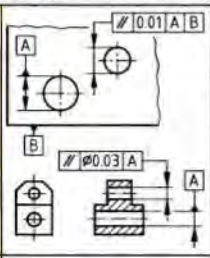
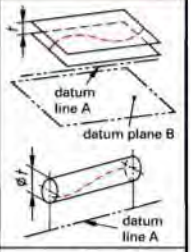
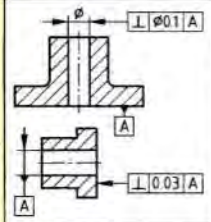
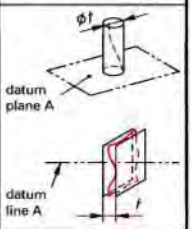
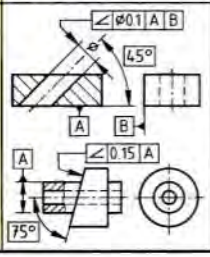
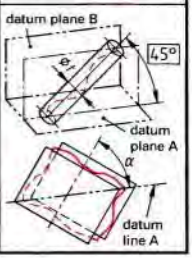
cf. DIN ISO 1101 (1985-03)

| Geometric characteristic symbols | | Representation in drawing (examples) | Explanation | Tolerance zone |
|---|---|---|---|---|
| **Geometric tolerances** | | | | |
| — | Straightness |   | At all points across width $b$, the surface curve must lie between two parallel lines spaced $t$ = 0.1 mm apart<br><br>The toleranced axis of the shaft must lie within a cylinder with diameter $t$ = 0.04 mm. |   |
| ▱ | Flatness |   | The toleranced surface must be located between two parallel planes spaced apart a distance of $t$ = 0.03 mm. |  |

# Geometric dimensioning and tolerancing GD & T

## Indications in drawings (continued)

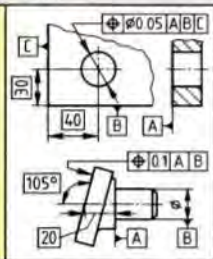
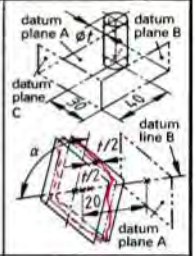
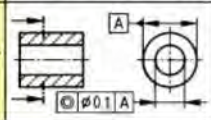
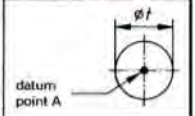
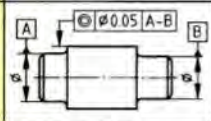
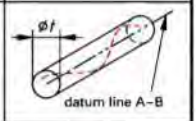
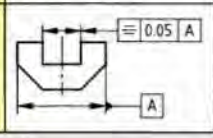
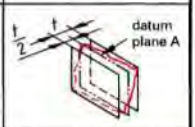
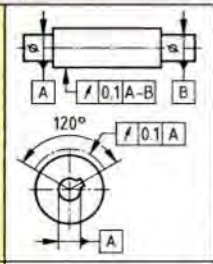
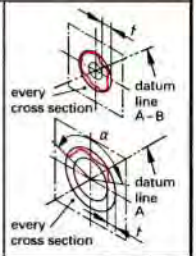
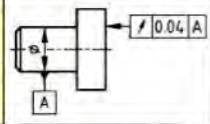
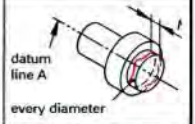
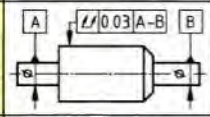
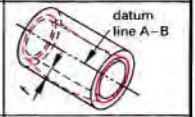
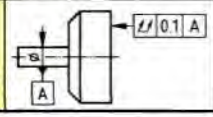
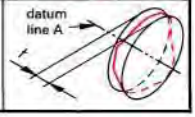
cf. DIN EN ISO 1101 (2006-02)

| Symbol and toleranced property | Representation in drawing | Explanation | Tolerance zone |
|---|---|---|---|
| **Tolerances of form** (continued) | | | |
| ○ Circularity |   | The cone's circumferential line must lie between two concentric circles spaced apart at a distance of $t$ = 0.08 mm in each point of the cone length $l$. |   |
| ⌭ Cylindricity |   | The shell surface of the cylinder must lie between two coaxial cylinders, which are spaced apart at a radial distance of $t$ = 0.1 mm. |  |
| ⌒ Profile of line |   | The profile line must lie between two enveloping lines, whose gap is bounded by circles of diameter $t$ = 0.05 mm in each point of the workpiece thickness $b$. The centers of these circles lie on a geometrically ideal line. |   |
| ⌓ Profile of surface |   | The surface of the sphere must lie between two enveloping surfaces, whose gap $t$ = 0.3 mm is created by spheres. The centers of these spheres lie on the geometrically ideal surface. |   |
| **Orientation tolerances** | | | |
| // Parallelism |   | The hole's centerline must lie between two parallel planes spaced apart at a distance of $t$ = 0.01 mm. The planes are parallel to datum line A and datum plane B and in line with the defined direction (vertical in this case).<br><br>The hole's centerline must lie within a cylinder of diameter $t$ = 0.03 mm. The centerline of this cylinder is parallel to datum line (axis) A. |   |
| ⊥ Perpendicularity |   | The hole's centerline must lie within a cylinder of diameter $t$ = 0.1 mm that is perpendicular to datum plane A.<br><br>The plane surface must lie between two planes perpendicular to datum line A that are spaced apart at a distance of $t$ = 0.03 mm. |   |
| ∠ Angularity |   | The hole's centerline must lie within a cylinder of diameter $t$ = 0.1 mm. The centerline of the cylinder is parallel to datum plane B and inclined at a theoretically exact angle of $\alpha$ = 45° with reference to datum plane A.<br><br>The inclined plane must lie between two parallel planes spaced at a distance of $t$ = 0.15 mm that are inclined at a theoretically exact angle of $\alpha$ = 75° with reference to datum line A. |   |

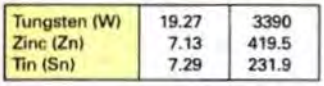
# Geometric dimensioning and tolerancing GD & T

## Indications in drawings (continued)

cf. DIN EN ISO 1101 (2006-02)

| Symbol and toleranced property | Representation in drawing | Explanation | Tolerance zone |
|---|---|---|---|
| **Tolerances of location** | | | |
| ⌖ Position |  | The hole's centerline must lie within a cylinder of diameter $t = 0.05$ mm. The cylinder's centerline must coincide with the theoretically exact location of the hole's centerline in regard to the datum planes A, B and C.<br><br>The surface must lie between two parallel planes spaced apart at a distance of $t = 0.1$ mm that are symmetrical to the theoretically exact location of the toleranced surface in regard to datum plane A and datum line B. |  |
| ◎ Concentricity |  | The center of the hole must lie in a circle of diameter $t = 0.1$ mm that is concentric to the datum point A in the cross section. |  |
| ◎ Coaxiality |  | The centerline of all diameters must lie within a cylinder of diameter $t = 0.05$ mm. The centerline of this cylinder must coincide with the common datum axis A–B. |  |
| ⌯ Symmetry |  | The midplane of the slot must lie between two parallel planes spaced apart at a distance of $t = 0.05$ mm that are located symmetrical to datum plane A. |  |
| **Runout tolerances** | | | |
| ↗ Radial circular runout |  | In every cross section, the circumferential line must be perpendicular to the common datum line A–B between two concentric circles in the same plane having a radial distance of $t = 0.1$ mm.<br><br>In every cross section, the 120° circumferential line must be perpendicular to datum line A and lie between two concentric circles in the same plane that have a radial distance of $t = 0.1$ mm. |  |
| ↗ Axial circular runout |  | In every diameter, the circumferential line must lie in the plane surface between two circles that have a radial distance of $t = 0.04$ mm. The centerline of each diameter must coincide with datum line A. |  |
| ⌰ Total radial runout |  | The shell surface must lie between two coaxial cylinders having a radial distance of $t = 0.03$ mm. The centerlines of these cylinders must coincide with the common datum line A–B. |  |
| ⌰ Total axial runout |  | The plane surface must lie between two parallel planes spaced apart at a distance of $t = 0.1$ mm that are perpendicular to datum line A. |  |

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# Material characteristics of solids

## Solid material

| Material | Density $\varrho$ kg/dm³ | Melting temperature at 1.013 bar $\vartheta$ °C | Boiling temperature at 1.013 bar $\vartheta$ °C | Latent heat of fusion at 1.013 bar $q$ kJ/kg | Thermal conductivity at 20 °C $\lambda$ W/(m · K) | Mean specific heat at 0–100 °C $c$ kJ/(kg · K) | Specific electrical resistivity at 20 °C $\varrho_{20}$ Ω · mm²/m | Coefficient of linear expansion 0–100 °C $\alpha_l$ 1/°C or 1/K |
|---|---|---|---|---|---|---|---|---|
| Aluminum (Al) | 2.7 | 659 | 2467 | 356 | 204 | 0.94 | 0.028 | 0.0000238 |
| Antimony (Sb) | 6.69 | 630.5 | 1637 | 163 | 22 | 0.21 | 0.39 | 0.0000108 |
| Asbestos | 2.1–2.8 | ≈ 1300 | – | – | – | 0.81 | – | – |
| Beryllium (Be) | 1.85 | 1280 | ≈ 3000 | – | 165 | 1.02 | 0.04 | 0.0000123 |
| Bismuth (Bi) | 9.8 | 271 | 1560 | 59 | 8.1 | 0.12 | 1.25 | 0.0000125 |
| Cadmium (Cd) | 8.64 | 321 | 765 | 54 | 91 | 0.23 | 0.077 | 0.00003 |
| Carbide (K 20) | 14.8 | > 2000 | ≈ 4000 | – | 81.4 | 0.80 | – | 0.000005 |
| Carbon (diamond) | 3.51 | ≈ 3550 | – | – | – | 0.52 | – | 0.00000118 |
| Cast iron | 7.25 | 1150–1200 | 2500 | 125 | 58 | 0.50 | 0.6–1.6 | 0.0000105 |
| Chromium (Cr) | 7.2 | 1903 | 2642 | 134 | 69 | 0.46 | 0.13 | 0.0000084 |
| Cobalt (Co) | 8.9 | 1493 | 2880 | 268 | 69.1 | 0.43 | 0.062 | 0.0000127 |
| Coke | 1.6–1.9 | – | – | – | 0.18 | 0.83 | – | – |
| Concrete | 1.8–2.2 | – | – | – | ≈ 1 | 0.88 | – | 0.00001 |
| Constantan | 8.89 | 1260 | ≈ 2400 | – | 23 | 0.41 | 0.49 | 0.0000152 |
| Copper (Cu) | 8.96 | 1083 | ≈ 2595 | 213 | 384 | 0.39 | 0.0179 | 0.0000168 |
| Cork | 0.1–0.3 | – | – | – | 0.04–0.06 | 1.7–2.1 | – | – |
| Corundum ($Al_2O_3$) | 3.9–4.0 | 2050 | 2700 | – | 12–23 | 0.96 | – | 0.0000065 |
| CuAl alloys | 7.4–7.7 | 1040 | 2300 | – | 61 | 0.44 | – | 0.0000195 |
| CuSn alloys | 7.4–8.9 | 900 | 2300 | – | 46 | 0.38 | 0.02–0.03 | 0.0000175 |
| CuZn alloys | 8.4–8.7 | 900–1000 | 2300 | 167 | 105 | 0.39 | 0.05–0.07 | 0.0000185 |
| Foam rubber | 0.06–0.25 | – | – | – | 0.04–0.06 | – | – | – |
| Glass (quartz glass) | 2.4–2.7 | 520–550[1] | – | – | 0.8–1.0 | 0.83 | $10^{18}$ | 0.000009 |
| Gold (Au) | 19.3 | 1064 | 2707 | 67 | 310 | 0.13 | 0.022 | 0.0000142 |
| Graphite (C) | 2.26 | ≈ 3550 | ≈ 4800 | – | 168 | 0.71 | – | 0.0000078 |
| Greases | 0.92–0.94 | 30–175 | ≈ 300 | – | 0.21 | – | – | – |
| Ice | 0.92 | 0 | 100 | 332 | 2.3 | 2.09 | – | 0.000051 |
| Iodine (I) | 5.0 | 113.6 | 183 | 62 | 0.44 | 0.23 | – | – |
| Iridium (Ir) | 22.4 | 2443 | > 4350 | 135 | 59 | 0.13 | 0.053 | 0.0000065 |
| Iron oxide (rust) | 5.1 | 1570 | – | – | 0.58 (pwdr) | 0.67 | – | – |
| Iron, pure (Fe) | 7.87 | 1536 | 3070 | 276 | 81 | 0.47 | 0.13 | 0.000012 |
| Lead (Pb) | 11.3 | 327.4 | 1751 | 24.3 | 34.7 | 0.13 | 0.208 | 0.000029 |
| Magnesium (Mg) | 1.74 | 650 | 1120 | 195 | 172 | 1.04 | 0.044 | 0.000026 |
| Magnesium alloy | ≈ 1.8 | ≈ 630 | 1500 | – | 46–139 | – | – | 0.0000245 |
| Manganese (Mn) | 7.43 | 1244 | 2095 | 251 | 21 | 0.48 | 0.39 | 0.000023 |
| Molybdenum (Mo) | 10.22 | 2620 | 4800 | 287 | 145 | 0.26 | 0.054 | 0.0000052 |
| Nickel (Ni) | 8.91 | 1455 | 2730 | 306 | 59 | 0.45 | 0.095 | 0.000013 |
| Niobium (Nb) | 8.55 | 2468 | ≈ 4800 | 288 | 53 | 0.273 | 0.217 | 0.0000071 |
| Phosph., yellow (P) | 1.82 | 44 | 280 | 21 | – | 0.80 | – | – |
| Pit coal | 1.35 | – | – | – | 0.24 | 1.02 | – | – |
| Plaster | 2.3 | 1200 | – | – | 0.45 | 1.09 | – | – |
| Platinum (Pt) | 21.5 | 1769 | 4300 | 113 | 70 | 0.13 | 0.098 | 0.000009 |
| Polystyrene | 1.05 | – | – | – | 0.17 | 1.3 | $10^{10}$ | 0.00007 |
| Porcelain | 2.3–2.5 | ≈ 1600 | – | – | 1.6[3] | 1.2[3] | $10^{12}$ | 0.000004 |
| Quartz, flint ($SiO_2$) | 2.1–2.5 | 1480 | 2230 | – | 9.9 | 0.8 | – | 0.000008 |
| Selenium, red (Se) | 4.4 | 220 | 688 | 83 | 0.2 | 0.33 | – | – |
| Silicon (Si) | 2.33 | 1423 | 2355 | 1658 | 83 | 0.75 | $2.3 \cdot 10^9$ | 0.0000042 |
| Silicon carbide (SiC) | 2.4 disintegrates into C and Si above 3000 °C | | | | 9[1] | 1.05[1] | – | – |
| Silver (Ag) | 10.5 | 961.5 | 2180 | 105 | 407 | 0.23 | 0.015 | 0.0000193 |

[1] transformation temperature [2] cross grain [3] at 800 °C

# Material characteristics of solid, liquid and gaseous materials

## Solid materials (continued)

| Material | Density $\varrho$ kg/dm³ | Melting temperature at 1.013 bar $\vartheta$ °C | Boiling temperature at 1.013 bar $\vartheta$ °C | Latent heat of fusion at 1.013 bar $q$ kJ/kg | Thermal conductivity at 20 °C $\lambda$ W/(m · K) | Mean specific heat at 0–100 °C $c$ kJ/(kg · K) | Specific electrical resistivity at 20 °C $\varrho_{20}$ Ω · mm²/m | Coefficient of linear expansion 0–100 °C $\alpha_l$ 1/°C or 1/K |
|---|---|---|---|---|---|---|---|---|
| Sodium (Na) | 0.97 | 97.8 | 890 | 113 | 126 | 1.3 | 0.04 | 0.000071 |
| Steel, unalloyed | 7.85 | ≈ 1500 | 2500 | 205 | 48–58 | 0.49 | 0.14–0.18 | 0.0000119 |
| Steel, alloyed | 7.9 | ≈ 1500 | – | – | 14 | 0.51 | 0.7 | 0.0000161 |
| Sulfur (S) | 2.07 | 113 | 344.6 | 49 | 0.2 | 0.70 | – | – |
| Tantalum (Ta) | 16.6 | 2996 | 5400 | 172 | 54 | 0.14 | 0.124 | 0.0000065 |
| Tin (Sn) | 7.29 | 231.9 | 2687 | 59 | 65.7 | 0.24 | 0.114 | 0.000023 |
| Titanium (Ti) | 4.5 | 1670 | 3280 | 88 | 15.5 | 0.47 | 0.42 | 0.0000082 |
| Tungsten (W) | 19.27 | 3390 | 5500 | 54 | 130 | 0.13 | 0.055 | 0.0000045 |
| Uranium (U) | 19.1 | 1133 | ≈ 3800 | 356 | 28 | 0.12 | – | – |
| Vanadium (V) | 6.12 | 1890 | ≈ 3380 | 343 | 31.4 | 0.50 | 0.2 | – |
| Wood (air dried) | 0.20–0.72 | – | – | – | 0.06–0.17 | 2.1–2.9 | – | ≈ 0.00004[2] |
| Zinc (Zn) | 7.13 | 419.5 | 907 | 101 | 113 | 0.4 | 0.06 | 0.000029 |

## Liquid materials

| Material | Density at 20 °C $\varrho$ kg/dm³ | Ignition temperature $\vartheta$ °C | Freezing or melting temperature at 1.013 bar $\vartheta$ °C | Boiling temperature at 1.013 bar $\vartheta$ °C | Latent heat of vaporization[2] $r$ kJ/kg | Thermal conductivity at 20 °C $\lambda$ W/(m · K) | Specific heat at 20 °C $c$ kJ/(kg · K) | Coefficient of volume expansion $\alpha_V$ 1/°C or 1/K |
|---|---|---|---|---|---|---|---|---|
| Alcohol 95 % | 0.81 | 520 | –114 | 78 | 854 | 0.17 | 2.43 | 0.0011 |
| Diesel fuel | 0.81–0.85 | 220 | –30 | 150–360 | 628 | 0.15 | 2.05 | 0.00096 |
| Ethyl ether $(C_2H_5)_2O$ | 0.71 | 170 | –116 | 35 | 377 | 0.13 | 2.28 | 0.0016 |
| Fuel oil EL | ≈ 0.83 | 220 | –10 | > 175 | 628 | 0.14 | 2.07 | 0.00096 |
| Gasoline | 0.72–0.75 | 220 | –30– –50 | 25–210 | 419 | 0.13 | 2.02 | 0.0011 |
| Machine oil | 0.91 | 400 | –20 | > 300 | – | 0.13 | 2.09 | 0.00093 |
| Mercury (Hg) | 13.5 | – | –39 | 357 | 285 | 10 | 0.14 | 0.00018 |
| Petroleum | 0.76–0.86 | 550 | –70 | > 150 | 314 | 0.13 | 2.16 | 0.001 |
| Water, distilled | 1.00[3] | – | 0 | 100 | 2256 | 0.60 | 4.18 | 0.00018 |

[1] above 1000 °C [2] at boiling temperature and 0.013 bar [3] at 4 °C

## Gaseous materials

| Material | Density at 0 °C and 1.013 bar $\varrho$ kg/m³ | Specific gravity[1] $\varrho/\varrho_L$ | Melting temperature at 1.013 bar $\vartheta$ °C | Boiling temperature at 1.013 bar $\vartheta$ °C | Thermal conductivity at 20 °C $\lambda$ W/(m · K) | Coefficient of thermal conductivity[2] $\lambda/\lambda_A$ | Specific heat at 20 °C and 1,013 bar $c_p$[3] \| $c_v$[4] kJ/(kg · K) | |
|---|---|---|---|---|---|---|---|---|
| Acetylene $(C_2H_2)$ | 1.17 | 0.905 | –84 | –82 | 0.021 | 0.81 | 1.64 | 1.33 |
| Air | 1.293 | 1.0 | –220 | –191 | 0.026 | 1.00 | 1.005 | 0.716 |
| Ammonia $(NH_3)$ | 0.77 | 0.596 | –78 | –33 | 0.024 | 0.92 | 2.06 | 1.56 |
| Butane $(C_4H_{10})$ | 2.70 | 2.088 | –135 | –0.5 | 0.016 | 0.62 | – | – |
| Carbon diox. $(CO_2)$ | 1.98 | 1.531 | –57[5] | –78 | 0.016 | 0.62 | 0.82 | 0.63 |
| Carbon monox. (CO) | 1.25 | 0.967 | –205 | –190 | 0.025 | 0.96 | 1.05 | 0.75 |
| Freon $(CF_2Cl_2)$ | 5.51 | 4.261 | –140 | –30 | 0.010 | 0.39 | – | – |
| Hydrogen $(H_2)$ | 0.09 | 0.07 | –259 | –253 | 0.180 | 6.92 | 14.24 | 10.10 |
| Methane $(CH_4)$ | 0.72 | 0.557 | –183 | –162 | 0.033 | 1.27 | 2.19 | 1.68 |
| Nitrogen $(N_2)$ | 1.25 | 0.967 | –210 | –196 | 0.026 | 1.00 | 1.04 | 0.74 |
| Oxygen $(O_2)$ | 1.43 | 1.106 | –219 | –183 | 0.026 | 1.00 | 0.91 | 0.65 |
| Propane $(C_3H_8)$ | 2.00 | 1.547 | –190 | –43 | 0.018 | 0.69 | – | – |

[1] Specific gravity = density of a gas $\varrho$ divided by the density of air $\varrho_A$.
[2] Coefficient of thermal conductivity = the thermal conductivity $\lambda$ of a gas divided by the thermal conductivity $\lambda_A$ of air.
[3] at constant pressure [4] at constant volume [5] at 5.3 bar

# Periodic table of the elements

| Period | Main groups I A | II A | Transition elements III B | IV B | V B | VI B | VII B | VIII B | | | I B | II B | Main groups III A | IV A | V A | VI A | VII A | VIII A |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 H Hydrogen 1.008 | | | | | | | | | | | | | | | | | 2 He Helium 4.002 |
| 2 | 3 Li Lithium 6.941 | 4 Be Beryllium 9.012 | | | | | | | | | | | 5 B Boron 10.811 | 6 C Carbon 12.011 | 7 N Nitrogen 14.007 | 8 O Oxygen 15.999 | 9 F Fluorine 18.998 | 10 Ne Neon 20.179 |
| 3 | 11 Na Sodium 22.989 | 12 Mg Magnesium 24.305 | | | | | | | | | | | 13 Al Aluminum 26.982 | 14 Si Silicon 28.086 | 15 P Phosphorus 30.974 | 16 S Sulfur 32.066 | 17 Cl Chlorine 35.453 | 18 Ar Argon 39.948 |
| 4 | 19 K Potassium 39.102 | 20 Ca Calcium 40.078 | 21 Sc Scandium 44.950 | 22 Ti Titanium 47.880 | 23 V Vanadium 50.942 | 24 Cr Chromium 51.996 | 25 Mn Manganese 54.938 | 26 Fe Iron 55.847 | 27 Co Cobalt 58.933 | 28 Ni Nickel 58.690 | 29 Cu Copper 63.546 | 30 Zn Zinc 65.390 | 31 Ga Gallium 69.732 | 32 Ge Germanium 75.590 | 33 As Arsenic 74.922 | 34 Se Selenium 78.960 | 35 Br Bromine 79.904 | 36 Kr Krypton 83.800 |
| 5 | 37 Rb Rubidium 85.468 | 38 Sr Strontium 87.620 | 39 Y Yttrium 88.906 | 40 Zr Zirconium 91.224 | 41 Nb Niobium 92.906 | 42 Mo Molybdenum 95.940 | 43 Tc Technetium (98) | 44 Ru Ruthenium 101.070 | 45 Rh Rhodium 102.906 | 46 Pd Palladium 106.420 | 47 Ag Silver 107.868 | 48 Cd Cadmium 112.410 | 49 In Indium 114.820 | 50 Sn Tin 118.710 | 51 Sb Antimony 121.750 | 52 Te Tellurium 127.600 | 53 I Iodine 126.905 | 54 Xe Xenon 131.290 |
| 6 | 55 Cs Cesium 132.905 | 56 Ba Barium 137.340 | * 71 Lu Lutecium 174.967 | 72 Hf Hafnium 178.490 | 73 Ta Tantalum 180.948 | 74 W Tungsten 183.850 | 75 Re Rhenium 186.207 | 76 Os Osmium 190.200 | 77 Ir Iridium 192.200 | 78 Pt Platinum 195.080 | 79 Au Gold 196.967 | 80 Hg Mercury 200.590 | 81 Tl Thallium 204.383 | 82 Pb Lead 207.200 | 83 Bi Bismuth 208.980 | 84 Po Polonium 210 | 85 At Astatine 210 | 86 Rn Radon 222 |
| 7 | 87 Fr Francium 223 | 88 Ra Radium 226.025 | † 103 Lr Lawrencium (260) | 104 Rf Rutherfordium* (261) | 105 Ha Hahnium* (262) | 106 Sg Seaborgium* (263) | 107 Ns Nielsbohrium* (264) | 108 Hs Hassium* (265) | 109 Mt Meitnerium* (268) | | | | | | | | | |

* Only name suggestions exist for elements 104 to 109.
* Element 104: also Kurtschatovium (Ku) or Dubnium (Db);
* Element 105: also Joliotium; * Element 106: also Unilhexium (Unh);
* Element 107: also Bohrium (Bh) or Unilsptium (Uns);
* Element 108: also Hahnium (Hn) or Uniloctium (Uno);
* Element 109: also Unilenneadium (Une)

Atomic number (= proton number) — 11 Na — Letter symbols
Sodium — Element name; state at 273 K (0 °C) and 1.013 bar:
Relative atomic mass — 22.989
solid: black print
liquid: brown print
gaseous: blue print
Radioactive elements in red, e.g. 222
Synthetic elements in parentheses, e.g. (261)

[1] Light metals $\varrho \leq 5$ kg/dm³; Heavy non-ferrous metals $\varrho > 5$ kg/dm³

| | | | |
|---|---|---|---|
| Nonmetals | * Lanthanides 57–71 | 57 La Lanthanum 138.906 | 58 Ce Cerium 140.120 | 59 Pr Praseodymium 140.908 | 60 Nd Neodymium 144.240 | 61 Pm Promethium 145 | 62 Sm Samarium 150.360 | 63 Eu Europium 151.960 | 64 Gd Gadolinium 157.250 | 65 Tb Terbium 158.925 | 66 Dy Dysprosium 162.500 | 67 Ho Holmium 164.930 | 68 Er Erbium 167.260 | 69 Tm Thulium 168.934 | 70 Yb Ytterbium 173.040 |
| Metalloids | † Actinides 89–103 | 89 Ac Actinium 227.028 | 90 Th Thorium 232.038 | 91 Pa Protactinium 231.036 | 92 U Uranium 238.029 | 93 Np Neptunium 237 | 94 Pu Plutonium 244 | 95 Am Americium (243) | 96 Cm Curium (247) | 97 Bk Berkelium (247) | 98 Cf Californium (251) | 99 Es Einsteinium (252) | 100 Fm Fermium (257) | 101 Md Mendelevium (258) | 102 No Nobelium (259) |
| Light metals[1] | | | | | | | | | | | | | | | |
| Heavy metals[1] | | | | | | | | | | | | | | | |
| Precious metals | | | | | | | | | | | | | | | |
| Halogens | | | | | | | | | | | | | | | |
| Noble gases | | | | | | | | | | | | | | | |

# Chemicals used in metal technology, molecular groups, pH value

## Important chemicals used in metal technology

| Technical designation | Chemical designation | Formula | Properties | Use |
|---|---|---|---|---|
| Acetone | Acetone (propanone) | $(CH_3)_2CO$ | Colorless, combustible, lightly volatile liquid | Solvent for paint, acetylene and plastics |
| Acetylene | Acetylene, Ethane | $C_2H_2$ | Highly reactive, colorless gas, highly explosive | Fuel for welding, source material for plastics |
| Aqueous cleaner | Various surfactants | —COO⁻<br>—$OSO_3^-$<br>—$SO_3^-$ | Various water soluble substances | Solvent, cleaning agent; emulsifying and thickening agent |
| Carbonic acid | Carbon dioxide | $CO_2$ | Water soluble, non-combustible gas, solidifies at −78 °C | Shielding gas for MAG welding, dry ice as refrigerant |
| Carbon tetrachloride | Carbon tetrachloride | $CCl_4$ | Colorless, non-combustible liquid, harmful to health | Solvent for fats, oils and paint |
| Cleaning agent | Organic solvent | $C_nH_{2n+2}$ | Colorless, sometimes lightly combustible liquids | Solvent for fats and oils, cleaning agent |
| Copper vitriol | Copper sulfate | $CuSO_4$ | Blue, water soluble crystal, moderately toxic | Electroplating baths, pest control, for scribing |
| Corundum | Aluminum oxide | $Al_2O_3$ | Very hard colorless crystal, melting point 2050 °C | Grinding and polishing agent, oxide ceramic materials |
| Ethyl alcohol | Ethyl alcohol, denatured | $C_2H_5OH$ | Colorless, lightly combustible liquid, boiling point 78 °C | Solvent, cleaning agent, for heating purposes, fuel additive |
| Hydrochloric acid | Hydrochloric acid | HCl | Colorless, pungent smelling, strong acid | Etching and pickling of metals, manufacture of chemicals |
| Nitric acid | Nitric acid | $HNO_3$ | Very strong acid, dissolves metals (except precious metals) | Etching and pickling of metals, manufacture of chemicals |
| Soda | Sodium carbonate | $Na_2CO_3$ | Colorless crystal, slightly water soluble, basic | Degreasing and cleaning baths, water softening |
| Spirits of ammonia | Ammonium hydroxide | $NH_4OH$ | Colorless, pungent smelling liquid, weak lye | Cleaning agent (fat solvent), neutralization of acids |
| Sulfuric acid | Sulfuric acid | $H_2SO_4$ | Colorless, oily, odorless liquid, strong acid | Pickling of metals, electroplating baths, storage batteries |
| Table salt | Sodium chloride | NaCl | Colorless, crystalline salt, slightly water soluble | Condiment, for freezing mixtures, for chlorine extraction |

## Frequently occurring molecular groups

| Molecular group Designation | Formula | Description | Example Designation | Formula |
|---|---|---|---|---|
| Carbide | =C | Carbon compounds; to some extent very hard | Silicon carbide | SiC |
| Carbonate | $=CO_3$ | Compounds of carbonic acid, addition of heat yields $CO_2$ | Calcium carbonate | $CaCO_3$ |
| Chloride | −Cl | Salts of the hydrochloric acids; usu. dissolve readily in water | Sodium chloride | NaCl |
| Hydroxide | −OH | Hydroxides are produced from metal oxides and water; behave as basics | Calcium hydroxide | $Ca(OH)_2$ |
| Nitrate | $-NO_3$ | Salts of the nitric acids; usu. dissolve readily in water | Potassium nitrate | $KNO_3$ |
| Nitride | =N | Nitrogen compounds; some of them are very hard | Silicone nitride | SiN |
| Oxide | =O | Oxygen compounds; most commonly occurring molecular group on earth | Aluminum oxide | $Al_2O_3$ |
| Sulfate | $=SO_4$ | Salts of the sulfuric acids; usu. dissolve readily in water | Copper sulfate | $CuSO_4$ |
| Sulfide | =S | Sulfur compounds; important ores, chip breaker in free cutting steels | Iron(II) sulfide | FeS |

## pH value

| Type of aqueous solution | ← increasingly acidic | | | | | | | neutral | increasingly basic → | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| pH value | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| Concentration $H^+$ in mol/l | $10^0$ | $10^{-1}$ | $10^{-2}$ | $10^{-3}$ | $10^{-4}$ | $10^{-5}$ | $10^{-6}$ | $10^{-7}$ | $10^{-8}$ | $10^{-9}$ | $10^{-10}$ | $10^{-11}$ | $10^{-12}$ | $10^{-13}$ | $10^{-14}$ |

# Definition and classification of steel

cf. DIN EN 10020 (2000-07)

**Steel** — Alloy with iron as the main component and a carbon content under 2.0 %.

**Microstructure** — The **microstructural components**, e.g. ferrite, pearlite, carbides, and the **crystalline structure**, e.g. fine grain, coarse grain, bands, determine the **steel properties**, e.g. strength, toughness, workability, machinability, weldability.

Influenced by

**Steel manufacture**

| Composition | Degree of purity | Deoxidation |
|---|---|---|
| – carbon content<br>– alloying elements | – non-metallic inclusions<br>– phosphorus and sulfur content | rimmed, semi-killed or killed cast |

**Subsequent processing**

For example:

- **Forming**: rolling, stamping, drawing, bending etc.
- **Heat treatment**: quenching and tempering, surface hardening etc.
- **Annealing**: normalizing, spheroidizing, full annealing etc.
- **Joining**: welding, brazing etc.
- **Coating**: galvanizing etc.

Classification

**Unalloyed steels**

No alloying element reached the limit value according to **table 1**

**Alloy steels**

- at least one alloying element reaches the limit value according to **table 1**
- steel types not conforming to the definition for stainless steels

**Stainless steels**[2]

- chrome content at least 10.5 %
- carbon content maximum 1.2 %

Classification by main characteristics into

- corrosion-resistant steels (pages 136, 137)
- heat resistant steels
- high-temperature steels

Classification[1]

**Quality steels** | **High-grade steels**

High-grade steels differ from quality steels due to:

- more careful production
- higher degree of purity
- improved deoxidation
- more exact composition
- improved hardenability

**Table 1: Limit values for unalloyed steels**

| Element | % | Element | % | Element | % |
|---|---|---|---|---|---|
| Al | 0.30 | Mn | 1.65 | Se | 0.10 |
| Bi | 0.10 | Mo | 0.08 | Si | 0.60 |
| Co | 0.30 | Nb | 0.06 | Ti | 0.05 |
| Cu | 0.40 | Ni | 0.30 | V | 0.10 |
| Cr | 0.30 | Pb | 0.40 | W | 0.30 |

**Main grades**

| Unalloyed quality steels | | Alloy quality steels | |
|---|---|---|---|
| Steel group (excerpt) | Example | Steel group (excerpt) | Example |
| Unalloyed structural steels | S235JR | Rail steels | R0900Mn |
| Unalloyed steels for quenching & tempering | C45 | Magnetic steel sheet and strip | M390-50E |
| Free cutting steels | 10S20 | Microalloyed steels with high yield strengths | H400M |
| Weldable unalloyed fine-grain steels | S275N | Phosphorus alloyed steels with high yield strengths | H180P |
| Unalloyed press. vessel steels | P235GH | | |

| Unalloyed high-grade steels | | Alloy high-grade steels | |
|---|---|---|---|
| Steel group (excerpt) | Example | Steel group (excerpt) | Example |
| Unalloyed steels for quenching and tempering | C45E | Alloy steels for quenching and tempering | 42CrMo4 |
| Unalloyed case hard. steels | C15E | Case hardening alloy steels | 16MnCr5 |
| Unalloyed tool steels | C45U | Nitriding steels | 34CrAlNi7 |
| Unalloyed steels for flame and induction hardening | C60E | Alloy tool steels | X40Cr14 |
| | | High-speed steels | HS6-5-2-5 |

[1] The main grade "Basic steels" was omitted. All previous basic steels are produced as quality steels.

[2] The stainless steels have their own group. They are alloy steels, so they are not classified as quality or high-grade steels.

# Designation of steels using material numbers

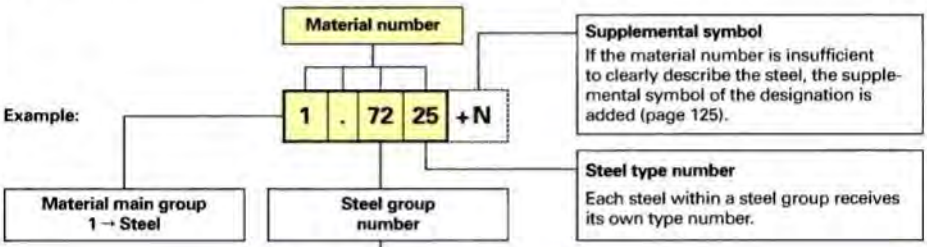
## Material numbers

cf. DIN EN 10027-2 (1992-09), replaces DIN 17007[1)]

Steel designations (page 122) or material numbers are used to identify and differentiate steels.

| Designation of steel (examples): | Designation | | Material number (with additional symbol +N) |
|---|---|---|---|
| | 42CrMo4+N | or | 1.7225+N |

The material numbers consist of a 6-character number (five numeric characters and a decimal point). They are better suited for data processing than designations.




### Unalloyed steels

| Steel group number | Steel groups[2)] |
|---|---|
| | **Quality steels** |
| 01, 91 | General structural steels, $R_m < 500$ N/mm² |
| 02, 92 | Other structural steels not specified for heat treatment with $R_m < 500$ N/mm² |
| 03, 93 | Steels with C < 0.12% or $R_m < 400$ N/mm² |
| 04, 94 | Steels with 0.12% ≤ C < 0.25% or 400 N/mm² ≤ $R_m$ < 500 N/mm² |
| 05, 95 | Steels with 0.25% ≤ C < 0.55% or 500 N/mm² ≤ $R_m$ < 700 N/mm² |
| 06, 96 | Steels with C ≥ 0.55% or $R_m \geq 700$ N/mm² |
| 07, 97 | Steels with high phosphorus and sulfur content |
| | **High-grade steels** |
| 10 | Steels with special physical properties |
| 11 | Structural, machine and vessel steels with C < 0.5% |
| 12 | Machine steels with C ≥ 0.5% |
| 13 | Structural, machine and vessel steels with special requirements |
| 15–18 | Unalloyed tool steels |

### Alloy steels

| Steel group number | Steel groups |
|---|---|
| | **Quality steels** |
| 08, 98 | Steels with special physical properties |
| 09, 99 | Steels for various areas of application |
| | **High-grade steels** |
| 20–28 | Alloy tool steels |
| 32 | High-speed steels with cobalt |
| 33 | High-speed steels without cobalt |
| 35 | Roller bearing steels |
| 36, 37 | Steels with special magnetic properties |
| 38, 39 | Steels with special physical properties |
| 40–45 | Stainless steels |
| | Nickel alloys, chemical resistant, high-temperature |
| 47, 48 | Heat resistant steels |
| 49 | High-temperature materials |
| 50–84 | Structural, machine and vessel steels with various alloy combinations |
| 85 | Nitriding steels |
| 87–89 | High-strength weldable steels |

[1)] The material numbers remained unchanged with the conversion from DIN 17007 to DIN EN 10027-2.

[2)] C carbon, $R_m$ tensile strength
Values for tensile strength $R_m$ and for carbon content C are mean values.

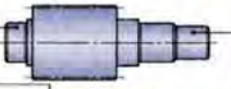
# Designation system for steels

cf. DIN EN 10027-1 (2005-10)

## Designation by application

The codes for steels are composed of main and supplemental symbols. Main symbols reflect the application or chemical composition. Supplemental symbols depend on to the steel or product group.

Example: Pinion shaft



| Main symbol | Suppl. symbol | Material (examples) | | Material blank |
|---|---|---|---|---|
| S355JR+AR | | Unalloyed structural steel | 42CrMo4+N | Hot-rolled round steel bar |
| Designation | | Steel group | Designation according to the chemical composition (page 124) | |
| DIN EN 10027-1 | | DIN EN 10025-2 | | DIN EN 10060 |

## Main symbols for the designation by application

| Application | Main symbol[1] | | Application | Main symbol[1] | |
|---|---|---|---|---|---|
| Steels for steel construction | S | 235[2] | Prestressing steels | Y | 1770[3] |
| Steels for machine construction | E | 360[2] | Flat rolled products for cold working | D | X52[4] |
| Steels for pressure vessel construction | P | 265[2] | Rail steels | R | 260[5] |
| Steels for pipes and tubes | L | 360[2] | Flat products of high-strength steels | H | C400[6] |
| Concrete reinforcing steels | B | 500[2] | Magnetic steel, sheet and strip | M | 400-50[7] |
| Packaging steel, sheet and strip | T | S550[2] | To identify **cast steel**, the main symbol is preceded by the letter **G**. | | |

[1] The main symbol is composed of the code letter and a number and may include an additional letter.
[2] Yield strength $R_e$ for the smallest product thickness
[3] Nominal value for minimum tensile strength $R_m$
[4] As-rolled condition C, D, X followed by two symbols
[5] Minimum hardness in accordance with Brinell HBW
[6] As-rolled condition C, D, X and minimum yield strength $R_e$ or as-rolled condition CT, DT, XT and minimum tensile strength $R_m$
[7] Maximum magnetic hysteresis loss in W/kg x 100 and nominal thickness x 100 separated by a hyphen

### Steels for steel construction

Designation example: **S 235 JR+N**

- S: Code letter for steel construction
- 235: Yield strength $R_e$ for smallest product thickness
- JR+N: Supplemental symbols

| Product group (selection) | Standard | Supplemental symbols |
|---|---|---|
| Hot-rolled unalloyed structural steels | DIN EN 10025-2 | Notch impact energy in J at °C: JR 27 20° J2 27 −20°; J0 27 0° K2 40 −20°. C special cold workability; +AR delivered in as-rolled condition; +N normalized |
| Normalized/normalizing rolled, grain-refined structural steels suitable for welding | DIN EN 10025-3 | N normalized or normalizing rolled, notch impact energy values at −20 °C.<br>NL like N, but notch impact energy values at −50 °C |
| Thermomechanically rolled structural steels suitable for welding | DIN EN 10025-4 | M thermomechanically rolled, notch impact energy values at −20 °C<br>ML like M, but with notch impact energy values at −50 °C |
| Hot-rolled structural steels with higher yield strength in the quenched and tempered state | DIN EN 10025-6 | Q quenched and tempered, notch impact energy values at −20 °C<br>QL quenched and tempered, notch impact energy values at −40 °C<br>QL1 quenched and tempered, notch impact energy values at −60 °C |
| Steels for bright steel products | DIN EN 10277-1, 2 | C special cold workability<br>+C drawn +PL polished<br>+SH peeled +SL ground |
| Hot-rolled hollow sections of unalloyed structural steels and grain-refined structural steels | DIN EN 10210-1 | JR, J0, J2 and K2 as with DIN EN 10025-2<br>N, NL as with DIN EN 10025-3<br>H hollow section |

⇒ **S235JR+N:** Steel-construction steel $R_e$ = 235 N/mm², notch impact energy 27 J at −20 °C, normalized (+N)

# Designation system for steels

cf. DIN EN 10027-1 (2005-10)

## Steels for machine construction

Designation example: **E 355 +AR**

- **E** – Code letter for machine construction
- **355** – Yield strength for the smallest product thickness
- **+AR** – Supplemental symbols

| Product group (selection) | Standard | Supplemental symbols |
|---|---|---|
| Hot-rolled unalloyed structural steels | DIN EN 10025-2 | GC special cold workability<br>+AR delivered in as-rolled condition +N normalized |
| Steels for bright steel products | DIN EN 10277-1, 2 | GC special cold workability<br>+C drawn +PL polished<br>+SH peeled +SL ground |
| Pipes and tubes, seamless, cold-drawn | DIN EN 10305-1 | +A annealed +C bright-drawn/hard +LC brigth-drawn/soft<br>+N normalized +SR bright-drawn and stress relieved |
| Seamless tubes made of unalloyed and alloyed steel | DIN EN 10297-1 | J2 notch impact energy values at –20 °C<br>K2 notch impact energy values at –40 °C<br>+AR delivered in as-rolled condition +N normalized +QT quenched and tempered |

⇒ **E355+AR:** machine construction steel, yield strength $R_e$ = 355 N/mm², delivered in as-rolled condition (+AR)

## Flat products for cold working

Designation example: **D C 04 – A – m**

- **D** – Code letter for flat product for cold working
- **C** – Code letter for rolling condition (X rolling condition not specified, C cold-rolled, D hot-rolled)
- **04** – Code number for the type of steel, main properties page 141
- **A – m** – Supplemental symbols (product-group specific definition)

| Product group (selection) | Standard | Supplemental symbols |
|---|---|---|
| Cold-rolled flat products made of soft steels for cold working | DIN EN 10130 | **Surface type and finish**<br>A Faults not affecting workability and adhesion of surface coating are permissible.<br>B The better face must be flawless to the extent that the look of quality lacquer finish or coating is not affected.<br>b particularly smooth g smooth m dull r rough |
| Continuously hot-dip finished strip and sheet made of soft steels for cold working | DIN EN 10327 | D hot-dip coating<br>**Coating** (followed by coating mass in g/m², e.g. Z140)<br>+AS aluminum-silicon alloy +AZ aluminum-zinc alloy<br>+Z zinc +ZA zinc-aluminum alloy +ZF zinc-iron alloy<br>**Coating finish:** M small zinc flower with +Z<br>N typical zinc flower with +Z R typical finish with +ZF<br>**Type of surface:** A typical finish<br>B improved finish C best finish |

⇒ **DC04 – A – m:** Flat product for cold working (D), cold-rolled (C), steel type 04 (page 141), surface type A, surface finish dull (m)

## Flat products made of high-strength steels for cold working

Designation example: **H C 300 – B – g**

- **H** – Code letter for flat product of high-strength steel for cold working
- **C** – Code letter for rolling condition (X rolling condition not specified, C cold-rolled, D hot-rolled)
- **300** – 300 yield strength $R_e$ = 300 N/mm², T500 minimum tensile strength $R_m$ = 500 N/mm²
- **B – g** – Supplemental symbols (product group-specific definition)

| Product group (selection) | Standard | Supplemental symbols |
|---|---|---|
| Cold-rolled strip and sheet made of micro-alloy steels | DIN EN 10268 | B bake-hardening steel Y high-strength I-F steel I isotropic steel<br>P phosphor-alloy steel LA low-alloy/micro-alloy steel<br>**Surface type and finish**<br>for rolling width < 600 mm as with DIN EN 10139<br>for rolling width ≥ 600 mm as with DIN EN 10130 |

⇒ **HCT500 – B – g:** Cold-rolled flat product made of high-strength steel (H), cold-rolled (C), minimum tensile strength $R_m$ = 500 N/mm² (T500), surface type B, smooth surface (g)

# Designation system for steels

cf. DIN EN 10027-1 (2005-10)

## Designation by chemical composition

The main symbols reflect the chemical composition and are created on the basis of four different designation groups. The supplemental symbols depend on the steel group or product group.

Example: Pinion shaft



| Main symbol | Suppl. symbol | Material (examples) | | | Material blank |
|---|---|---|---|---|---|
| 42CrMo4 | +N | Quenched and tempered steel | | S355JR+AR | Hot-rolled round steel bar |
| Designation | | Steel group | | Designation according to the application (page 122) | |
| DIN EN 10027-1 | | DIN EN 10083-1 | | | DIN EN 10060 |

## Designation groups, examples and application of the main symbols[1)]

| Unalloyed steels<br>manganese content < 1% except free-cutting steels | Alloy steels, free-cutting steels<br>unalloyed steels with a manganese content > 1% | Alloy steels<br>average content of individual alloying element above 5% | High-speed steels<br>HS 10-4-3-10 |
|---|---|---|---|
| C15E | 42CrMo4 | X12CrNi18-8 | Code letter for high-speed steel |
| **Application examples:**<br>unalloyed case-hardening steels,<br>unalloyed quenched and tempered steels,<br>unalloyed tool steels | **Application examples:**<br>free-cutting steels,<br>case-hardening alloy steels,<br>quenched and tempered alloy steels,<br>tool alloy steels,<br>spring steels | **Application examples:**<br>**Stainless steels**<br>corrosion-resistant, heat-resistant, high-temperature steels<br>**Tool steels:**<br>cold work steels<br>hot work steels | Content of alloying elements in percent in the following order W-Mo-V-Co<br>10 → 10% tungsten (W)<br>4 → 4% molybdenum (Mo)<br>3 → 3% vanadium (V)<br>10 → 10% cobalt (Co) |

[1)] To identify cast steel, the main symbol is preceded by the letter **G**; to identify powder metallurgical steel, the main symbol is preceded by the letters **PM**.

### Unalloyed steels with a manganese content < 1%, except free-cutting steels

Designation example: **C15 E+S+BC**

| Main symbols | Supplemental symbols |
|---|---|
| C code letter (carbon steel)<br>15 code number for the carbon content<br>$C_{medium}$ = 15/100 ≙ 0.15% | Refer to such aspects as special applications, control of the sulphur content, special cold workability, heat treatment states. The definition of the supplemental symbols varies according to the steel group (page 125). |

⇒ **C45E+S+BC:** quenched and tempered unalloyed steel, C content 0.45%, prescribed max. sulphur content (E), treated for shearability (+S), blasted (+BC) (supplemental symbols on page 125, quenched & tempered steels)

### Alloy steels, free-cutting steels, unalloyed steels with a manganese content > 1%

Designation example: **18CrNiMo7-6 +TH+BC**

| Main symbols | Supplemental symbols |
|---|---|
| 18 code number for the carbon content<br>$C_{medium}$ = 18/100 ≙ 0.18%<br>Cr, Ni, Mo alloying elements (in the order of their mass portion)<br>7-6 Alloy contents<br>$Cr_{medium}$ = 7/4 ≙ 1.75%<br>$Ni_{medium}$ = 6/4 ≙ 1.5%<br>Mo = low content | Refer to such aspects as special applications, heat treatment states, quenching stress, surface finish, degree of deformation. The definition of the supplemental symbols varies according to the steel group (page 125). |

| Factors for alloy contents | |
|---|---|
| Alloying elements | Factor |
| Cr, Co, Mn, Ni, Si, W | 4 |
| Al, Be, Cu, Mo, Nb, Pb, Ta, Ti, V, Zr | 10 |
| C, Ce, N, P, S | 100 |
| B | 1000 |

⇒ **17CrNiMo6-4+TH+BC:** Case-hardening alloy steel, C content 0.17% (17), Cr content of 1.5% (6), Ni content 1.0% (4), low Mo content, treated for quenching stress (+TH) and blasted (+BC) (supplemental symbols on page 125, case-hardening steels)

# Designation system for steels

cf. DIN EN 10027-1 (2005-10)

| Steel group/ product group (selection) | Standard | Supplemental symbols |
|---|---|---|
| Hot-worked case-hardening steels | DIN EN 10084 | E prescribed maximum sulphur content<br>R prescribed sulphur content range<br>+H normal hardenability +HH restricted hardness tolerance, upper range<br>+HL restricted hardness tolerance, lower range<br>**Treatment conditions:**<br>+A soft-annealed +S treated for shearability<br>+FP treated for ferrite-pearlite microstructure and quenching stress<br>+U untreated +TH treated for quenching stress<br>**Surface finish:**<br>+BC blasted +HW hot worked +PI pickled |
| Hot-worked quenched and tempered steels | DIN EN 10083-1 10083-2 | E, R as with care-hardening steels as per DIN EN 10084 (above)<br>**Treatment conditions**<br>+A soft-annealed +H normal hardenability +N normalized<br>+HL restricted hardness tolerance, lower range<br>+HH restricted hardness tolerance, upper range<br>+QT quenched and tempered +S treated for shearability +U untreated<br>**Surface finish:**<br>+BC blasted +HW hot-worked +P pickled<br>+RM hot-worked and pre-machined |
| Hot-worked free-cutting steels | DIN EN 10087 | Under normal conditions, no supplemental symbols provided (in special cases for direct quenching types: +QT quenched and tempered) |
| Bright steel products made of case-hardening steel, quenched & tempered steel, free-cutting steel | DIN EN 10277-1 10277,3..5 | +C cold-drawn +SH peeled<br>+SL ground +PL polished |
| Seamless steel tubes made of case-hardening steels and quenched & tempered steels | DIN EN 10297-1 | +A soft-annealed +AR as rolled +N normalized<br>+FP treated for ferrite-pearlite microstructure and quenching stress<br>+QT quenched & tempered +TH treated for quenching stress |

⇒ **16MnCr5+A:** Case-hardening alloy steel, C content 0.16% (16), Mn content 1.25% (5), low Cr content, soft-annealed (+A)

**Alloy steels, the content of at least one alloying element is above 5%** (without high-speed steels)

Designation example: **X4CrNi18-12 +2D**

**Main symbols**

X code letter for the designation group
4 code number for medium carbon content
$C_{medium}$ = 4/100 = 0.04%
Cr, Ni main alloying elements (Cr > Ni)
18-12 alloy contents in %
chromium = 18%, nickel = 12%

**Supplemental symbols**

Specification of heat treatment conditions, the rolling condition, the type of execution, the surface finish.
The definition of the supplemental symbols varies according to the product group.

| Steel group/ product group (selection) | Standard | Supplemental symbols (selection) | |
|---|---|---|---|
| | | Treatment condition | Type of execution/surface finish |
| Hot-rolled corrosion-resistant sheets and strips | DIN EN 10088-2 | +A annealed<br>+QT quenched & tempered<br>+QT650 quenched & tempered to $R_m$ = 650 N/mm²<br>+AT solution annealed<br>+P precipitation hardened<br>+P1300 precipitation hardened to $R_m$ = 1300 N/mm²<br>+SR stress relieved annealed | +1 hot-rolled products<br>1U not heat-treated, not descaled<br>1C heat treated, not descaled<br>1E heat treated, mechanically descaled<br>1D heat treated, pickled, smooth<br>1G ground |
| Cold-rolled corrosion-resistant sheets and strips | DIN EN 10088-2 | | +2 cold-rolled products<br>2C, E, D, G as with hot-rolled products<br>2B like D but cold-rolled in addition<br>2R bright-annealed<br>2Q hardened and tempered, scale-free<br>2H strain-hardened (with different hardness stages), bright surface |

⇒ **X2CrNi18-9+AT+2D:** Alloy steel, C content 0.02% (2), Cr content 18%, Ni content 9%, solution annealed (+AT), cold-rolled (+2), hot-treated, pickled, smooth surface (D)

# Steels – Overview

| Subgroups, delivery conditions | Standard | Main characteristics | Areas of application | Product forms[1] S | B | P | W |
|---|---|---|---|---|---|---|---|
| **Unalloyed structural steels, hot-rolled** | | | | | | | page 130 |
| Steels for steel and machine construction | DIN EN 10025-2 | • good machinability<br>• weldable, except for S185<br>• cold and hot workable | Welded constructions in steel and machine construction, simple machine parts | • | • | • | • |
| Steels for machine construction | | • machinable<br>• not weldable<br>• cold and hot workable | Machine parts without heat treatment, e.g. by hardening, quenching and tempering | • | • | – | • |
| **Fine-grain steels suitable for welding** | | | | | | | page 131 |
| Normalized | DIN EN 10025-3 | • weldable<br>• hot workable | Weldments with high toughness, resistance to brittle fracture and aging stability in machine and steel construction | • | • | • | • |
| Thermomechanically rolled | DIN EN 10025-4 | • weldable<br>• not hot workable | | • | • | – | • |
| **Quenched and tempered structural steels with high yield strength** | | | | | | | page 131 |
| Alloy steels | DIN EN 10025-6 | • weldable<br>• hot workable | High-strength weldments in machine and steel constructions | • | – | – | – |
| **Case hardened steels** | | | | | | | page 132 |
| Unalloyed steels | DIN EN 10084 | • in spheroidized condition good machinability<br>• hot workable<br>• after surface carburization surface hardenable | Small parts with wear-resistant surface | • | • | – | • |
| Alloy steels | | | Dynamically stressed parts with wear-resistant surface | • | • | – | • |
| **Quenched and tempered steels** | | | | | | | page 133 |
| Unalloyed quality steels | DIN EN 10083-2 | • in spheroidized condition good machinability<br>• hot workable<br>• hardenable (uncertain results with unalloyed quality steels) | Parts with high strength, which are not hardened | • | • | – | • |
| Unalloyed high-grade steels | | | Parts with high strength and good toughness | • | • | – | • |
| Alloy steels | DIN EN 10083-3 | | Highly stressed parts with good toughness | • | • | – | • |
| **Steels for flame and induction hardening** | | | | | | | page 134 |
| Unalloyed steels | DIN EN 10083-2, | • in spheroidized condition good machinability<br>• hot workable<br>• directly hardenable; possible to harden individual workpiece areas, e.g. tooth faces<br>• quenching and tempering of workpieces before hardening | Parts with low core strength but hardening of specific areas | • | • | – | • |
| Alloy steels | DIN EN 10083-3 | | Larger parts with high core strength and hardening of specific areas | • | • | – | • |
| **Nitriding steels** | | | | | | | page 134 |
| Alloy steels | DIN EN 10085 | • in spheroidized condition good machinability<br>• hardenable by nitride forming elements, lowest quenching distortion<br>• quenching and tempering of workpieces before nitriding | Parts with increased fatigue strength, parts subject to wear, Parts subjected to temperatures up to 500 °C | • | • | – | • |
| **Spring steels** | | | | | | | page 138 |
| Unalloyed and alloy steels | DIN EN 10270 DIN EN 10089 | • cold or hot workable<br>• high elastic formability<br>• high fatigue strength | Leaf springs, helical springs, disc springs, torsion bars | – | – | – | • |

[1] Product forms: S sheets, strips; B bars, e.g. flat, square and round bars; W wires; P profiles, e.g. channels, angles, tees

# Steels – Overview

| Subgroups, delivery conditions | Standard | Main characteristics | Areas of application | Product forms[1] S | B | P | W |
|---|---|---|---|---|---|---|---|
| **Free cutting steels** | | | | | | | page 134 |
| Non-heat-treatable steels | DIN EN 10087 | • optimal machinability (short chipping)<br>• non-weldable<br>• might not respond uniformly to heat treatment with case hardening or quench and tempering | Mass produced turned parts with low strength requirements | – | • | – | • |
| Free cutting case hardened steels | DIN EN 10087 | | Like unalloyed case hardened steels; better machinability | – | • | – | • |
| Free cutting quenched and tempered steels | DIN EN 10087 | | Like unalloyed quenched and tempered steels; better machinability, less fatigue strength | – | • | – | • |
| **Tool steels** | | | | | | | page 135 |
| Cold work steels, unalloyed | DIN EN ISO 4957 | • in spheroidized condition good machinability<br>• non-cutting cold and hot-workable<br>• full hardening up to max. 10 mm diameter | Low stressed tools for cutting and non-cutting forming at operating temperatures up to 200 °C | • | • | • | • |
| Cold work steels, alloy | DIN EN ISO 4957 | • in spheroidized condition machinable<br>• hot workable<br>• larger case hardening depth, higher strength, more wear-resistant than unalloyed cold work steels | Highly stressed tools for cutting and non-cutting forming at operating temperatures over 200 °C | • | • | – | • |
| Hot work steels | DIN EN ISO 4957 | • in spheroidized condition machinable<br>• hot workable<br>• hardens over the entire cross section | Tools for non-cutting forming at operating temperatures over 200 °C | • | • | – | • |
| High-speed steels | DIN EN ISO 4957 | • in spheroidized condition machinable<br>• hot workable<br>• hardens over the entire cross section | Cutting materials for cutting tools, operating temperatures up to 600 °C, highly stressed forming tools | • | • | – | • |
| **Corrosion resistant steels** | | | | | | | pages 136, 137 |
| Ferritic steels | DIN EN 10088-2, DIN EN 10088-3 | • machinable<br>• good cold-workable<br>• weldable<br>• heat treatment does not increase strength | Low stressed rust-free parts; parts with high resistance to chlorine induced stress, corrosion cracking | • | • | • | • |
| Austenitic steels | DIN EN 10088-2, DIN EN 10088-3 | • machinable<br>• very good cold workability<br>• weldable<br>• no increase in strength through heat treatment | Non-rusting parts with high corrosion resistance, widest application range of all stainless steels | • | • | • | • |
| Martensitic steels | DIN EN 10088-2, DIN EN 10088-3 | • machinable<br>• in spheroidized condition cold-workable<br>• with low carbon content weldable<br>• heat treatable | Highly stressed non-rusting parts, which can also be quenched and tempered | • | • | • | • |

[1] Product forms: S sheets, strip; B bars, e.g. flat, square and round bars; W wires; P profiles, e.g. channels, angles, tees

# Selecting structural steels by application

**Unalloyed steels**

Heat treatment, e.g. hardening or quenching and tempering not intended

Heat treatment intended (page 129)

**Selection by application**

Main characteristics are determined by

| Example: unalloyed structural steels (page 130) | | Composition • carbon (C) • manganese (Mn) • silicon (Si) • copper (Cu) maximum values in % | | | | Purity grade • phosphorus (P) • sulphur (S) • nitrogen (N) maximum values in % | | | Deoxidation |
|---|---|---|---|---|---|---|---|---|---|
| Minimum requirements | Type of steel, designation | C | Mn | Si | Cu | P | S | N | DO[1] |
| • strength | S185 | not specified | | | | not specified | | | – |
| • strength<br>• toughness | E295, E335, E360 | not specified | | | | 0.045 | 0.045 | 0.014 | FN |
| • strength<br>• toughness<br>• weldability | S235JR | 0.17 | 1.40 | – | 0.35 | 0.035 | 0.035 | 0.012 | FN |
| | S275JR | 0.21 | 1.50 | – | | | | | |
| | S355JR | 0.24 | 1.60 | 0.55 | | | | | |
| • strength<br>• higher toughness<br>• weldability | S235J0 | 0.17 | 1.40 | – | 0.55 | 0.030 | 0.030 | 0.012 | FN |
| | S275J0 | 0.18 | 1.50 | – | | | | | |
| | S355J0 | 0.20 | 1.60 | 0.55 | 0.55 | 0.030 | 0.030 | 0.012 | FN |
| | S450J0[2] | 0.20 | 1.70 | 0.55 | | | | 0.025 | FF |
| • strength<br>• highest toughness<br>• weldability | S235J2 | 0.17 | 1.40 | – | 0.55 | 0.025 | 0.025 | 0.012 | FF |
| | S275J2 | 0,18 | 1,50 | – | | | | | |
| | S355J2 | 0.20 | 1.60 | 0.55 | 0.55 | 0.025 | 0.025 | – | FF |
| | S355K2 | 0.20 | 1.60 | 0.55 | | | | | |

More steel groups, e.g.

- cold-rolled flat products of high-strength steels
- flat products for cold working
- pressure vessel steels
- packaging steel sheet and strip
- steels for pipes and tubes
- concrete reinforcing steels
- prestressing steels
- magnetic steel sheet

Required properties are not achieved

For selection according to chemical composition, see page 129

[1] DO type of deoxidation: FN semi-killed steel; FF killed steel with nitrogen binding elements
[2] Additional alloying elements: niobium 0.06% max.; vanadium 0.15% max.; titanium 0.06% max.

# Selecting structural steels by chemical composition

**Unalloyed steels**

Heat treatment provided, e.g. hardening or quench and tempering — yes

no → page 128 or

**Selection according to carbon content**

**Main properties are determined by**

| Minimum requirements | Steel group | Designation | Composition • carbon (C) • manganese (Mn) • silicon (Si) • other alloying elements (L) | Purity grade • phosphorus (P) • sulfur (S) | Deoxidation DO[2] |
|---|---|---|---|---|---|

| | | | C in % | Mn in % | Si in % | L[1] in % | $P_{max}$ in % | $S_{max}$ in % | DO |
|---|---|---|---|---|---|---|---|---|---|
| • heat treatment | Case hardened steels[3] | C10 | 0.10 | 0.45 | 0.40 | – | 0.045 | 0.045 | FN |
| | | C15 | 0.15 | 0.45 | | – | | | FN |
| | Quenched and tempered steels | C35 | 0.35 | 0.65 | | 0.63 | | | FN |
| | | C60 | 0.60 | 0.75 | | | | | FN |
| • heat treatment with proven values | Case hardened steels | C10E | 0.10 | 0.45 | 0.40 | – | 0.035 | 0.035 | FN |
| | | C15E | 0.15 | 0.45 | | – | | | FN |
| | Quenched and tempered steels | C35E | 0.35 | 0.65 | | 0.63 | | | FN |
| | | C60E | 0.60 | 0.75 | | | | | FN |

Further requirements → Alloy steels

1) L Maximum percentage (Cr + Mo + Ni)
2) DO Type of deoxidation: FN semi-killed cast
3) The steels C10 and C15 are no longer included in the standard case hardened steels DIN EN 10084. However, they are still available from specialty dealers.

**Effect of alloying elements** (selection)

| Properties influenced by alloying elements | Alloying elements Cr | Ni | Al | W | V | Co | Mo | Si | Mn | S | P |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Tensile strength | ● | ● | – | ● | ● | ● | ● | ● | ● | – | ● |
| Yield strength | ● | ● | – | ● | ● | ● | ● | ● | ● | – | ● |
| Impact toughness | ○ | – | ○ | – | ● | ○ | ● | ○ | – | ○ | ○ |
| Wear-resistance | ● | ○ | – | ● | ● | ● | ● | ○ | ○ | – | – |
| Hot workability | ○ | ● | ○ | ○ | ● | ○ | ● | ○ | ● | ○ | – |
| Cold workability | – | – | – | ○ | – | ○ | ○ | ○ | ○ | ○ | ○ |
| Machinability | – | ○ | – | ○ | – | – | ○ | ○ | ○ | ● | ● |
| High-temperature strength | ● | ● | – | ● | ● | ● | ● | ● | – | – | – |
| Corrosion resistance | ● | – | – | – | ● | – | – | – | – | ○ | – |
| Hardening temperature | ● | – | – | ● | ● | – | ● | ● | ○ | – | – |
| Hardenability, temperability | ● | ● | – | ● | ● | ● | ● | ● | ● | – | – |
| Nitridability | ● | – | ● | ● | ● | – | ● | ○ | ● | – | – |
| Weldability | ○ | ○ | ● | – | ● | – | ○ | – | ○ | ○ | ○ |

● **increase** ○ **decrease** – **no significant effect**

**Example:** Gears, case hardened, rough parts drop forged, reliable heat treatment is required
**Wanted:** Suitable steels
**Solution:** Heat treatment (case hardening) provided → case hardened steel, C ≤ 0.2 %
The properties of unalloyed quality and high-grade steels are insufficient → alloy steels
Increase of hot workability: Mn, V; increase of hardenability: Cr, Ni
Steel selection: 16MnCr5, 20MnCr5, 15NiCr13 (page 132)

# Unalloyed structural steels

## Unalloyed structural steels, hot-rolled

cf. DIN EN 10025-2 (2005-04), replaces DIN EN 10025

| Steel type: Designation | Material number | DO[1] | Notch impact energy: at °C | KV J | Tensile strength $R_m$[2] N/mm² | Yield strength $R_e$ in N/mm² for product thickness in mm: ≤ 16 | > 16 ≤ 40 | > 40 ≤ 63 | > 63 ≤ 80 | Elongation at fracture $A$[3] % | Properties, application |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Structural and machine construction steels** | | | | | | | | | | | |
| S185 | 1.0035 | – | – | – | 290–510 | 185 | 175 | 175 | 175 | 18 | Non-weldable, simple steel constructions |
| S235JR | 1.0038 | FN | 20 | | | | | | | | Basic machine parts, weldments in steel and machine construction; levers, bolts, axles, shafts |
| S235J0 | 1.0114 | FN | 0 | 27 | 360–510 | 235 | 225 | 215 | 215 | 26 | |
| S235J2 | 1.0117 | FF | –20 | | | | | | | | |
| S275JR | 1.0044 | FN | 20 | | | | | | | | |
| S275J0 | 1.0143 | FN | 0 | 27 | 410–560 | 275 | 265 | 255 | 245 | 23 | |
| S275J2 | 1.0145 | FF | –20 | | | | | | | | |
| S355JR | 1.0045 | FN | 20 | | | | | | | | Highly stressed weldments in steel, crane and bridge construction |
| S355J0 | 1.0553 | FN | 0 | 27 | 470–630 | 355 | 345 | 335 | 325 | 22 | |
| S355J2 | 1.0577 | FF | –20 | | | | | | | | |
| S355K2 | 1.0596 | FF | –20 | 40 | 470–630 | 355 | 345 | 335 | 325 | 22 | |
| S450J0 | 1.0590 | FF | 0 | 27 | 550–720 | 450 | 430 | 410 | 390 | 17 | |
| **Steels for machine construction** | | | | | | | | | | | |
| E295 | 1.0050 | FN | – | – | 470–610 | 295 | 285 | 275 | 265 | 20 | Axles, shafts, bolts |
| E335 | 1.0060 | FN | – | – | 570–710 | 335 | 325 | 315 | 305 | 16 | Wear parts; pinion gears, worms, spindles |
| E360 | 1.0070 | FN | – | – | 670–830 | 360 | 355 | 345 | 335 | 11 | |

[1] DO Type of deoxidation: – manufacturer's option; FF killed cast steel.
FN semi-killed cast steel;

[2] Values apply to product thicknesses from 3 mm to 100 mm.

[3] Values apply to product thicknesses from 3 mm to 40 mm and longitudinal test pieces with $L_0 = 5.65 \cdot \sqrt{S_0}$ (page 190)

The steel types listed in the table are unalloyed quality steels acc. to DIN EN 10020 (page 120)

### Technical properties

#### Weldability

Steels of grade groups JR – J0 – J2– K2 are weldable using all processes.
Increased strength and product thickness also increase the risk of cold cracks.
Steels S185, E295, E335 and E360 are not weldable, because the chemical composition is not specified.

#### Hot workability

The steels are hot workable. Only products which are ordered and delivered in normalized (+N) or normalizing rolled (+N) condition must meet the requirements of the above table. The treatment condition must be specified at the time of ordering.
Example: S235J0+N or 1.0114+N

#### Cold workability

The additional C or GC symbol is appended to the designation of a steel type suitable for cold working (edge folding, roll forming, cold-drawing), and these types are also assigned their own material number.

#### Steel types for cold working

| Designation | Material number | Suitable for[1] F | R | C | Designation | Material number | Suitable for[1] F | R | C | Designation | Material number | Suitable for[1] F | R | C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S235JRC | 1.0122 | | | | S275JRC | 1.0128 | | | | S355J0C | 1.0554 | | | |
| S235J0C | 1.0115 | • | • | • | S275J0C | 1.0140 | • | • | • | S355J2C | 1.0579 | • | • | • |
| S235J2C | 1.0119 | | | | S275J2C | 1.0142 | | | | S355K2C | 1.0594 | | | |
| E295GC | 1.0533 | – | – | • | E335GC | 1.0543 | – | – | • | E360GC | 1.0633 | – | – | • |

[1] Forming process: F edge folding: R roll forming: C cold drawing: • well-suited – unsuitable

# Weldable fine-grain and quenched & tempered structural steels

## Weldable fine-grained structural steels (selection)

cf. DIN EN 10025-3 and DIN EN 10025-4 (2005-04), replaces DIN EN 10113

| Steel type: Designation | Material number | DC[1] | Notch impact energy $KV^{2)}$ in J at temperatures in °C: +20 | 0 | −20 | Tensile strength $R_m$ N/mm² | Yield strength $R_e$ in N/mm² for nominal thicknesses in mm: ≤ 16 | > 16 ≤ 40 | > 40 ≤ 63 | Elongation at fracture $A$ % | Properties, application |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Unalloyed quality steels** | | | | | | | | | | | |
| S275N | 1.0490 | N | 55 | 47 | 40 | 370–510 | 275 | 265 | 255 | 24 | High toughness, brittle fracture and aging resistant; weldments in machinery, crane and bridge construction, automotive manufacturing, conveyors |
| S275M | 1.8818 | M | | | | 370–530 | | | | | |
| S355N | 1.0545 | N | 55 | 47 | 40 | 470–630 | 355 | 345 | 335 | 22 | |
| S355M | 1.8823 | M | | | | | | | | | |
| **Alloy high-grade steels** | | | | | | | | | | | |
| S420N | 1.8902 | N | 55 | 47 | 40 | 520–680 | 420 | 400 | 390 | 19 | |
| S420M | 1.8825 | M | | | | | | | | | |
| S460N | 1.8901 | N | 55 | 47 | 40 | 550–720 | 460 | 440 | 430 | 17 | |
| S460M | 1.8827 | M | | | | 540–720 | | | | | |

1) DC Delivery condition: N normalized/normalizing rolled M thermomechanically rolled
2) Values apply to V-notch longitudinal test pieces.
Assignment of steels: DIN EN 10025-3 → S275N, S355N, S420N, S460N
DIN EN 10025-4 → S275M, S355M, S420M, S460M

### Technical properties

| Weldability | Hot workability | Cold workability |
|---|---|---|
| The steels are weldable. Increased strength and product thickness also increase the risk of cold cracks. | Only steels S275N, S355N, S420N and S480N are hot workable. | Cold-bending or edge folding is guaranteed for nominal thicknesses up to 16 mm, if cold-workability is specified in the order. |

## Quenched and tempered struc. steels with higher yield strength (selection)

cf. DIN EN 10025-6 (2005-02), replaces DIN EN 10137-2

| Steel type: Designation[1] | Material number | Notch impact energy $KV$ in J at temperatures in °C: 0 | −20 | −40 | Tensile strength $R_m$ N/mm² | Yield strength $R_e$ in N/mm² for nominal thicknesses in mm: > 3 ≤ 50 | > 50 ≤ 100 | > 100 ≤ 150 | Elongation at fracture $A$ % | Properties, application |
|---|---|---|---|---|---|---|---|---|---|---|
| S460Q | 1.8908 | 40 | 30 | – | 550–720 | 460 | 440 | 400 | 17 | High toughness, high resistance to brittle fracture and aging stability; highly stressed weldments in machinery, crane and bridge construction, automotive manufacturing, conveyors |
| S460QL | 1.8906 | 50 | 40 | 30 | | | | | | |
| S500Q | 1.8924 | 40 | 30 | – | 590–770 | 500 | 480 | 440 | 17 | |
| S500QL | 1.8909 | 50 | 40 | 30 | | | | | | |
| S620Q | 1.8914 | 40 | 30 | – | 700–890 | 620 | 580 | 560 | 15 | |
| S620QL | 1.8927 | 50 | 40 | 30 | | | | | | |
| S890Q | 1.8940 | 40 | 30 | – | 940–1100 | 890 | 830 | – | 11 | |
| S890QL | 1.8983 | 50 | 40 | 30 | | | | | | |
| S960Q | 1.8941 | 40 | 30 | – | 980–1150 | 960 | – | – | 10 | |
| S960QL | 1.8933 | 50 | 40 | 30 | | | | | | |

1) Q quenched and tempered; QL quenched and tempered, guaranteed minimum values for notched bar impact values to −40 °C

### Technical properties

| Weldability | Hot workability | Cold workability |
|---|---|---|
| The steels are not weldable without limitations. Professional planning of the welding parameters is required. Increased strength and product thickness also increase the risk of cold cracks. | The steels are hot workable up to the temperature limit for stress relief annealing. | Cold-bending or edge folding is guaranteed for nominal thicknesses up to 16 mm, if cold-workability is specified in the order. |

# Case hardened steels, unalloyed and alloy

## Case hardened steels (selection)

cf. DIN EN 10084 (2008-06)

| Steel type: Designation[1] | Material number | Hardness HB in delivery condition[2]: +A | +FP | Core properties after case hardening[3]: Tensile strength $R_m$ N/mm² | Yield strength $R_e$ N/mm² | Elong. at fracture $A$ % | Hardening method[4]: D | S | Properties, applications |
|---|---|---|---|---|---|---|---|---|---|
| **Unalloyed case hardened steels** | | | | | | | | | |
| C10E<br>C10R | 1.1121<br>1.1207 | 131 | 90–125 | 49–640 | 295 | 16 | • | • | Small parts with average stress; levers, pegs, bolts, rollers, spindles, pressed and stamped parts |
| C15E<br>C15R | 1.1141<br>1.1140 | 143 | 103–140 | 590–780 | 355 | – | • | • | |
| **Alloy case hardened steels** | | | | | | | | | |
| 17Cr3<br>17CrS3 | 1.7016<br>1.7014 | 174 | – | 700–900 | 450 | 11 | • | • | Parts subject to alternating stresses, e.g. in gearbox; gears, bevel and ring gears, driving pinions, shafts, propellershafts |
| 28Cr4<br>28CrS4 | 1.7030<br>1.7036 | 217 | 156–207 | ≥ 700 | – | – | • | • | |
| 16MnCr5<br>16MnCrS5 | 1.7131<br>1.7139 | 207 | 140–187 | 780–1080<br>780–1080 | 590<br>590 | 10<br>10 | ○ | • | |
| 16NiCr4<br>16NiCrS4 | 1.5714<br>1.5715 | 217 | 156–207 | ≥ 900 | – | – | – | • | |
| 18CrMo4<br>18CrMoS4 | 1.7243<br>1.7244 | 207 | 140–187 | ≥ 900 | – | – | ○ | • | |
| 20MoCr3<br>20MoCrS3 | 1.7320<br>1.7319 | 217 | 145–185 | ≥ 900 | – | – | • | – | |
| 20MoCr4<br>20MoCrS4 | 1.7321<br>1.7323 | 207 | 140–187 | 880–1180 | 590 | 10 | • | – | |
| 17CrNi6-6<br>22CrMoS3-3 | 1.5918<br>1.7333 | 229<br>217 | 156–207<br>152–201 | ≥ 1100<br>– | –<br>– | –<br>– | –<br>○ | •<br>• | |
| 15NiCr13<br>10NiCr5-4 | 1.5752<br>1.5805 | 229<br>192 | 166–207<br>137–187 | 920–1230<br>≥ 900 | 785<br>– | 10<br>– | –<br>– | •<br>• | Parts subject to highly alternating stresses, e.g. in gearbox; gears, bevel and ring gears, driving pinion, shafts, propellershafts |
| 20NiCrMo2-2<br>20NiCrMoS2-2 | 1.6523<br>1.6526 | 212 | 149–194 | 780–1080 | 590 | 10 | • | • | |
| 17NiCrMo6-4<br>17NiCrMoS6-4<br>20NiCrMoS6-4 | 1.6566<br>1.6569<br>1.6571 | 229 | 149–201<br>149–201<br>154–207 | ≥ 1000<br>≥ 1000<br>≥ 1100 | –<br>–<br>– | –<br>–<br>– | – | • | |
| 20MnCr5<br>20MnCrS5 | 1.7147<br>1.7149 | 217 | 152–201 | 980–1270 | 685 | 8 | □ | • | Parts subject to larger dimensions; pinion shafts, gears, ring gears |
| 18NiCr5-4<br>14NiCrMo13-4<br>18CrNiMo7-6 | 1.5810<br>1.6657<br>1.6587 | 223<br>241<br>229 | 156–207<br>166–217<br>159–207 | ≥ 1100<br>1030–1390<br>1060–1320 | –<br>–<br>785 | –<br>10<br>8 | –<br>–<br>– | •<br>•<br>• | |

[1] Steel types with added sulfur, e.g. 16MnCrS5, have an improved machinability.

[2] Delivery condition: +A spheroidized; +FP treated for ferrite-pearlite microstructure and hardness range

[3] Strength values are valid for test pieces with 30 mm nominal diameter.

[4] Hardening methods:

D Direct hardening: The workpieces are quenched directly from the carburizing temperature.

S Simple hardening: After carburizing the workpieces are usually left to cool at room temperature. For hardening they are reheated.

• well-suited ○ conditionally suitable – unsuitable

For heat treatment of case hardened steels, see page 155

# Quenched and tempered steels, unalloyed and alloy

## Quenched and tempered steels (selection)

cf. DIN EN 10083-2 and DIN EN 10083-3

| Steel type: Designation | Material number | T[1] | Strength values for rolled diameter $d$ in mm: Tensile strength $R_m$ in N/mm² > 16 ≤ 40 | Tensile strength $R_m$ in N/mm² > 40 ≤ 100 | Yield strength $R_e$ in N/mm² > 16 ≤ 40 | Yield strength $R_e$ in N/mm² > 40 ≤ 100 | Elongation at fracture $EL$ in % > 16 ≤ 40 | Elongation at fracture $EL$ in % > 40 ≤ 100 | Properties, applications |
|---|---|---|---|---|---|---|---|---|---|
| **Unalloyed quenched and tempered steels[2]** | | | | | | | | | cf. DIN EN 10083-2 (2006-10) |
| C22E | 1.1151 | +N | 410 | 410 | 210 | 210 | 25 | 25 | Parts subject to lower stresses and small quench and tempering diameters; screws, bolts, axles, shafts, gears |
| | | +QT | 470–620 | – | 290 | – | 22 | – | |
| C35 | 1.0501 | +N | 520 | 520 | 270 | 270 | 19 | 19 | |
| C35E | 1.1181 | +QT | 600–750 | 550–700 | 380 | 320 | 19 | 20 | |
| C45 | 1.0503 | +N | 580 | 580 | 305 | 305 | 16 | 16 | |
| C45E | 1.1191 | +QT | 650–800 | 630–780 | 430 | 370 | 16 | 17 | |
| C55 | 1.0535 | +N | 640 | 640 | 330 | 330 | 12 | 12 | |
| C55E | 1.1203 | +QT | 750–900 | 700–850 | 490 | 420 | 14 | 15 | |
| C60 | 1.0601 | +N | 670 | 670 | 340 | 340 | 11 | 11 | |
| C60E | 1.1221 | +QT | 800–950 | 750–900 | 520 | 450 | 13 | 14 | |
| 28Mn6 | 1.1170 | +N | 600 | 600 | 310 | 310 | 18 | 18 | |
| | | +QT | 700–850 | 650–800 | 490 | 440 | 15 | 16 | |
| **Alloy quenched and tempered steels** | | | | | | | | | cf. DIN EN 10083-3 (2007-01) |
| 38Cr2 | 1.7003 | +QT | 700–850 | 600–750 | 450 | 350 | 15 | 17 | Parts subject to higher stresses and larger quenched and tempered diameters; drive shafts, worms, gears |
| 46Cr2 | 1.7006 | | 800–950 | 650–800 | 550 | 400 | 14 | 15 | |
| 34Cr4 | 1.7033 | +QT | 800–950 | 700–850 | 590 | 460 | 14 | 15 | |
| 37Cr4 | 1.7034 | | 850–1000 | 750–900 | 630 | 510 | 13 | 14 | |
| 25CrMo4 | 1.7218 | +QT | 800–950 | 700–850 | 600 | 450 | 14 | 15 | |
| 25CrMoS4 | 1.7213 | | | | | | | | |
| 41Cr4 | 1.7035 | +QT | 900–1100 | 800–950 | 660 | 560 | 12 | 14 | Parts subject to high stresses and larger quenched and tempered diameters; shafts, gears, larger forged parts |
| 41CrS4 | 1.7039 | | | | | | | | |
| 34CrMo4 | 1.7220 | +QT | 900–1100 | 800–950 | 650 | 550 | 12 | 14 | |
| 34CrMoS4 | 1.7226 | | | | | | | | |
| 42CrMo4 | 1.7225 | +QT | 1000–1200 | 900–1100 | 750 | 650 | 11 | 12 | |
| 42CrMoS4 | 1.7227 | | | | | | | | |
| 50CrMo4 | 1.7228 | +QT | 1000–1200 | 900–1100 | 780 | 700 | 10 | 12 | |
| 51CrV4 | 1.8159 | | | | 800 | | | | |
| 30NiCrMo16-6 | 1.6747 | +QT | 1080–1230 | 1080–1230 | 880 | 880 | 10 | 10 | Parts subject to highest stresses and large quenched and tempered diameters |
| 34CrNiMo6 | 1.6582 | | 1100–1300 | 1000–1200 | 900 | 900 | | 11 | |
| 36NiCrMo16 | 1.6773 | +QT | 1250–1450 | 1100–1300 | 1050 | 900 | 9 | 10 | |
| 30CrNiMo8 | 1.6580 | | | | | | | | |
| 20MnB5 | 1.5530 | +QT | 750–900 | – | 600 | – | 15 | – | |
| 30MnB5 | 1.5531 | | 800–950 | – | 650 | – | 13 | – | |
| 27MnCrB5-2 | 1.7182 | +QT | 900–1150 | 800–1000 | 750 | 700 | 14 | 15 | |
| 39MnCrB6-2 | 1.7189 | | 1050–1250 | 1000–1200 | 850 | 800 | 12 | 12 | |

[1] T treatment condition: +N normalized; +QT quenched and tempered

For unalloyed quenched and tempered steels the treatment conditions +N and +QT also apply to the quality and high-grade steels, for example for C45 and C45E.

[2] Unalloyed quenched and tempered steels C35, C45, C55 and C60 are quality steels, steels C22E, C35E, C45E, C55E and C60E are produced as high-grade steels.

For heat treatment of quenched and tempered steels, see page 156

# Nitriding steels, Steels for flame and induction hardening, Free cutting steels

## Nitriding steels (selection)

cf. DIN EN 10085 (2001-07), replaces DIN 17211

| Steel type: Designation | Material number | Spheroidized hardness HB | Tensile strength[1] $R_m$ N/mm² | Yield strength[1] $R_e$ N/mm² | Elongation at fracture[1] $EL$ % | Properties, applications |
|---|---|---|---|---|---|---|
| 31CrMo12 | 1.8515 | 248 | 980–1180 | 785 | 11 | Wear parts up to 250 mm thickness |
| 31CrMoV9 | 1.8519 | 248 | 1000–1200 | 800 | 10 | Wear parts up to 100 mm thickness |
| 34CrAlMo5-10 | 1.8507 | 248 | 800–1000 | 600 | 14 | Wear parts up to 80 mm thickness |
| 40CrAlMo7-10 | 1.8509 | 248 | 900–1100 | 720 | 13 | High-temperature wear parts up to 500 °C |
| 34CrAlNi7-10 | 1.8550 | 248 | 850–1050 | 650 | 12 | Large parts; piston rods, spindles |

[1] Strength values: The values for tensile strength $R_m$, yield strength $R_e$ and elongation at fracture $EL$ apply to material thicknesses from 40 to 100 mm in the quenched and tempered condition.

For heat treatment of nitriding steels, see page 157

## Steels for flame and induction hardening (selection)

cf. DIN EN 10083[1]

| Steel type: Designation | Material number | Spheroidized hardness HB | T[2] | Tensile strength[2] $R_m$ N/mm² | Yield strength $R_e$ in N/mm² for nominal thicknesses in mm: ≤ 16 | > 16 ≤ 40 | > 40 ≤ 100 | Elongation at fracture $EL$ % | Properties, applications |
|---|---|---|---|---|---|---|---|---|---|
| C45E[1] | 1.1191 | 207 | +QT | 650–800 | 490 | 430 | 370 | 16 | Wear parts with high core strength and good toughness; crank shafts, drive shafts, cam shafts, worms, gears |
| C60E[1] | 1.1221 | 241 | | 800–950 | 580 | 520 | 450 | 13 | |
| 37Cr4 | 1.7034 | 255 | +QT | 850–1000 | 750 | 630 | 510 | 14 | |
| 46Cr2 | 1.7006 | | | 800–950 | 650 | 550 | 400 | 13 | |
| 41Cr4 | 1.7035 | 255 | +QT | 900–1100 | 800 | 660 | 560 | 12 | |
| 42CrMo4 | 1.7225 | | | 1000–1200 | 900 | 750 | 650 | 11 | |

[1] The previous standard DIN 17212 was withdrawn without replacement. For flame and induction hardenable steels, see quenched and tempered steels DIN EN 10083-3 (page 133). For unalloyed high-quality steels acc. to DIN EN 10083-2, hardness results are only assured if the steels are ordered with austenite grain size ≤ 5.

[2] T treatment condition: +QT quenched and tempered

For heat treatment of steels for flame and induction hardening, see page 156

## Free cutting steels (selection)

cf. DIN EN 10087 (1999-01)

| Steel type: Designation[1] | Material number | T[2] | For product thicknesses from 16 to 40 mm: Hardness HB | Tensile strength $R_m$ N/mm² | Yield strength $R_e$ N/mm² | Elongation at fracture $EL$ % | Properties, applications |
|---|---|---|---|---|---|---|---|
| 11SMn30 | 1.0715 | +U | 112–169 | 380–570 | – | – | • Steels unsuitable for heat treatment<br>Small parts subject to low stress; levers, pegs |
| 11SMnPb30 | 1.0718 | | | | | | |
| 11SMn37 | 1.0736 | +U | 112–169 | 380–570 | – | – | |
| 11SMnPb37 | 1.0737 | | | | | | |
| 10S20 | 1.0721 | +U | 107–156 | 360–530 | – | – | • Case hardened steels<br>Wear-resistant small parts; shafts, bolts, pins |
| 10SPb20 | 1.0722 | | | | | | |
| 15SMn13 | 1.0725 | +U | 128–178 | 430–600 | – | – | |
| 35S20 | 1.0726 | +U | 154–201 | 520–680 | – | – | • Quenched and tempered steels<br>Larger parts subject to higher stress; spindles, shafts, gears |
| 35SPb20 | 1.0756 | +QT | – | 600–750 | 380 | 16 | |
| 44SMn28 | 1.0762 | +U | 187–238 | 630–800 | – | – | |
| 44SMnPb28 | 1.0763 | +QT | – | 700–850 | 420 | 16 | |
| 46S20 | 1.0727 | +U | 175–225 | 590–760 | – | – | |
| 46SPb20 | 1.0757 | +QT | – | 650–800 | 430 | 13 | |

[1] Steel types with lead additives, e.g. 11SMnPb30, have better machinability.

[2] T treatment condition: +U untreated; +QT quenched and tempered

All free cutting steels are unalloyed quality steels. It is not possible to guarantee a uniform response to case hardening or quench and tempering.

For heat treatment of free cutting steels, see page 157

# Cold work steels, Hot work steels, High-speed steels

**Tool steels** (selection) cf. DIN EN ISO 4957 (2001-02), replaces DIN 17350

| Steel type: Designation | Material number | Hardness HB[1] max. | Hardening temperature °C | QM[2] | Tempering temperat. °C | Application examples, properties |
|---|---|---|---|---|---|---|
| **Cold work steels, unalloyed** | | | | | | |
| C45U | 1.1730 | 190 | 800–830 | O | 180–300 | Non-hardened mounted parts for tools, screwdrivers, chisels, knives |
| C70U | 1.1520 | 190 | 790–820 | O | 180–300 | Centering pins, small dies, vise jaws, trimming press |
| C80U | 1.1525 | 190 | 780–810 | W | 180–300 | Dies with flat cavities, chisels, cold extruding dies, knives |
| C105U | 1.1545 | 213 | 770–800 | W | 180–300 | Simple cutting tools, coining dies, scribers, piercing plugs, twist drills |
| **Cold work steels, alloy** | | | | | | |
| 21MnCr5 | 1.2162 | 215 | 810–840 | O | 150–180 | Complex case hardened press forms for plastics; easily polished |
| 60WCrV8 | 1.2550 | 230 | 880–930 | O | 180–300 | Cutters for steel sheet from 6 to 15 mm, cold punching dies, chisels, center punches |
| 90MnCrV8 | 1.2842 | 220 | 790–820 | O | 150–250 | Cutting dies, stamps, plastic stamping molds, reamers, measuring tools |
| 102Cr6 | 1.2067 | 230 | 820–850 | O | 100–180 | Drills, milling cutters, reamers, small cutting dies, turning centers for lathes |
| X38CrMo16 | 1.2316 | 250 | 1000–1040 | O | 650–700 | Tools for processing chemically aggressive thermoplastics |
| 40CrMnNiMo8-6-4 | 1.2738 | 235 | 840–870 | O | 180–220 | Plastic molds of all types |
| 45NiCrMo16 | 1.2767 | 260 | 840–870 | O, A | 160–250 | Bending and embossing tools, shearing blades for thick material |
| X153CrMoV12 | 1.2379 | 250 | 1020–1050 | O, A | 180–250 | Cutting tools sensitive to breaking, milling cutters, broaching tools, shearing blades |
| X210CrW12 | 1.2436 | 255 | 950–980 | O, A | 180–250 | High-performance cutting tools, broaching tools, stamping tools |
| **Hot work steels** | | | | | | |
| 55NiCrMoV7 | 1.2714 | 250 | 840–870 | O | 400–650 | Plastic molds, small and medium sized dies, hot shearing blades |
| X37CrMoV5-1 | 1.2343 | 235 | 1020–1050 | O, A | 550–650 | Die casting molds for light alloys, extrusion tools |
| 32CrMoV12-28 | 1.2365 | 230 | 1020–1050 | O, A | 500–670 | Die casting molds for heavy non-ferrous metals, extrusion tools for all metals |
| X38CrMoV5-3 | 1.2367 | 235 | 1030–1080 | O, A | 600–700 | High-quality dies, highly stressed tools for manufacture of screws |
| **High-speed steels** | | | | | | |
| HS6-5-2C | 1.3343 | 250 | 1190–1230 | O, A | 540–560 | Twist drills, reamers, milling cutters, thread cutters, circular saw blades |
| HS6-5-2-5 | 1.3243 | 270 | 1210–1250 | O, A | 550–570 | Highly stressed twist drills, milling cutters, roughing tools with high toughness |
| HS10-4-3-10 | 1.3207 | 270 | 1210–1250 | O, A | 550–570 | Lathe tools for automatic machining, high cutting capacity |
| HS2-9-2 | 1.3348 | 250 | 1190–1230 | O, A | 540–580 | Milling cutters, twist drills and thread cutters, high cutting hardness, high-temp. strength, toughness |

[1] Delivery condition: annealed [2] QM Quenching medium; W water; O oil; A air

For designations of tool steels, see page 125; for heat treatment of tool steels, see page 155

# Stainless steels

**Corrosion-resistant steels** (selection) cf. DIN EN 10088-2 and 10088-3 (2005-09)

| Steel type: Designation | Material number | D[1]: S | D[1]: B | DC[2] | Thickness $d$ mm | Tensile strength $R_m$ N/mm² | Yield strength $R_{p0,2}$ N/mm² | Elongation at fracture $EL$ % | Properties, applications |
|---|---|---|---|---|---|---|---|---|---|
| **Austenitic steels** | | | | | | | | | |
| X10CrNi18-8 | 1.4310 | • | | C | ≤ 8 | 600–950 | 250 | 40 | Springs for temperatures up to 300 °C, automotive manufacturing |
| | | | • | – | ≤ 40 | 500–750 | 195 | 40 | |
| X2CrNi18-9 | 1.4307 | • | | C | ≤ 8 | 520–700 | 220 | 45 | Household containers, chemical and food industry |
| | | • | | P | ≤ 75 | 500–650 | 200 | | |
| | | | • | – | ≤ 160 | 500–700 | 175 | 45 | |
| X2CrNiN19-11 | 1.4306 | • | | C | ≤ 8 | 520–700 | 220 | 45 | Equipment and parts exposed to organic and fruit acids |
| | | • | | P | ≤ 75 | 500–700 | 200 | | |
| | | | • | – | ≤ 160 | 460–680 | 180 | 45 | |
| X2CrNi18-10 | 1.4311 | • | | C | ≤ 8 | 550–750 | 290 | 40 | Equipment for the dairy and brewery industry, pressure vessels |
| | | • | | P | ≤ 75 | 540–750 | 270 | | |
| | | | • | – | ≤ 160 | 550–760 | 270 | 40 | |
| X5CrNi18-10 | 1.4301 | • | | C | ≤ 8 | 540–750 | 230 | 45 | Deep-drawn parts in the food industry, easily polished |
| | | • | | P | ≤ 75 | | 210 | | |
| | | | • | – | ≤ 160 | 500–700 | 190 | 45 | |
| X8CrNiS18-9 | 1.4305 | • | | P | ≤ 75 | 500–700 | 190 | 35 | Parts in the food and dairy industry |
| | | | • | – | ≤ 160 | 500–750 | 190 | 35 | |
| X6CrNiTi18-10 | 1.4541 | • | | C | ≤ 8 | 520–720 | 220 | 40 | Consumer goods used in the household, parts in the photo industry |
| | | • | | P | ≤ 75 | 500–700 | 200 | | |
| | | | • | – | ≤ 160 | 500–700 | 190 | 40 | |
| X4CrNi18-12 | 1.4303 | • | | C | ≤ 8 | 500–650 | 220 | 45 | Chemical industry; bolts, nuts |
| | | | • | – | ≤ 160 | 500–700 | 190 | 45 | |
| X5CrNiMo17-12-2 | 1.4401 | • | | C | ≤ 8 | 530–680 | 240 | 40 | Parts in the paint, oil and textile industry |
| | | • | | P | ≤ 75 | 520–670 | 220 | 45 | |
| | | | • | – | ≤ 160 | 500–700 | 200 | 40 | |
| X6CrNiMoTi17-12-2 | 1.4571 | • | | C | ≤ 8 | 540–690 | 240 | 40 | Parts in the textile, synthetic resin and rubber industry |
| | | • | | P | ≤ 75 | 520–670 | 220 | | |
| | | | • | – | ≤ 160 | 500–700 | 200 | 40 | |
| X2CrNiMo18-14-3 | 1.4435 | • | | C | ≤ 8 | 550–700 | 240 | 40 | Parts with improved chemical resistance for the pulp industry |
| | | • | | P | ≤ 75 | 520–670 | 220 | 45 | |
| | | | • | – | ≤ 160 | 500–700 | 200 | 40 | |
| X2CrNiMoN17-13-3 | 1.4429 | • | | C | ≤ 8 | 580–780 | 300 | 35 | Pressure vessels with increased chemical resistance |
| | | • | | P | ≤ 75 | | 280 | 40 | |
| | | | • | – | ≤ 160 | 580–800 | 280 | 35 | |
| X2CrNiMoN17-13-5 | 1.4439 | • | | C | ≤ 8 | 580–780 | 290 | 35 | Resistant to chlorine and higher temperatures; chemical industry |
| | | • | | P | ≤ 75 | | 270 | 40 | |
| | | | • | – | ≤ 160 | 580–800 | 280 | 35 | |
| X1NiCrMoCu25-20-5 | 1.4539 | • | | C | ≤ 8 | 530–730 | 240 | 35 | Resistant to phosphoric, sulfuric and hydrochloric acids; chemical industry |
| | | • | | P | ≤ 75 | 520–720 | 220 | | |
| | | | • | – | ≤ 160 | 700–800 | 200 | 35 | |

[1] D Delivery forms: S sheet, strip; B bars, profile

[2] DC Delivery condition: C cold-rolled strip; P hot-rolled sheet

# Stainless steels

## Corrosion-resistant steels (continued)

cf. DIN EN 10088-2 and 10088-3 (2005-09)

| Steel type: Designation | Material number | D[1]: S | D[1]: B | DC[2] | Thickness $d$ mm | Tensile strength $R_m$ N/mm² | Yield strength $R_{p0,2}$ N/mm² | Elongation at fracture $EL$ % | Properties, applications |
|---|---|---|---|---|---|---|---|---|---|
| **Ferritic steels** | | | | | | | | | |
| X2CrNi12 | 1.4003 | • | | C<br>P | ≤ 8<br>≤ 25 | 450–650 | 280<br>250 | 20<br>18 | Automotive and container manufacturing, conveyors |
| | | | • | – | ≤ 100 | 450–600 | 260 | 20 | |
| X6Cr13 | 1.4000 | •<br>• | | C<br>P | ≤ 8<br>≤ 25 | 400–600 | 240<br>220 | 19 | Resistant to water and steam; household equipment, fittings |
| | | | • | – | ≤ 25 | 400–630 | 230 | 20 | |
| X6Cr17 | 1.4016 | •<br>• | | C<br>P | ≤ 8<br>≤ 25 | 450–600 | 260<br>240 | 20 | Good cold workability, able to be polished; flatware, bumpers |
| | | | • | – | ≤ 100 | 400–630 | 240 | 20 | |
| X2CrTi12 | 1.4512 | • | | C | ≤ 8 | 450–650 | 280 | 23 | Catalytic converters |
| X6CrMo17-1 | 1.4113 | • | | C | ≤ 8 | 450–630 | 260 | 18 | Automotive manufacturing; trim, hub caps |
| | | | • | – | ≤ 100 | 440–660 | 280 | 18 | |
| X3CrTi17 | 1.4510 | • | | C | ≤ 8 | 450–600 | 260 | 20 | Welded parts in food industry |
| X2CrMoTi18-2 | 1.4521 | •<br>• | | C<br>P | ≤ 8<br>≤ 12 | 420–640<br>420–620 | 300<br>280 | 20 | Bolts, nuts, heaters |

[1] D Delivery forms: S sheet, strip; B bars, profile
[2] MF Mill finish: C cold-rolled strip; P hot-rolled sheet

**Martensitic steels**

| Steel type: Designation | Mat. no. | D[1]: S | D[1]: B | DC[2] | Thickness $d$ mm | H[3] | Tensile strength $R_m$ N/mm² | Yield strength $R_{p0,2}$ N/mm² | Elongation at fracture $EL$ % | Properties, applications |
|---|---|---|---|---|---|---|---|---|---|---|
| X12Cr13 | 1.4006 | •<br>• | | C<br>P | ≤ 8<br>≤ 75 | A<br>QT650 | ≤ 600<br>650–850 | –<br>450 | 20<br>12 | Resistant to water and steam, food industry |
| | | | • | – | ≤ 160 | QT650 | 650–850 | 450 | 15 | |
| X20Cr13 | 1.4021 | •<br>• | | C<br>P | ≤ 8<br>≤ 75 | A<br>QT750 | ≤ 700<br>750–950 | –<br>550 | 15<br>10 | Axles, shafts, pump parts, propellers |
| | | | • | – | ≤ 160 | QT800 | 800–950 | 600 | 12 | |
| X30Cr13 | 1.4028 | •<br>• | | C<br>P | ≤ 8<br>≤ 75 | A<br>QT800 | ≤ 740<br>800–1000 | –<br>600 | 15<br>10 | Bolts, nuts, springs, piston rods |
| | | | • | – | ≤ 160 | QT850 | 850–1000 | 650 | 10 | |
| X46Cr13 | 1.4034 | • | | C<br>– | ≤ 8<br>≤ 160 | A<br>QT800 | ≤ 780<br>850–1000 | 245<br>650 | 12<br>10 | Hardenable; table knives and machine knives |
| X39CrMo17-1 | 1.4122 | • | | C<br>– | ≤ 8<br>≤ 60 | A<br>QT900 | ≤ 900<br>900–1100 | 280<br>800 | 12<br>11 | Shafts, spindles, armatures up to 600 °C |
| X3CrNiMo13-4 | 1.4313 | • | | P | ≤ 75 | QT900 | 900–1100 | 800 | 11 | High toughness; pumps, turbine wheels, reactor construction |
| | | | •<br>• | – | –<br>≤ 160 | A<br>QT900 | ≤ 1100<br>900–1100 | 320<br>800 | –<br>12 | |

[1] D Delivery forms: S sheet, strip; B bars, profile
[2] DC Delivery condition: C cold-rolled strip; P hot-rolled sheet
[3] H Heat treatment condition: A solution annealed; QT750 → quenched and tempered to minimum tensile strength $R_m$ = 750 N/mm²

# Spring steel

## Steel wire for springs, patented drawn

cf. DIN EN 10270-1 (2001-12), replaces DIN 17223

| Wire type | Minimum tensile strength $R_m$ in N/mm² for the nominal diameter $d$ in mm | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0.5 | 0.8 | 1.0 | 1.5 | 2.0 | 2.5 | 3.0 | 3.4 | 4.0 | 4.5 | 5.0 | 6.0 | 8.0 | 10.0 | 15.0 | 20.0 |
| SL | – | – | 1720 | 1600 | 1510 | 1460 | 1410 | 1370 | 1320 | 1290 | 1260 | 1210 | 1120 | 1060 | – | – |
| SM | 2200 | 2050 | 1980 | 1850 | 1740 | 1690 | 1630 | 1590 | 1530 | 1500 | 1460 | 1400 | 1310 | 1240 | 1110 | 1020 |
| SH | 2480 | 2310 | 2330 | 2090 | 1970 | 1900 | 1840 | 1790 | 1740 | 1690 | 1660 | 1590 | 1490 | 1410 | 1270 | 1160 |
| DM | 2200 | 2050 | 1980 | 1850 | 1740 | 1690 | 1630 | 1590 | 1530 | 1500 | 1460 | 1400 | 1310 | 1240 | 1110 | 1020 |
| DH | 2480 | 2310 | 2230 | 2090 | 1970 | 1900 | 1840 | 1790 | 1740 | 1690 | 1660 | 1590 | 1490 | 1410 | 1270 | 1160 |

**Wire diameter $d$ in mm** (selection)

| | |
|---|---|
| all types, except SL[1] | 0.30 – 0.32 – 0.34 – 0.36 – 0.38 – 0.40 – 0.43 – 0.48 – 0.50 – 0.53 – 0.56 – 0.60 – 0.63 – 0.65 – 0.70 – 0.75 – 0.80 – 0.90 – 1.00 – 1.10 – 1.20 – 1.25 – 1.30 – 1.40 – 1.50 – 1.60 – 1.70 – 1.80 – 1.90 – 2.00 – 2.10 – 2.25 – 2.40 – 2.50 – 2.60 – 2.80 – 3.00 – 3.20 – 3.40 – 3.60 – 3.80 – 4.00 – 4.25 – 4.50 – 4.75 – 5.00 – 5.30 – 5.60 – 6.00 – 6.30 – 6.50 – 7.00 – 7.50 – 8.00 – 8.50 – 9.00 – 9.50 – 10.00 |

[1] Wire type SL is only supplied in diameters $d$ = 1 to 10 mm.

**Operating conditions, applications**

| Wire type | Suitable for springs with: | Applications |
|---|---|---|
| SL | Low static loading | Tension springs, compression springs, torsion springs in equipment and machine construction, wire type DH is also suitable for shaped springs. |
| SM | Moderate static **or**, less often, dynamic loading | |
| SH | High static **or** low dynamic loading | |
| DM | Moderate dynamic loading | |
| DH | High static **or** average dynamic loading | |

**Wire coatings, delivery forms**

| Designation | Wire surfaces | Letter symbol | Wire surfaces | Delivery forms |
|---|---|---|---|---|
| ph | phosphatize | Z | with zinc coating | • in coils or on spools<br>• straightened rods in bundles |
| cu | copper coated | ZA | with zinc/aluminum coating | |
| ⇒ | **Spring wire EN 10270-1 DM 3,4 ph:** Spring type DM, $d$ = 3,4 mm, phosphatized surface (ph) | | | |

## Hot-rolled steels for quenched and tempered springs

cf. DIN EN 10089 (2003-04), replaces DIN 17221

| Steel type | | Hot-rolled | Spheroidized +A | In quenched and tempered condition (+QT)[1] | | | Properties, applications |
|---|---|---|---|---|---|---|---|
| Designation | Material number | Hardness HB | Hardness HB | Tensile strength $R_m$ N/mm² | Yield strength $R_{p0,2}$ N/mm² | Elongation at fracture $EL$ % | |
| 38Si7 | 1.5023 | 240 | 217 | 1300–1600 | 1150 | 8 | Spring screw locks |
| 46Si7 | 1.5024 | 270 | 248 | 1400–1700 | 1250 | 7 | Leaf springs, helical springs |
| 55Cr3 | 1.7176 | > 310 | 248 | 1400–1700 | 1250 | 3 | Larger tension and compression springs |
| 54SiCr6 | 1.7102 | 310 | 248 | 1450–1750 | 1300 | 6 | Spring wire |
| 61SiCr7 | 1.7108 | 310 | 248 | 1550–1850 | 1400 | 5.5 | Leaf springs, helical springs |
| 51CrV4 | 1.8159 | > 310 | 248 | 1400–1700 | 1200 | 6 | Highly stressed springs |

Explanation [1] Strength values apply to test pieces with $d$ = 10 mm diameter.

⇒ **Round bar EN 10089 – 20 x 8000 – 51CrV4+A:** Bar diameter $d$ = 20 mm, bar length $l$ = 8000 mm, steel type 51CrV4, delivery condition spheroidized (+A)

| **Wire diameter $d$ in mm** (selection) | **Delivery forms** |
|---|---|
| 5.0 – 5.5 – 6.0 – 6.5 – 7.0 – 7.5 – 8.0 – 8.5 – 9.0 – 9.5 – 10.0 – 10.5 – 11.0 – 11.5 – 12.0 – 19.0 – 19.5 – 20.0 – 21.0 – 22.0 – 23.0 – 27.0 – 28.0 – 29.0 – 30.0 | • directional rods<br>• wire coils |

# Sheet and strip metal – Classification, overview

Classification according to

| Delivery form | |
|---|---|
| Type | Commercial formats |
| **Sheet**  | Usually rectangular plates in<br>small format: $w \times l$ = 1000 x 2000 mm<br>med. format: $w \times l$ = 1250 x 2500 mm<br>large format: $w \times l$ = 1500 x 3000 mm<br>Sheet thicknesses: $s$ = 0,14–250 mm |
| **Strip**  | Rolled (coils) continuous strip<br>Strip thickness $s$ = 0,14–approx. 10 mm<br>Strip width $w$ up to 2000 mm<br>Coil diameter up to 2400 mm<br>• for feed stock at automatic manufacturing plants or sheet metal blanks for secondary processing |

| Fabrication method | |
|---|---|
| Process | Remarks |
| Hot-rolled | Sheet thicknesses up to approx. 250 mm, surfaces in rolled condition or pickled |
| Cold-rolled | Sheet thicknesses up to approx. 10 mm, smooth surfaces, tight process tolerances |
| Cold-rolled with surface finishing | • higher corrosion resistance, e.g. from galvanizing, organic coating<br>• for decorative purposes, e.g. with plastic coating<br>• better workability, e.g. by textured surfaces |

## Sheet metal types – Overview (selection)

| Main characteristics | Designation, steel types | Standard | Delivery form[1] Sh | St | thickness range |
|---|---|---|---|---|---|
| **Cold-rolled sheet and strip** | | | | | |
| • cold workable (deep drawing)<br>• weldable<br>• surface paintable | Flat rolled products from soft steels | DIN EN 10130 | • | • | 0.35–3 mm |
| | Cold strip from soft steels | DIN EN 10207 | – | • | ≤ 10 mm |
| | Flat products with high yield strengths | DIN EN 10268 | • | • | ≤ 3 mm |
| | Flat products for enameling | DIN EN 10209 | • | • | ≤ 3 mm |
| **Cold-rolled sheet and strip with surface finishing** | | | | | |
| • higher corrosion resistance<br>• possibly better workability | Hot-dip finished sheet and strip | DIN EN 10327 | • | • | ≤ 3 mm |
| | Zinc electroplated flat products from steel for cold working | DIN EN 10152 | • | • | 0.35–3 mm |
| | Organically coated flat products from steel | DIN EN 10169-1 | • | • | ≤ 3 mm |
| **Cold-rolled sheets and strip for packaging** | | | | | |
| • corrosion resistant<br>• cold workable<br>• weldable | Black plate for manufacture of tinplate | DIN EN 10205 | • | • | 0.14–0.49 mm |
| | Packaging sheet metal from electrolytically tinned or chromed steel | DIN EN 10202 | • | • | 0.14–0.49 mm |
| **Hot-rolled sheet and strip** | | | | | |
| Same properties as the corresponding steel groups (pages 126, 127) | Sheet and strip from unalloyed and alloy steels, e.g. structural steels as per DIN EN 10025, fine-grain structural steels as per DIN EN 10113, case hardened steels as per DIN EN 10084, quenched and tempered steels as per DIN EN 10083, stainless steels as per DIN EN 10088 | DIN EN 10051 | • | • | sheet up to 25 mm thickness, strip up to 10 mm thickness |
| • high yield strength | Sheet metal from structural steels with higher yield strength, quenched and tempered | DIN EN 10025-6 | • | – | 3–150 mm |
| • cold workability | Flat products of steel with high yield strength | DIN EN 10149-1 | • | • | sheet up to 20 mm thickness |

[1] Delivery forms: Sh sheet; St strip

# Cold-rolled sheet and strip for cold working

## Cold-rolled strip and sheet from soft steels

cf. DIN EN 10130 (2007-02)

| Steel type: Designation | Material number | Type of surface | Tensile strength $R_m$ N/mm² | Yield strength $R_e$ N/mm² | Elongation at fracture $EL$ % | Lack of flow-lines[1] | Properties, Application |
|---|---|---|---|---|---|---|---|
| DC01 | 1.0330 | A<br>B | 270–410 | 140<br>280 | 28 | –<br>3 months | Cold workable, e.g. by deep drawing, weldable, surface paintable; worked sheet parts in automotive, general machine and equipment manufacturing, in the construction industry |
| DC03 | 1.0347 | A<br>B | 270–370 | 140<br>240 | 34 | 6 months | |
| DC04 | 1.0338 | A<br>B | 270–350 | 140<br>210 | 38 | 6 months | |
| DC05 | 1.0312 | A<br>B | 270–330 | 140<br>180 | 40 | 6 months | |
| DC06 | 1.0873 | A<br>B | 270–350 | 120<br>180 | 38 | unlimited time | |

| | |
|---|---|
| Delivery forms (standard values) | Sheet thicknesses: 0.25 – 0.35 – 0.4 – 0.5 – 0.6 – 0.7 – 0.8 – 0.9 – 1.0 – 1.2 – 1.5 – 2.0 – 2.5 – 3.0 mm<br>Metal sheet dimensions: 1000 x 2000 mm, 1250 x 2500 mm, 1500 x 3000 mm, 2000 x 6000 mm<br>strip (coils) up to approx. 2000 mm wide |
| Explanation | [1] In subsequent non-cutting processes, e.g. deep drawing, no flow lines appear within the given time period. The time period begins at the agreed upon delivery date. |

| **Type of surface** | | **Surface finish** | | |
|---|---|---|---|---|
| Designation | Description of the surface | Designation | Finish | Average roughness $Ra$ |
| A | Defects, e.g. pores, scoring, may not influence the workability and the adhesion of surface coatings. | b<br>g | very smooth<br>smooth | $Ra \leq 0.4$ µm<br>$Ra \leq 0.9$ µm |
| B | One side of the sheet must be free of defects so that its surface finish will not influence quality painting. | m<br>r | matt<br>rough | 0.6 µm < $Ra \leq$ 1.9 µm<br>$Ra >$ 1.6 µm |
| ⇒ | **Sheet EN 10130 – DC06 – B – g:** Sheet metal from DC06 material, surface type B, smooth surface | | | |

## Cold-rolled strip and sheet of high yield steels (selection)

cf. DIN EN 10268 (2006-10)

| Steel type: Designation | Material number | Tensile strength $R_m$ N/mm² | Yield strength $R_e$ N/mm² | Elongation at fracture $EL$ % | Properties, Application |
|---|---|---|---|---|---|
| HC180Y<br>HC220Y<br>HC260Y | 1.0922<br>1.0925<br>1.0928 | 340–400<br>350–420<br>380–440 | 180–230<br>220–270<br>260–320 | 36<br>34<br>32 | Cold workability at high mechanical strength, sophisticated deep-drawn parts |
| HC180B<br>HC220B<br>HC300B | 1.0395<br>1.0396<br>1.0444 | 300–360<br>320–400<br>400–480 | 180–230<br>220–270<br>300–360 | 34<br>32<br>26 | Good cold workability, increase of the yield strength through heat treatment after the shaping process; exterior parts of the vehicle body |
| HC180P<br>HC260P<br>HC300P | 1.0342<br>1.0417<br>1.0448 | 280–360<br>360–440<br>400–480 | 180–230<br>280–320<br>300–360 | 34<br>29<br>26 | Good cold workability, high impact resistance and fatigue strength; parts of the body skin, deep-drawn parts |
| HC260LA<br>HC380LA<br>HC420LA | 1.0480<br>1.0550<br>1.0556 | 350–430<br>440–560<br>470–590 | 260–330<br>380–480<br>420–520 | 26<br>19<br>17 | Good weldability and limited cold workability, good impact resistance and fatigue strength; reinforcing parts of the vehicle body |

| | |
|---|---|
| Forms of delivery, surface finishes | Forms of delivery see DIN EN 10130 (table on top)<br>Surface finishes: The products are available with the surface finish types A and B in accordance with DIN EN 10130. For LA types, e.g. HC380LA, only surface finish type A is available.<br>For rolling width > 600 mm, the surface finishes also comply with DIN EN 10130. |
| ⇒ | **Sheet metal EN 10628 – HC380LA – A – m:** Sheet metal of material HC380LA, surface finish A, matt (m) |

# Cold-rolled and hot-rolled sheet

## Hot-dip galvanized strip and sheet from soft steels for cold working

cf. DIN EN 10327 (2004-09)
replaces DIN EN 10142

| Steel type: Designation | Material number | Guarantee for strength values[1] | Tensile strength $R_m$ N/mm² | Yield strength $R_e$ N/mm² | Elongation at fracture $EL$ % | Lack of flow lines[2] | Cold working grade |
|---|---|---|---|---|---|---|---|
| DX51D+Z<br>DX51D+ZF | 1.0226+Z<br>1.0226+ZF | 8 days | 270–500 | – | 22 | 1 month | machine seamed quality |
| DX52D+Z<br>DX52D+ZF | 1.0350+Z<br>1.0350+ZF | 8 days | 270–420 | 140–300 | 26 | 1 month | drawing grade |
| DX53D+Z<br>DX53D+ZF | 1.0355+Z<br>1.0355+ZF | 6 months | 270–380 | 140–260 | 30 | 6 months | deep drawing grade |
| DX54D+Z<br>DX54D+ZF | 1.0306+Z<br>1.0306+ZF | 6 months | 260–350 | 120–220 | 36<br>34 | 6 months | extra deep drawing grade |
| DX56D+Z<br>DX56D+ZF | 1.0322+Z<br>1.0322+ZF | 6 months | 270–350 | 120–180 | 39<br>37 | 6 months | special deep drawing grade |

| | |
|---|---|
| Delivery forms (standard values) | Sheet thicknesses: 0.25 – 0.35 – 0.4 – 0.5 – 0.6 – 0.7 – 0.8 – 0.9 – 1.0 – 1.2 – 1.5 – 2.0 – 2.5 – 3.0 mm<br>Metal sheet dimensions: 1000 x 2000 mm, 1250 x 2500 mm, 1500 x 3000 mm, 2000 x 6000 mm<br>strip (coils) up to approx. 2000 mm wide |
| Explanation | [1] Values for tensile strength $R_m$, yield strength $R_e$ and elongation at fracture $EL$ are only guaranteed within the given time period. The time period begins at the agreed upon delivery date.<br>[2] In subsequent working, e.g. deep drawing, no flow lines appear within a given period. The time period begins at the agreed upon delivery date. |

**Composition, properties and structures of the coating**

| Designation | Composition, properties | Designation | Structure |
|---|---|---|---|
| +Z | Coatings of pure zinc, shiny flower patterned surface, protection against atmospheric corrosion | N<br>M | Zinc flowers in different sizes<br>Small zinc flowers, often not visible. |
| +ZF | Abrasion resistant coating of a zinc-iron alloy, uniform matt gray surface, corrosion resistant like +Z | R | Uniform matt gray surface (texture information only combined with coating +ZF) |

**Type of surface**

| Designation | Meaning |
|---|---|
| A<br>B<br>C | No surface defects are allowed, e.g. dots, stripes<br>Improved surface compared to A<br>Best surface, high-quality painting must be assured on one side of the sheet |
| ⇒ | **Sheet EN 10142 – DX53D+ZF100-R-B:** Sheet of DX53D material, coating of iron-zinc alloy with 100 g/m², uniform matt gray (R) and improved (B) surface |

## Hot-rolled sheet and strip

cf. DIN EN 10051 (1997-11)

| | | | | |
|---|---|---|---|---|
| Materials | Hot-rolled sheet and strip according to DIN EN 10051 are manufactured from steels of various material groups, for example: | | | Properties and applications of the steels are given on the pages for the individual steel. |
| | Steel group, designation | Standard | Page | |
| | Structural steels<br>Case hardened steels<br>Quenched and tempered steels | DIN EN 10025<br>DIN EN 10084<br>DIN EN 10083 | 130<br>132<br>133 | |
| | Weldable fine-grain steels<br>Heat-treatable structural steels, high yield strength | DIN EN 10113<br>DIN EN 10137 | 131<br>131 | |
| | Stainless steels<br>Pressure vessel steels | DIN EN 10088<br>DIN EN 10028 | 136<br>– | |

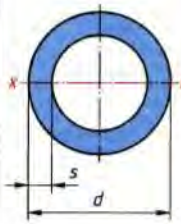
| | |
|---|---|
| Delivery forms (standard values) | Sheet thicknesses: 0.5 – 1.0 – 1.5 – 2.0 – 2.5 – 3.0 – 3.5 – 4.0 – 4.5 – 5.0 – 6.0 – 8.0 – 10.0 – 12.0 – 15.0 – 18.0 – 20.0 – 25.0 mm. Sheet and strip dimensions see DIN EN 10142. |
| ⇒ | **Sheet EN 10051 – 2,0 x 1200 x 2500:** Sheet thickness 2,0 mm, sheet dimensions 1200 x 2500 mm<br>**Steel EN 10083-1 – 34Cr4:** Carbon quenched and tempered steel 34Cr4 |

# Tubes for machine construction, Precision steel tube

## Seamless tube for machine construction (selection)

cf. DIN EN 10297-1 (2003-06)

$d$ outside diameter
$s$ wall thickness
$S$ cross-sectional area
$m'$ linear mass density
$W_x$ axial section modulus
$I_x$ axial geometrical moment of inertia




| d x s | S cm² | m' kg/m | $W_x$ cm³ | $I_x$ cm⁴ | d x s | S cm² | m' kg/m | $W_x$ cm³ | $I_x$ cm⁴ |
|---|---|---|---|---|---|---|---|---|---|
| 26.9 x 2.3 | 1.78 | 1.40 | 1.01 | 1.36 | 54 x 5.0 | 7.70 | 6.04 | 8.64 | 23.34 |
| 26.9 x 2.6 | 1.98 | 1.55 | 1.10 | 1.48 | 54 x 8.0 | 11.56 | 9.07 | 11.67 | 31.50 |
| 26.9 x 3.2 | 2.38 | 1.87 | 1.27 | 1.70 | 54 x 10.0 | 13.82 | 10.85 | 13.03 | 35.18 |
| 35 x 2.6 | 2.65 | 2.08 | 2.00 | 3.50 | 60.3 x 8 | 13.14 | 10.31 | 15.25 | 45.99 |
| 35 x 4.0 | 3.90 | 3.06 | 2.72 | 4.76 | 60.3 x 10 | 15.80 | 12.40 | 17.23 | 51.95 |
| 35 x 6.3 | 5.68 | 4.46 | 3.50 | 6.13 | 60.3 x 12.5 | 18.77 | 14.73 | 19.00 | 57.28 |
| 40 x 4 | 4.52 | 3.55 | 3.71 | 7.42 | 70 x 8 | 15.58 | 12.23 | 21.75 | 76.12 |
| 40 x 5 | 5.50 | 4.32 | 4.30 | 8.59 | 70 x 12.5 | 22.58 | 17.73 | 27.92 | 97.73 |
| 40 x 8 | 8.04 | 6.31 | 5.47 | 10.94 | 70 x 16 | 27.14 | 21.30 | 30.75 | 107.6 |
| 44.5 x 4 | 5.09 | 4.00 | 4.74 | 10.54 | 82.5 x 8 | 18.72 | 14.70 | 31.85 | 131.4 |
| 44.5 x 5 | 6.20 | 4.87 | 5.53 | 12.29 | 82.5 x 12.5 | 27.49 | 21.58 | 42.12 | 173.7 |
| 44.5 x 8 | 9.17 | 7.20 | 7.20 | 16.01 | 82.5 x 20 | 39.27 | 30.83 | 51.24 | 211.4 |
| 51 x 5 | 7.23 | 5.68 | 7.58 | 19.34 | 88.9 x 10 | 24.79 | 19.46 | 44.09 | 196.0 |
| 51 x 8 | 10.81 | 8.49 | 10.13 | 25.84 | 88.9 x 16 | 36.64 | 28.76 | 57.40 | 255.2 |
| 51 x 10 | 12.88 | 10.11 | 11.25 | 28.68 | 88.9 x 20 | 43.29 | 33.98 | 62.66 | 278.6 |

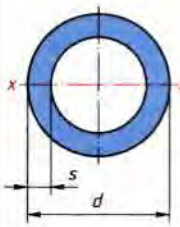
| Material, annealing condition | Steel group | Steel type, examples | Annealing condition[1] |
|---|---|---|---|
| | Machine construction steels: unalloyed | E235, E275, E315 | +AR or +N |
| | Machine construction steels: alloy | E355K2, E420J2 | +N |
| | Quenched and tempered steels: unalloyed | C22E, C45E, C60E | +N or +QT |
| | Quenched and tempered steels: alloy | 41Cr4, 42CrMo4 | +QT |
| | Case hard. steel, unall., alloy | C10E, C15E, 16MnCr5 | +A or +N |

Properties and applications of steels, see pages 126 and 127.

## Precision steel tube, cold-drawn seamless (selection)

cf. DIN EN 10305-1 (2003-02)

$d$ outside diameter
$s$ wall thickness
$S$ cross-sectional area
$m'$ linear mass density
$W_x$ axial section modulus
$I_x$ axial geometrical moment of inertia



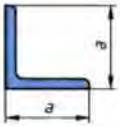
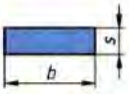
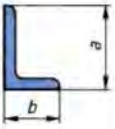
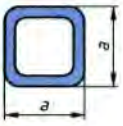
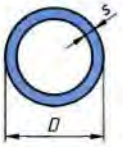
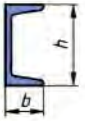

| d x s | S cm² | m' kg/m | $W_x$ cm³ | $I_x$ cm⁴ | d x s | S cm² | m' kg/m | $W_x$ cm³ | $I_x$ cm⁴ |
|---|---|---|---|---|---|---|---|---|---|
| 10 x 1 | 0.28 | 0.22 | 0.06 | 0.03 | 35 x 3 | 3.02 | 2.37 | 2.23 | 3.89 |
| 10 x 1.5 | 0.40 | 0.31 | 0.07 | 0.04 | 35 x 5 | 4.71 | 3.70 | 3.11 | 5.45 |
| 10 x 2 | 0.50 | 0.39 | 0.09 | 0.04 | 35 x 8 | 5.53 | 4.34 | 2.53 | 3.79 |
| 12 x 1 | 0.35 | 0.27 | 0.09 | 0.05 | 40 x 4 | 4.52 | 3.55 | 3.71 | 7.42 |
| 12 x 1.5 | 0.49 | 0.38 | 0.12 | 0.07 | 40 x 5 | 5.50 | 4.32 | 4.30 | 8.59 |
| 12 x 2 | 0.63 | 0.49 | 0.14 | 0.08 | 40 x 8 | 8.04 | 6.31 | 5.47 | 10.94 |
| 15 x 2 | 0.82 | 0.64 | 0.24 | 0.18 | 50 x 5 | 7.07 | 5.55 | 7.25 | 18.11 |
| 15 x 2.5 | 0.98 | 0.77 | 0.27 | 0.20 | 50 x 8 | 10.56 | 8.29 | 9.65 | 24.12 |
| 15 x 3 | 1.13 | 0.89 | 0.29 | 0.22 | 50 x 10 | 12.57 | 9.87 | 10.68 | 26.70 |
| 20 x 2.5 | 1.37 | 1.08 | 0.54 | 0.54 | 60 x 5 | 8.64 | 6.78 | 10.98 | 32.94 |
| 20 x 4 | 2.01 | 1.58 | 0.68 | 0.68 | 60 x 8 | 13.07 | 10.26 | 15.07 | 45.22 |
| 20 x 5 | 2.36 | 1.85 | 0.74 | 0.74 | 60 x 10 | 15.71 | 12.33 | 17.02 | 51.05 |
| 25 x 2.5 | 1.77 | 1.39 | 0.91 | 1.13 | 70 x 5 | 10.21 | 8.01 | 15.50 | 54.24 |
| 25 x 5 | 3.14 | 2.46 | 1.34 | 1.67 | 70 x 10 | 18.85 | 14.80 | 24.91 | 87.18 |
| 25 x 6 | 3.58 | 2.81 | 1.42 | 1.78 | 70 x 12 | 21.87 | 17.17 | 27.39 | 95.88 |
| 30 x 3 | 2.54 | 1.99 | 1.56 | 2.35 | 80 x 8 | 18.10 | 14.21 | 29.68 | 118.7 |
| 30 x 5 | 3.93 | 3.08 | 2.13 | 3.19 | 80 x 10 | 21.99 | 17.26 | 34.36 | 137.4 |
| 30 x 6 | 4.52 | 3.55 | 2.31 | 3.46 | 80 x 16 | 32.17 | 25.25 | 43.75 | 175.0 |

| Materials, surface, annealing condition | Steel group | Surfaces | Annealing condition[1] |
|---|---|---|---|
| | Unalloyed structural steels, free cutting steels, quenched and tempered steels | Tubes with smooth interior and exterior surfaces, surface roughness $Ra \leq 0{,}4$ µm | +C or +A or +N |

Properties and applications of steels, see pages 126 and 127.

Explanation: [1] +A spheroidized; +AR condition after hot working; +C cold-rolled; +N normalized; +QT quenched and tempered

# Hot-rolled steel profiles

| Cross-section | Designation, dimensions | Standard, page | Cross-section | Designation, dimensions | Standard, page |
|---|---|---|---|---|---|
|  | **Round steel bar**<br>$d$ = 8 – 200 | DIN EN 10060 page 144 |  | **Z profile steel**<br>$h$ = 30 – 200 | DIN 1027 |
|  | **Square steel bar**<br>$a$ = 8 – 120 | DIN EN 10059 page 144 |  | **Equal leg steel angle**<br>$a$ = 20 – 250 | DIN EN 10056-1 page 148 |
|  | **Flat steel bar**<br>$b \times s$ = 10 x 5 to 150 x 60 | DIN EN 10058 page 144 |  | **Unequal leg steel angle**<br>$a \times b$ =<br>30 x 20 to 200 x 150 | DIN EN 10056-1 page 147 |
|  | **Square tube**<br>$a$ = 40 – 400 | DIN EN 10210-2 page 151 |  | **Narrow I-beam**<br>I series<br>$h$ = 80 – 160 | DIN 1025-1 |
|  | **Rectangular tubes**<br>$a \times b$ =<br>50 x 25 to 500 x 300 | DIN EN 10210-2 page 151 |  | **Medium width I-beam**<br>IPE series<br>$h$ = 80 – 600 | DIN 1025-5 page 149 |
|  | **Circular tube**<br>$D \times s$ =<br>21.3 x 2.3 to 1219 x 25 | DIN EN 10210-1 |  | **Wide I-beam**<br>IPB series[1]<br>$h$ = 100 – 1000 | DIN 1025-2 page 150 |
|  | **Equal leg tee**<br>$b = h$ = 30 – 140 | DIN EN 10055 page 146 |  | **Wide I-beam**<br>light duty<br>IPBl series[1]<br>$h$ = 100 – 1000 | DIN 1025-3 page 149 |
|  | **Steel channel**<br>$h$ = 30 – 400 | DIN 1026-1 page 146 |  | **Wide I-beam**<br>reinforced design<br>IPBv series[1]<br>$h$ = 100 – 1000 | DIN 1025-4 page 150 |

[1] according to EURONORM 53-62: IPB = HE to B, IPBl = HE to A, IPBv = HE to M

# Steel bar, hot-rolled

## Hot-rolled round steel bar

cf. DIN EN 10060 (2004-02), replaces for DIN 1013-1




**Material:** Unalloyed structural steel according to DIN EN 10025 or quenched and tempered steel according to DIN EN 10083

**Type of delivery:** Manufactured lengths (M) ≥ 3 m < 13 m, normal lengths (F) ≤ 13 m ± 100 mm, precision lengths (E) < 6 m ± 25 mm, ≥ 6 m < 13 m ± 50 mm

| Diameter *d* in mm | 10 – 12 – 13 – 14 – 15 – 16 – 18 – 19 – 20 – 22 – 24 – 25 – 26 – 27 – 28 – 30 – 32 – 35 – 36 – 38 – 40 – 42 – 45 – 48 – 50 – 52 – 55 – 60 – 63 – 65 – 70 – 73 – 75 – 80 – 85 – 90 – 95 – 100 – 105 – 110 – 115 – 120 – 125 – 130 – 135 – 140 – 145 – 150 – 155 – 160 – 165 – 170 – 175 – 180 – 190 – 200 – 220 – 250 |
|---|---|

| Diameter *d* in mm | Limit deviations in mm | Diameter *d* in mm | Limit deviations in mm | Diameter *d* in mm | Limit deviations in mm | Diameter *d* in mm | Limit deviations in mm |
|---|---|---|---|---|---|---|---|
| 10–15 | ± 0.4 | 36–50 | ± 0.8 | 105–120 | ± 1.5 | 220 | ± 3.0 |
| 16–25 | ± 0.5 | 52–80 | ± 1.0 | 125–160 | ± 2.0 | 250 | ± 4.0 |
| 26–35 | ± 0.6 | 85–100 | ± 1.3 | 165–200 | ± 2.5 | | |

⇒ **Round bar EN 10060 – 40 x 6000 F steel EN 10025-S235JR:** Hot-rolled round steel bar, *d* = 40 mm, normal length 6000 mm, made of S235JR

## Hot-rolled square steel bar

cf. DIN EN 10059 (2004-02), replaces DIN 1014-1




**Material:** Unalloyed structural steel according to DIN EN 10025

**Type of delivery:** Manufactured lengths (M) ≥ 3 m < 13 m, normal lengths (F) ≤ 13 m ± 100 mm, precision lengths (E) < 6 m ± 25 mm, ≥ 6 m < 13 m ± 50 mm

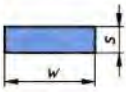
| Length of side *a* in mm | 8 – 10 – 12 – 13 – 14 – 15 – 16 – 18 – 20 – 22 – 24 – 25 – 26 – 28 – 30 – 32 – 35 – 40 – 45 – 50 – 55 – 60 – 65 – 70 – 75 – 80 – 90 – 100 – 110 – 120 – 130 – 140 – 150 |
|---|---|

| Length of side *a* in mm | Limit deviations in mm | Length of side *a* in mm | Limit deviations in mm | Length of side *a* in mm | Limit deviations in mm | Length of side *a* in mm | Limit deviations in mm |
|---|---|---|---|---|---|---|---|
| 8–14 | ± 0.4 | 26–35 | ± 0.6 | 55–90 | ± 1.0 | 110–120 | ± 1.5 |
| 15–25 | ± 0.5 | 40–50 | ± 0.8 | 100 | ± 1.3 | 130–150 | ± 1.8 |

⇒ **Square bar EN 10059 – 60 x 6000 F steel EN 10025-S235JR:** Hot-rolled square steel bar, *a* = 2.36 in, normal length 6000 mm, made of S235JR

## Hot-rolled flat steel bar

cf. DIN EN 10058 (2004-02), replaces DIN 1017-1




**Material:** Unalloyed structural steel according to DIN EN 10025

**Type of delivery:** Manufactured lengths (M) ≥ 3 m < 13 m, normal lengths (F) ≤ 13 m ± 100 mm, precision length (E) < 6 m ± 25 mm, ≥ 6 m < 13 m ± 50 mm

| Nominal width *w* in mm | 10 – 12 – 15 – 16 – 20 – 25 – 30 – 35 – 40 – 45 – 50 – 60 – 70 – 80 – 90 – 100 – 120 – 150 |
|---|---|
| Nominal thickness *s* in mm | 5 – 6 – 8 – 10 – 12 – 15 – 20 – 25 – 30 – 35 – 40 – 50 – 60 – 80 |

**Allowable deviations to nominal width *w***

| Nominal width *w* in mm | Limit deviations in mm | Nominal width *w* in mm | Limit deviations in mm | Nominal width *w* in mm | Limit deviations in mm |
|---|---|---|---|---|---|
| 10–40 | ± 0.75 | 85–100 | ± 1.5 | 150 | ± 2.5 |
| 45–80 | ± 1.0 | 120 | ± 2.0 | | |

**Allowable deviations to nominal thickness *s***

| Nominal thickness *s* in mm | Limit deviations in mm | Nominal thickness *s* in mm | Limit deviations in mm | Nominal thickness *s* in mm | Limit deviations in mm |
|---|---|---|---|---|---|
| 5–20 | ± 0.5 | 25–40 | ± 1.0 | 50–80 | ± 1.5 |

⇒ **Flat steel bar EN 10058 – 20 x 5 x 6000 F steel EN 10025-S235JR:** Hot-rolled flat steel bar, *b* = 20 mm, *s* = 5 mm, normal length 6000 mm, made of S235JR

# Steel bars, bright

## Common dimensions of bright steel bars (selection)

**Designation** | **Nominal dimensions**

### Flat steel bar




Width *w*, height *h* in mm

| *w* | *h* | *w* | *h* | *w* | *h* | *w* | *h* | *w* | *h* | *w* | *h* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 2–3 | 12 | 2–10 | 18 | 2–12 | 28 | 2–20 | 45 | 2–32 | 70 | 4–40 |
| 6 | 2–4 | 14 | 2–10 | 20 | 2–16 | 32 | 2–25 | 50 | 2–32 | 80 | 5–25 |
| 8 | 2–6 | 15 | 2–12 | 22 | 2–12 | 36 | 2–20 | 56 | 3–32 | 90 | 5–25 |
| 10 | 2–8 | 16 | 2–12 | 25 | 2–20 | 40 | 2–32 | 63 | 3–40 | 100 | 5–25 |

Nominal thicknesses *h* in mm: 2 – 2.5 – 3 – 4 – 5 – 6 – 8 – 10 – 12 – 15 – 16 – 20 – 25 – 30 – 32 – 35 – 40

### Square steel bar




Side length *a* in mm

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 4 | 6 | 9 | 12 | 16 | 22 | 36 | 50 | 80 |
| 4.5 | 7 | 10 | 13 | 18 | 25 | 40 | 63 | 100 |
| 5 | 8 | 11 | 14 | 20 | 28 | 45 | 70 | |

### Hexagonal bar steel




Side length *s* in mm

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 2 | 4 | 7 | 12 | 17 | 27 | 41 | 65 | |
| 2.5 | 4.5 | 8 | 13 | 19 | 30 | 46 | 70 | 90 |
| 3 | 5 | 9 | 14 | 21 | 32 | 50 | 75 | 95 |
| 3.2 | 5.5 | 10 | 15 | 22 | 36 | 55 | 80 | 100 |
| 3.5 | 6 | 11 | 16 | 24 | 38 | 60 | 85 | |

### round steel bar



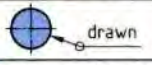

Diameter *d* in mm

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 2.5 | 6.5 | 11 | 19 | 27 | 38 | 58 | 90 | 160 |
| 3 | 7 | 12 | 20 | 28 | 40 | 60 | 100 | 180 |
| 3.5 | 7.5 | 13 | 21 | 29 | 42 | 63 | 110 | 200 |
| 4 | 8 | 14 | 22 | 30 | 45 | 65 | 120 | |
| 4.5 | 8.5 | 15 | 23 | 32 | 48 | 70 | 125 | |
| 5 | 9 | 16 | 24 | 34 | 50 | 75 | 130 | |
| 5.5 | 9.5 | 17 | 25 | 35 | 52 | 80 | 140 | |
| 6 | 10 | 18 | 26 | 36 | 55 | 85 | 150 | |

### polished round steel bar

| | | | | |
|---|---|---|---|---|
| common delivered diameters | 1 mm to 13 mm | > 13 mm to 25 mm | > 25 mm to 50 mm |
| common diameter gradation | 0.5 mm | 1 mm | 5 mm |

**Delivery conditions** cf. DIN EN 10278 (1999-12)




| Code | +C | +SH | +SL | +PL |
|---|---|---|---|---|
| Finished condition | cold drawn | peeled | ground | polished |

⇒ **Round EN 10278 – 20 h9 x mill length 6000 EN 10277-3 – 44SMn28+C – Class 3:** Round bright steel bar, *d* = 20 mm, Tolerance class h9, mill length 6000 mm, free cutting steel 44SMn28, cold drawn, surface quality class 3

**Material groups and assigned delivery conditions** cf. DIN EN 10277-1 to -5 (1999-10)

| Material groups | Delivery conditions[1] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | +SH | +C | +C +QT | +QT +C | +A +SH | +A +C | +FP +SH | +FP +C |
| Steels for general engineering use | • | • | | | | | | |
| Free cutting steels | • | • | | | | | | |
| Free cutting case hardened steels | • | • | | | | | | |
| Free cutting quenched and temp. steels | • | • | • | • | | | | |
| Unalloyed case hardened steels | • | • | | | • | • | | |
| Case hardened alloy steels | | | | | • | • | • | • |
| Unalloyed quenched and tempered steels | • | • | • | • | | | | |
| Quenched and tempered alloy steels | | | • | • | • | • | | |

[1] Explanation pages 124 and 125

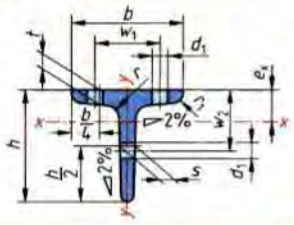
**Length types and length limit deviations** cf. DIN EN 10278 (1999-12)

| Length type | Length in mm | Limit deviations in mm | Order information |
|---|---|---|---|
| Manufactured length | 3000 – 9000 | ± 500 | length |
| Mill length | 3000 – 6000 | 0/+200 | e.g. mill length 6000 |
| Precision length | up to 9000 | by agreement, but min. ± 5 | length and limit deviation |

# Structural Tee, Steel channel

## Equal leg Tee, hot-rolled

cf. DIN EN 10055 (1995-12)




$S$ cross-sectional area — $W$ axial section modulus
$I$ second moment of inertia — $m'$ linear mass density

**Material:** Unalloyed structural steel DIN EN 10025, e.g. S235JR

**Delivery type:** Lengths to order with a usual limit deviation of ± 100 mm or a reduced limit deviation ± 50 mm, ± 25 mm, ± 10 mm

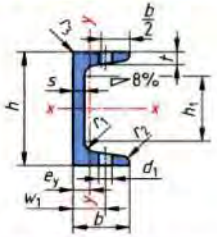
$r = s$ $\quad r_1 = \frac{s}{2}$

| Designation T | Dimensions in mm $b = h$ | $s = t$ | $S$ cm² | $m'$ kg/m | Distance of the $x$ axis $e_x$ cm | For the bending axis $x-x$ $I_x$ cm⁴ | $W_x$ cm³ | $y-y$ $I_y$ cm⁴ | $W_y$ cm³ | Tracing dimension accord. to DIN 997 $w_1$ mm | $w_2$ mm | $d_1$ mm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 30 | 30 | 4 | 2.26 | 1.77 | 0.85 | 1.72 | 0.80 | 0.87 | 0.58 | 17 | 17 | 4.3 |
| 35 | 35 | 4.5 | 2.97 | 2.33 | 0.99 | 3.10 | 1.23 | 1.04 | 0.90 | 19 | 19 | 4.3 |
| 40 | 40 | 5 | 3.77 | 2.96 | 1.12 | 5.28 | 1.84 | 2.58 | 1.29 | 21 | 22 | 6.4 |
| 50 | 50 | 6 | 5.66 | 4.44 | 1.39 | 12.1 | 3.36 | 6.06 | 2.42 | 30 | 30 | 6.4 |
| 60 | 60 | 7 | 7.94 | 6.23 | 1.66 | 23.8 | 5.48 | 12.2 | 4.07 | 34 | 35 | 8.4 |
| 70 | 70 | 8 | 10.6 | 8.23 | 1.94 | 44.4 | 8.79 | 22.1 | 6.32 | 38 | 40 | 11 |
| 80 | 80 | 9 | 13.6 | 10.7 | 2.22 | 73.7 | 12.8 | 37.0 | 9.25 | 45 | 45 | 11 |
| 100 | 100 | 11 | 20.9 | 16.4 | 2.74 | 179 | 24.6 | 88.3 | 17.7 | 60 | 60 | 13 |
| 120 | 120 | 13 | 29.6 | 23.2 | 3.28 | 366 | 42.0 | 179 | 29.7 | 70 | 70 | 17 |
| 140 | 140 | 15 | 39.9 | 31.3 | 3.80 | 660 | 64.7 | 330 | 47.2 | 80 | 75 | 21 |

⇒ **Tee profile EN 10055 – T50 – S235JR:** Structural steel tee, $h$ = 50 mm, from S235JR

## Steel channel, hot-rolled

cf. DIN 1026-1 (2000-03)




$S$ cross-sectional area — $W$ axial section modulus
$I$ second moment of inertia — $m'$ linear mass density

**Material:** Unalloyed structural steel DIN EN 10025, e.g. S235J0

**Delivery type:** Manufactured lengths 3 m to 15 m; normal lengths up to 15 m ± 50 mm; slope angle at $h \le 300$ mm: 8%; $h > 300$ mm: 5%

$r_1 = t$ $\quad r_2 \approx \frac{t}{2}$ $\quad r_3 \le 0{,}3 \cdot t$

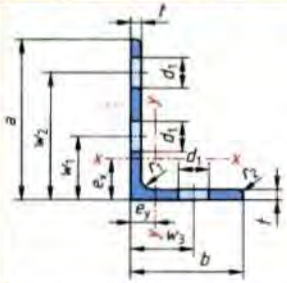
| Designation U | Dimensions in mm $h$ | $b$ | $s$ | $t$ | $h_1$ | $S$ cm² | $m'$ kg/m | Distance to the $y$ axis $e_y$ cm | For the bending axis $x-x$ $I_x$ cm⁴ | $W_x$ cm³ | $y-y$ $I_y$ cm⁴ | $W_y$ cm³ | Tracing dimensions DIN 997 $w_1$ mm | $d_1$ mm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 30 x 15 | 30 | 15 | 4 | 4.5 | 12 | 2.21 | 1.74 | 0.52 | 2.53 | 1.69 | 0.38 | 0.39 | 10 | 4.3 |
| 30 | 30 | 33 | 5 | 7 | 10 | 5.44 | 4.27 | 1.31 | 6.39 | 4.26 | 5.33 | 2.68 | 20 | 8.4 |
| 40 x 20 | 40 | 20 | 5 | 5.5 | 18 | 3.66 | 2.87 | 0.67 | 7.58 | 3.97 | 1.14 | 0.86 | 11 | 6.4 |
| 40 | 40 | 35 | 5 | 7 | 11 | 6.21 | 4.87 | 1.33 | 14.1 | 7.05 | 6.68 | 3.08 | 20 | 8.4 |
| 50 x 25 | 50 | 25 | 5 | 6 | 25 | 4.92 | 3.86 | 0.81 | 16.8 | 6.73 | 2.49 | 1.48 | 16 | 8.4 |
| 50 | 50 | 38 | 5 | 7 | 20 | 7.12 | 5.59 | 1.37 | 26.4 | 10.6 | 9.12 | 3.75 | 20 | 11 |
| 60 | 60 | 30 | 6 | 6 | 35 | 6.46 | 5.07 | 0.91 | 31.6 | 10.5 | 4.51 | 2.16 | 18 | 8.4 |
| 80 | 80 | 45 | 6 | 8 | 46 | 11.0 | 8.64 | 1.45 | 106 | 26.5 | 19.4 | 6.36 | 25 | 13 |
| 100 | 100 | 50 | 6 | 8.5 | 64 | 13.5 | 10.6 | 1.55 | 206 | 41.2 | 29.3 | 8.49 | 30 | 13 |
| 120 | 120 | 55 | 7 | 9 | 82 | 17.0 | 13.4 | 1.60 | 364 | 60.7 | 43.2 | 11.1 | 30 | 17 |
| 160 | 160 | 65 | 7.5 | 10.5 | 115 | 24.0 | 18.8 | 1.84 | 925 | 116 | 85.3 | 18.3 | 35 | 21 |
| 200 | 200 | 75 | 8.5 | 11.5 | 151 | 32.2 | 25.3 | 2.01 | 1 910 | 191 | 148 | 27.0 | 40 | 23 |
| 260 | 260 | 90 | 10 | 14 | 200 | 48.3 | 37.9 | 2.36 | 4 820 | 371 | 317 | 47.7 | 50 | 25 |
| 300 | 300 | 100 | 10 | 16 | 232 | 58.8 | 46.2 | 2.70 | 8 030 | 535 | 495 | 67.8 | 55 | 28 |
| 350 | 350 | 100 | 14 | 17.5 | 276 | 77.3 | 60.6 | 2.40 | 12 840 | 734 | 570 | 75.0 | 58 | 28 |
| 400 | 400 | 110 | 14 | 18 | 324 | 91.5 | 71.8 | 2.65 | 20 350 | 1020 | 846 | 102 | 60 | 28 |

⇒ **Channel DIN 1026 – U100 – S235J0:** Steel channel, $h$ = 100 mm, from S235J0

# Steel angle

## Unequal leg steel angle, hot-rolled (selection)

cf. DIN EN 10056-1 (1998-10)




*S* cross-sectional area
*I* second moment of inertia
*W* axial section modulus
*m'* linear mass density

**Material:** Unalloyed structural steel DIN EN 10025-2, e. g. S235J0

**Delivery type:** From 30 x 20 x 3 to 200 x 150 x 15, in manufactured lengths ≥ 6 m < 12 m, normal lengths ≥ 6 m < 12 m ± 100 mm

$r_1 \approx t$

$r_2 \approx \frac{t}{2}$

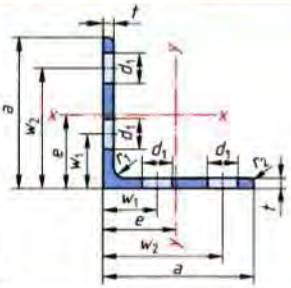
| Designation L | Dimensions in mm a | b | t | S cm² | m' kg/m | Distances to axes $e_x$ cm | $e_y$ cm | For the bending axis x – x $I_x$ cm⁴ | $W_x$ cm³ | y – y $I_y$ cm⁴ | $W_y$ cm³ | Tracing dimension accord. to DIN 997 $w_1$ mm | $w_2$ mm | $w_3$ mm | $d_1$ mm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 30 x 20 x 3 | 30 | 20 | 3 | 1.43 | 1.12 | 0.99 | 0.50 | 1.25 | 0.62 | 0.44 | 0.29 | 17 | – | 12 | 8.4 |
| 30 x 20 x 4 | 30 | 20 | 4 | 1.86 | 1.46 | 1.03 | 0.54 | 1.59 | 0.81 | 0.55 | 0.38 | 17 | – | 12 | 8.4 |
| 40 x 20 x 4 | 40 | 20 | 4 | 2.26 | 1.77 | 1.47 | 0.48 | 3.59 | 1.42 | 0.60 | 0.39 | 22 | – | 12 | 11 |
| 40 x 25 x 4 | 40 | 25 | 4 | 2.46 | 1.93 | 1.36 | 0.62 | 3.89 | 1.47 | 1.16 | 0.69 | 22 | – | 15 | 11 |
| 45 x 30 x 4 | 45 | 30 | 4 | 2.87 | 2.25 | 1.48 | 0.74 | 5.78 | 1.91 | 2.05 | 0.91 | 25 | – | 17 | 13 |
| 50 x 30 x 5 | 50 | 30 | 5 | 3.78 | 2.96 | 1.73 | 0.74 | 9.36 | 2.86 | 2.51 | 1.11 | 30 | – | 17 | 13 |
| 60 x 30 x 5 | 60 | 30 | 5 | 4.28 | 3.36 | 2.17 | 0.68 | 15.6 | 4.07 | 2.63 | 1.14 | 35 | – | 17 | 17 |
| 60 x 40 x 5 | 60 | 40 | 5 | 4.79 | 3.76 | 1.96 | 0.97 | 17.2 | 4.25 | 6.11 | 2.02 | 35 | – | 22 | 17 |
| 60 x 40 x 6 | 60 | 40 | 6 | 5.68 | 4.46 | 2.00 | 1.01 | 20.1 | 5.03 | 7.12 | 2.38 | 35 | – | 22 | 17 |
| 65 x 50 x 5 | 65 | 50 | 5 | 5.54 | 4.35 | 1.99 | 1.25 | 23.2 | 5.14 | 11.9 | 3.19 | 35 | – | 30 | 21 |
| 70 x 50 x 6 | 70 | 50 | 6 | 6.89 | 5.41 | 2.23 | 1.25 | 33.4 | 7.01 | 14.2 | 3.78 | 40 | – | 30 | 21 |
| 75 x 50 x 6 | 75 | 50 | 6 | 7.19 | 5.65 | 2.44 | 1.21 | 40.5 | 8.01 | 14.4 | 3.81 | 40 | – | 30 | 21 |
| 75 x 50 x 8 | 75 | 50 | 8 | 9.41 | 7.39 | 2.52 | 1.29 | 52.0 | 10.4 | 18.4 | 4.95 | 40 | – | 30 | 23 |
| 80 x 40 x 6 | 80 | 40 | 6 | 6.89 | 5.41 | 2.85 | 0.88 | 44.9 | 8.73 | 7.59 | 2.44 | 45 | – | 22 | 23 |
| 80 x 40 x 8 | 80 | 40 | 8 | 9.01 | 7.07 | 2.94 | 0.96 | 57.6 | 11.4 | 9.61 | 3.16 | 45 | – | 22 | 23 |
| 80 x 60 x 7 | 80 | 60 | 7 | 9.38 | 7.36 | 2.51 | 1.52 | 59.0 | 10.7 | 28.4 | 6.34 | 45 | – | 35 | 23 |
| 100 x 50 x 6 | 100 | 50 | 6 | 8.71 | 6.84 | 3.51 | 1.05 | 89.9 | 13.8 | 15.4 | 3.89 | 55 | – | 30 | 25 |
| 100 x 50 x 8 | 100 | 50 | 8 | 11.4 | 8.97 | 3.60 | 1.13 | 116 | 18.2 | 19.7 | 5.08 | 55 | – | 30 | 25 |
| 100 x 65 x 7 | 100 | 65 | 7 | 11.2 | 8.77 | 3.23 | 1.51 | 113 | 16.6 | 37.6 | 7.53 | 55 | – | 35 | 25 |
| 100 x 65 x 8 | 100 | 65 | 8 | 12.7 | 9.94 | 3.27 | 1.55 | 127 | 18.9 | 42.2 | 8.54 | 55 | – | 35 | 25 |
| 100 x 65 x 10 | 100 | 65 | 10 | 15.6 | 12.3 | 3.36 | 1.63 | 154 | 23.2 | 51.0 | 10.5 | 55 | – | 35 | 25 |
| 100 x 75 x 8 | 100 | 75 | 8 | 13.5 | 10.6 | 3.10 | 1.87 | 133 | 19.3 | 64.1 | 11.4 | 55 | – | 40 | 25 |
| 100 x 75 x 10 | 100 | 75 | 10 | 16.6 | 13.0 | 3.19 | 1.95 | 162 | 23.8 | 77.6 | 14.0 | 55 | – | 40 | 25 |
| 100 x 75 x 12 | 100 | 75 | 12 | 19.7 | 15.4 | 3.27 | 2.03 | 189 | 28.0 | 90.2 | 16.5 | 55 | – | 40 | 25 |
| 120 x 80 x 8 | 120 | 80 | 8 | 15.5 | 12.2 | 3.83 | 1.87 | 226 | 27.6 | 80.8 | 13.2 | 50 | 80 | 45 | 25 |
| 120 x 80 x 10 | 120 | 80 | 10 | 19.1 | 15.0 | 3.92 | 1.95 | 276 | 34.1 | 98.1 | 16.2 | 50 | 80 | 45 | 25 |
| 120 x 80 x 12 | 120 | 80 | 12 | 22.7 | 17.8 | 4.00 | 2.03 | 323 | 40.4 | 114 | 19.1 | 50 | 80 | 45 | 25 |
| 125 x 75 x 8 | 125 | 75 | 8 | 15.5 | 12.2 | 4.14 | 1.68 | 247 | 29.6 | 67.6 | 11.6 | 50 | – | 40 | 25 |
| 125 x 75 x 10 | 125 | 75 | 10 | 19.1 | 15.0 | 4.23 | 1.76 | 302 | 36.5 | 82.1 | 14.3 | 50 | – | 40 | 25 |
| 125 x 75 x 12 | 125 | 75 | 12 | 22.7 | 17.8 | 4.31 | 1.84 | 354 | 43.2 | 95.5 | 16.9 | 50 | – | 40 | 25 |
| 135 x 65 x 8 | 135 | 65 | 8 | 15.5 | 12.2 | 4.78 | 1.34 | 291 | 33.4 | 45.2 | 8.75 | 50 | – | 35 | 25 |
| 135 x 65 x 10 | 135 | 65 | 10 | 19.1 | 15.0 | 4.88 | 1.42 | 356 | 41.3 | 54.7 | 10.8 | 50 | – | 35 | 25 |
| 150 x 75 x 9 | 150 | 75 | 9 | 19.6 | 15.4 | 5.26 | 1.57 | 455 | 46.7 | 77.9 | 13.1 | 60 | 105 | 40 | 28 |
| 150 x 75 x 10 | 150 | 75 | 10 | 21.7 | 17.0 | 5.30 | 1.61 | 501 | 51.6 | 85.6 | 14.5 | 60 | 105 | 40 | 28 |
| 150 x 75 x 12 | 150 | 75 | 12 | 25.7 | 20.2 | 5.40 | 1.69 | 588 | 61.3 | 99.6 | 17.1 | 60 | 105 | 40 | 28 |
| 150 x 75 x 15 | 150 | 75 | 15 | 31.7 | 24.8 | 5.52 | 1.81 | 713 | 75.2 | 119 | 21.0 | 60 | 105 | 40 | 28 |
| 150 x 90 x 12 | 150 | 90 | 12 | 27.5 | 21.6 | 5.08 | 2.12 | 627 | 63.3 | 171 | 24.8 | 60 | 105 | 50 | 28 |
| 150 x 90 x 15 | 150 | 90 | 15 | 33.9 | 26.6 | 5.21 | 2.23 | 761 | 77.7 | 205 | 30.4 | 60 | 105 | 50 | 28 |
| 150 x 100 x 10 | 150 | 100 | 10 | 24.2 | 19.0 | 4.81 | 2.34 | 553 | 54.2 | 199 | 25.9 | 60 | 105 | 55 | 28 |
| 150 x 100 x 12 | 150 | 100 | 12 | 28.7 | 22.5 | 4.89 | 2.42 | 651 | 64.4 | 233 | 30.7 | 60 | 105 | 55 | 28 |
| 200 x 100 x 10 | 200 | 100 | 10 | 29.2 | 23.0 | 6.93 | 2.01 | 1220 | 93.2 | 210 | 26.3 | 65 | 150 | 55 | 28 |
| 200 x 100 x 15 | 200 | 100 | 15 | 43.0 | 33.8 | 7.16 | 2.22 | 1758 | 137 | 299 | 38.5 | 65 | 150 | 55 | 28 |

⇒ **L EN 10056-1 – 65 x 50 x 5 – S235J0:** Unequal leg steel angle, *a* = 65 mm, *b* = 50 mm, *t* = 5 mm, from S235J0

# Steel angle

## Equal leg steel angle, hot-rolled (selection)

cf. DIN EN 10056-1 (1998-10)




*S* cross-sectional area
*I* second moment of inertia
*W* axial section modulus
*m'* linear mass density

**Material:** Unalloyed structural steel DIN EN 10025-2, e. g. S235J0

**Delivery type:** From 20 x 20 x 3 to 200 x 250 x 35, in manufactured lengths ≥ 6 m < 12 m, normal lengths ≥ 6 m < 12 m ± 100 mm

$r_1 \approx t$

$r_2 \approx \frac{t}{2}$

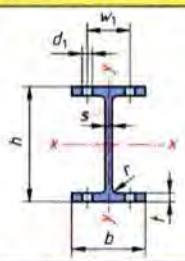
| Designation L | Dimensions in mm a | t | S cm² | m' kg/m | Distances to axes e cm | For the bending axis x – x and y – y $I_x = I_y$ cm⁴ | $W_x = W_y$ cm³ | Tracing dimension accord. to DIN 997 $w_1$ mm | $w_2$ mm | $d_1$ mm |
|---|---|---|---|---|---|---|---|---|---|---|
| 20 x 20 x 3 | 20 | 3 | 1.12 | 0.882 | 0.598 | 0.39 | 0.28 | 12 | – | 4.3 |
| 25 x 25 x 3 | 25 | 3 | 1.42 | 1.12 | 0.723 | 0.80 | 0.45 | 15 | – | 6.4 |
| 25 x 25 x 4 | 25 | 4 | 1.85 | 1.45 | 0.762 | 1.02 | 0.59 | 15 | – | 6.5 |
| 30 x 30 x 3 | 30 | 3 | 1.74 | 1.36 | 0.835 | 1.40 | 0.65 | 17 | – | 8.4 |
| 30 x 30 x 4 | 30 | 4 | 2.27 | 1.78 | 0.878 | 1.80 | 0.85 | 17 | – | 8.4 |
| 35 x 35 x 4 | 35 | 4 | 2.67 | 2.09 | 1.00 | 2.95 | 1.18 | 18 | – | 11 |
| 40 x 40 x 4 | 40 | 4 | 3.08 | 2.42 | 1.12 | 4.47 | 1.55 | 22 | – | 11 |
| 40 x 40 x 5 | 40 | 5 | 3.79 | 2.97 | 1.16 | 5.43 | 1.91 | 22 | – | 11 |
| 45 x 45 x 4.5 | 45 | 4.5 | 3.90 | 3.06 | 1.25 | 7.14 | 2.20 | 25 | – | 13 |
| 50 x 50 x 4 | 50 | 4 | 3.89 | 3.06 | 1.36 | 8.97 | 2.46 | 30 | – | 13 |
| 50 x 50 x 5 | 50 | 5 | 4.80 | 3.77 | 1.40 | 11.0 | 3.05 | 30 | – | 13 |
| 50 x 50 x 6 | 50 | 6 | 5.69 | 4.47 | 1.45 | 12.8 | 3.61 | 30 | – | 13 |
| 60 x 60 x 5 | 60 | 5 | 5.82 | 4.57 | 1.64 | 19.4 | 4.45 | 35 | – | 17 |
| 60 x 60 x 6 | 60 | 6 | 6.91 | 5.42 | 1.69 | 22.8 | 5.29 | 35 | – | 17 |
| 60 x 60 x 8 | 60 | 8 | 9.03 | 7.09 | 1.77 | 29.2 | 6.89 | 35 | – | 17 |
| 65 x 65 x 7 | 65 | 7 | 8.70 | 6.83 | 1.85 | 33.4 | 7.18 | 35 | – | 21 |
| 70 x 70 x 6 | 70 | 6 | 8.13 | 6.38 | 1.93 | 36.9 | 7.27 | 40 | – | 21 |
| 70 x 70 x 7 | 70 | 7 | 9.40 | 7.38 | 1.97 | 42.3 | 8.41 | 40 | – | 21 |
| 75 x 75 x 6 | 75 | 6 | 8.73 | 6.85 | 2.05 | 45.8 | 8.41 | 40 | – | 23 |
| 75 x 75 x 8 | 75 | 8 | 11.4 | 8.99 | 2.14 | 59.1 | 11.0 | 40 | – | 23 |
| 80 x 80 x 8 | 80 | 8 | 12.3 | 9.63 | 2.26 | 72.2 | 12.6 | 45 | – | 23 |
| 80 x 80 x 10 | 80 | 10 | 15.1 | 11.9 | 2.34 | 87.5 | 15.4 | 45 | – | 23 |
| 90 x 90 x 7 | 90 | 7 | 12.2 | 9.61 | 2.45 | 92.6 | 14.1 | 50 | – | 25 |
| 90 x 90 x 8 | 90 | 8 | 13.9 | 10.9 | 2.50 | 104 | 16.1 | 50 | – | 25 |
| 90 x 90 x 9 | 90 | 9 | 15.5 | 12.2 | 2.54 | 116 | 17.9 | 50 | – | 25 |
| 90 x 90 x 10 | 90 | 10 | 17.1 | 13.4 | 2.58 | 127 | 19.8 | 50 | – | 25 |
| 100 x 100 x 8 | 100 | 8 | 15.5 | 12.2 | 2.74 | 145 | 19.9 | 55 | – | 25 |
| 100 x 100 x 10 | 100 | 10 | 19.2 | 15.0 | 2.82 | 177 | 24.6 | 55 | – | 25 |
| 100 x 100 x 12 | 100 | 12 | 22.7 | 17.8 | 2.90 | 207 | 29.1 | 55 | – | 25 |
| 120 x 120 x 10 | 120 | 10 | 23.2 | 18.2 | 3.31 | 313 | 36.0 | 50 | 80 | 25 |
| 120 x 120 x 12 | 120 | 12 | 27.5 | 21.6 | 3.40 | 368 | 42.7 | 50 | 80 | 25 |
| 130 x 130 x 12 | 130 | 12 | 30.0 | 23.6 | 3.64 | 472 | 50.4 | 50 | 90 | 25 |
| 150 x 150 x 10 | 150 | 10 | 29.3 | 23.0 | 4.03 | 624 | 56.9 | 60 | 105 | 28 |
| 150 x 150 x 12 | 150 | 12 | 34.8 | 27.3 | 4.12 | 737 | 67.7 | 60 | 105 | 28 |
| 150 x 150 x 15 | 150 | 15 | 43.0 | 33.8 | 4.25 | 898 | 83.5 | 60 | 105 | 28 |
| 160 x 160 x 15 | 160 | 15 | 46.1 | 36.2 | 4.49 | 1100 | 95.6 | 60 | 115 | 28 |
| 180 x 180 x 18 | 180 | 18 | 61.9 | 48.6 | 5.10 | 1870 | 145 | 65 | 135 | 28 |
| 200 x 200 x 16 | 200 | 16 | 61.8 | 48.5 | 5.52 | 2340 | 162 | 65 | 150 | 28 |
| 200 x 200 x 20 | 200 | 20 | 76.3 | 59.9 | 5.68 | 2850 | 199 | 65 | 150 | 28 |
| 200 x 200 x 24 | 200 | 24 | 90.6 | 71.1 | 5.84 | 3330 | 235 | 70 | 150 | 28 |
| 250 x 250 x 28 | 250 | 28 | 133 | 104 | 7.24 | 7700 | 433 | 75 | 150 | 28 |

⇒ **L EN 10056-1 – 70 x 70 x 7 – S235J0:** Equal leg steel angle, *a* = 70 mm, *t* = 7 mm, from S235J0

# Medium width and wide I-beams

## Medium width I-beams (IPE), hot-rolled (selection)

cf. DIN 1025-5 (1994-03)




$S$ cross-sectional area
$I$ second moment of inertia
$W$ axial section modulus
$m'$ linear mass density

**Material:** Unalloyed structural steel DIN EN 10025-2, e.g. S235JR

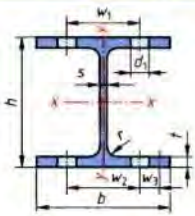
**Delivery type:** Standard lengths, 8 m to 16 m ± 50 mm with $h < 300$ mm,
8 m to 18 m ± 50 mm with $h \geq 300$ mm

| Designation | Dimensions in mm | | | | | For the bending axis | | | | | | Tracing dimension accord. to DIN 997 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | $x-x$ | | $y-y$ | | | |
| IPE | $h$ | $b$ | $s$ | $t$ | $r$ | $S$ cm² | $m'$ kg/m | $I_x$ cm⁴ | $W_x$ cm³ | $I_y$ cm⁴ | $W_y$ cm³ | $w_1$ mm | $d_1$ mm |
| 100 | 100 | 55 | 4.1 | 5.7 | 7 | 10.3 | 8.1 | 171 | 34.2 | 15.9 | 5.8 | 30 | 8.4 |
| 120 | 120 | 64 | 4.4 | 6.3 | 7 | 13.2 | 10.4 | 318 | 53.0 | 27.7 | 8.7 | 36 | 8.4 |
| 140 | 140 | 73 | 4.7 | 6.9 | 7 | 16.4 | 12.9 | 541 | 77.3 | 44.9 | 12.3 | 40 | 11 |
| 160 | 160 | 82 | 5.0 | 7.4 | 9 | 20.1 | 15.8 | 869 | 109 | 68.3 | 16.7 | 44 | 13 |
| 180 | 180 | 91 | 5.3 | 8.0 | 9 | 23.9 | 18.8 | 1320 | 146 | 101 | 22.2 | 50 | 13 |
| 200 | 200 | 100 | 5.6 | 8.5 | 12 | 28.5 | 22.4 | 1940 | 194 | 142 | 28.5 | 56 | 13 |
| 240 | 240 | 120 | 6.2 | 9.8 | 15 | 39.1 | 30.7 | 3890 | 324 | 284 | 47.3 | 68 | 17 |
| 270 | 270 | 135 | 6.6 | 10.2 | 15 | 45.9 | 36.1 | 5790 | 429 | 420 | 62.2 | 72 | 21 |
| 300 | 300 | 150 | 7.1 | 10.7 | 15 | 53.8 | 42.2 | 8360 | 557 | 604 | 80.5 | 80 | 23 |
| 360 | 360 | 170 | 8.0 | 12.7 | 18 | 72.7 | 57.1 | 16270 | 904 | 1040 | 123 | 90 | 25 |
| 400 | 400 | 180 | 8.6 | 13.5 | 21 | 84.5 | 66.3 | 23130 | 1160 | 1320 | 146 | 96 | 28 |
| 500 | 500 | 200 | 10.2 | 16.0 | 21 | 116 | 90.7 | 48200 | 1930 | 2140 | 214 | 110 | 28 |
| 600 | 600 | 220 | 12.0 | 19.0 | 24 | 156 | 122 | 92080 | 3070 | 3390 | 308 | 120 | 28 |

⇒ **I-profile DIN 1025 – S235JR – IPE 300:** Medium width I-beams with parallel flange surfaces, $h$ = 300 mm, from S235JR

## Wide I-beams light duty (IPEl), hot-rolled (selection)

cf. DIN 1025-2 (1994-3)




$S$ cross-sectional area
$I$ second moment of inertia
$W$ axial section modulus
$m'$ linear mass density

**Material:** Unalloyed structural steel DIN EN 10025-2, e.g. S235JR

**Delivery type:** Standard lengths, 8 m to 16 m ± 50 mm with $h < 300$ mm

$r \approx 3 \cdot s$

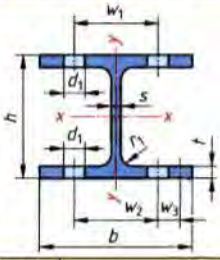
| Designation | Dimensions in mm | | | | | | For the bending axis | | | | Tracing dimension accord. to DIN 997 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | $x-x$ | | $y-y$ | | | | | |
| IPBl | $h$ | $b$ | $s$ | $t$ | $S$ cm² | $m'$ kg/m | $I_x$ cm⁴ | $W_x$ cm³ | $I_y$ cm⁴ | $W_y$ cm³ | $w_1$ | $w_2$ | $w_3$ | $d_1$ |
| 100 | 96 | 100 | 5 | 8 | 21.2 | 16.7 | 349 | 72.8 | 134 | 26.8 | 56 | – | – | 13 |
| 120 | 114 | 120 | 5 | 8 | 25.3 | 19.9 | 606 | 106 | 231 | 38.5 | 66 | – | – | 17 |
| 140 | 133 | 140 | 5.5 | 8.5 | 31.4 | 24.7 | 1030 | 155 | 389 | 55.6 | 76 | – | – | 21 |
| 160 | 152 | 160 | 6 | 9 | 38.8 | 30.4 | 1670 | 220 | 616 | 76.9 | 86 | – | – | 23 |
| 180 | 171 | 180 | 6 | 9.5 | 45.3 | 35.5 | 2510 | 294 | 925 | 103 | 100 | – | – | 25 |
| 200 | 190 | 200 | 6.5 | 10 | 53.8 | 42.3 | 3690 | 389 | 1340 | 134 | 110 | – | – | 25 |
| 240 | 230 | 240 | 7.5 | 12 | 76.8 | 60.3 | 7760 | 675 | 2770 | 231 | – | 94 | 35 | 25 |
| 280 | 270 | 280 | 8 | 13 | 97.3 | 76.4 | 13670 | 1010 | 4760 | 340 | – | 110 | 45 | 25 |
| 320 | 310 | 300 | 9 | 15.5 | 124.0 | 97.6 | 22930 | 1480 | 6990 | 466 | – | 120 | 45 | 28 |
| 400 | 390 | 300 | 11 | 19 | 159.0 | 125.0 | 45070 | 2310 | 8560 | 571 | – | 120 | 45 | 28 |
| 500 | 490 | 300 | 12 | 23 | 198.0 | 155.0 | 86970 | 3550 | 10370 | 691 | – | 120 | 45 | 28 |
| 600 | 590 | 300 | 13 | 25 | 226.0 | 178.0 | 141200 | 4790 | 11270 | 751 | – | 120 | 45 | 28 |
| 800 | 790 | 300 | 15 | 28 | 286.0 | 224.0 | 303400 | 7680 | 12640 | 843 | – | 130 | 40 | 28 |

⇒ **I-profile DIN 1025 – S235JR – IPBl 320:** Wide I-beams light duty from S235JR
Designation according to EURONORM 53-62: **HE 320 A**

# Wide I-beams

## Wide I-beams (IPB), hot-rolled (selection)

cf. DIN 1025-2 (1995-11)




$S$ cross-sectional area
$I$ second moment of inertia
$W$ axial selection modulus
$m'$ linear mass density

**Material:** unalloyed structural steel DIN EN 10025-2, e. g. S235JR

**Delivery type:** standard lengths, 8 m to 16 m ± 50 mm at $h < 300$ mm,
8 m to 18 m ± 50 mm at $h \geq 300$ mm

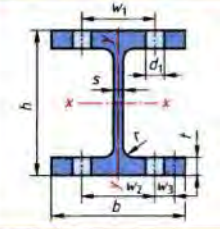
$r_1 \approx 2 \cdot s$

| Designation | Dimensions in mm | | | | $S$ | $m'$ | For the bending axis $x-x$ | | For the bending axis $y-y$ | | Tracing dimension according to DIN 997 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| IPB | $h$ | $b$ | $s$ | $t$ | cm² | kg/m | $I_x$ cm⁴ | $W_x$ cm³ | $I_y$ cm⁴ | $W_y$ cm³ | $w_1$ mm | $w_2$ mm | $w_3$ mm | $d_1$ mm |
| 100 | 100 | 100 | 6 | 10 | 26.0 | 20.4 | 450 | 89.9 | 167 | 33.5 | 56 | – | – | 13 |
| 120 | 120 | 120 | 6.5 | 11 | 34.0 | 26.7 | 864 | 144 | 318 | 52.9 | 66 | – | – | 17 |
| 140 | 140 | 140 | 7 | 12 | 43.0 | 33.7 | 1510 | 216 | 550 | 78.5 | 76 | – | – | 21 |
| 160 | 160 | 160 | 8 | 13 | 54.3 | 42.6 | 2490 | 311 | 889 | 111 | 86 | – | – | 23 |
| 180 | 180 | 180 | 8.5 | 14 | 65.3 | 51.2 | 3830 | 426 | 1360 | 151 | 100 | – | – | 25 |
| 200 | 200 | 200 | 9 | 15 | 78.1 | 61.3 | 5700 | 570 | 2000 | 200 | 110 | – | – | 25 |
| 240 | 240 | 240 | 10 | 17 | 106 | 83.2 | 11260 | 938 | 3920 | 327 | – | 96 | 35 | 25 |
| 280 | 280 | 280 | 10.5 | 18 | 131 | 103 | 19270 | 1380 | 6590 | 471 | – | 110 | 45 | 25 |
| 320 | 320 | 300 | 11.5 | 20.5 | 161 | 127 | 30820 | 1930 | 9240 | 616 | – | 120 | 45 | 28 |
| 400 | 400 | 300 | 13.5 | 24 | 198 | 155 | 57680 | 2880 | 10820 | 721 | – | 120 | 45 | 28 |
| 500 | 500 | 300 | 14.5 | 28 | 239 | 187 | 107200 | 4290 | 12620 | 842 | – | 120 | 45 | 28 |
| 600 | 600 | 300 | 15.5 | 30 | 270 | 212 | 171000 | 5700 | 13530 | 902 | – | 120 | 45 | 28 |
| 800 | 800 | 300 | 17.5 | 33 | 334 | 262 | 359100 | 8980 | 14900 | 994 | – | 130 | 40 | 28 |

⇒ **I-profile DIN 1025 – S235JR – IPB 240:** Wide I-beam with parallel flange faces, $h = 240$ mm, made of S235JR, designation according to EURONORM 53-62: **HE 240 B**

## Wide I-beams, reinforced version (IPBv) hot-rolled (selection)

cf. DIN 1025-4 (1994-03)




$S$ cross-sectional area
$I$ second moment of inertia
$W$ axial selection modulus
$m'$ linear mass density

**Material:** unalloyed structural steel DIN EN 10025-2, e. g. S235JR

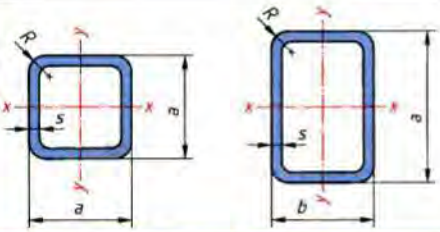
**Delivery type:** standard lengths, 8 m to 16 m ± 50 mm at $h < 300$ mm,
8 m to 16 m ± 50 mm at $h \geq 300$ mm

$r \approx s$

| Designation | Dimensions in mm | | | | $S$ | $m'$ | For the bending axis $x-x$ | | For the bending axis $y-y$ | | Tracing dimension according to DIN 997 in mm | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| IPBv | $h$ | $b$ | $s$ | $t$ | cm² | kg/m | $I_x$ cm⁴ | $W_x$ cm³ | $I_y$ cm⁴ | $W_y$ cm³ | $w_1$ | $w_2$ | $w_3$ | $d_1$ |
| 100 | 120 | 106 | 12 | 20 | 53.2 | 41.8 | 1140 | 190 | 399 | 75.3 | 60 | – | – | 13 |
| 120 | 140 | 126 | 12.5 | 21 | 66.4 | 52.1 | 2020 | 283 | 703 | 112 | 68 | – | – | 17 |
| 140 | 160 | 146 | 13 | 22 | 80.5 | 63.2 | 3290 | 411 | 1140 | 157 | 76 | – | – | 21 |
| 160 | 180 | 166 | 14 | 23 | 97.1 | 76.2 | 5100 | 568 | 1760 | 212 | 86 | – | – | 23 |
| 180 | 200 | 186 | 14.5 | 24 | 113 | 88.9 | 7480 | 748 | 2580 | 277 | 100 | – | – | 25 |
| 200 | 220 | 206 | 15 | 25 | 131 | 103 | 10640 | 967 | 3650 | 354 | 110 | – | – | 25 |
| 240 | 270 | 248 | 18 | 32 | 200 | 157 | 24290 | 1800 | 8150 | 657 | – | 100 | 35 | 25 |
| 280 | 310 | 288 | 18.5 | 33 | 240 | 189 | 39550 | 2550 | 13160 | 914 | – | 116 | 45 | 25 |
| 320 | 359 | 309 | 21 | 40 | 312 | 245 | 68130 | 3800 | 19710 | 1280 | – | 126 | 47 | 28 |
| 400 | 432 | 307 | 21 | 40 | 319 | 250 | 104100 | 4820 | 19340 | 1260 | – | 126 | 47 | 28 |
| 500 | 524 | 306 | 21 | 40 | 344 | 270 | 161900 | 6180 | 19150 | 1250 | – | 130 | 45 | 28 |
| 600 | 620 | 305 | 21 | 40 | 364 | 285 | 237400 | 7660 | 18280 | 1240 | – | 130 | 45 | 28 |
| 800 | 814 | 303 | 21 | 40 | 404 | 317 | 442600 | 10870 | 18630 | 1230 | – | 132 | 42 | 28 |

⇒ **I-profile DIN 1025 – S235JR – IPBv 400:** Wide I-beam, reinforced version, made of S235JR, designation according to EURONORM 53-62: **HE 400 M**

# Tubes




**Material:** Unalloyed structural steel DIN EN 10025

**Delivery type:** DIN EN 10210-2
manufactured lengths 4 m to 16 m, profile dimensions $a \times a = 20 \times 20$ to $400 \times 400$
DIN EN 10219-2
manufactured lengths 4 m to 16 m, profile dimensions $a \times a = 20 \times 20$ to $400 \times 400$

DIN EN 10210 and DIN EN 10219 also contain circular tubes, along with square and rectangular tubes.

## Hot worked square and rectangular tubes

cf. DIN EN 10210-2 (1997-11)

| Nominal dimension $a \times a$ $a \times b$ mm | Wall thickness $s$ mm | Linear mass density $m'$ kg/m | Cross section $S$ cm² | Area moments and section moduli for the bending axes $x-x$ $I_x$ cm⁴ | $W_x$ cm³ | $y-y$ $I_y$ cm⁴ | $W_y$ cm³ | for torsion $I_p$ cm⁴ | $W_p$ cm³ |
|---|---|---|---|---|---|---|---|---|---|
| 40 x 40 | 3.0 | 3.41 | 4.34 | 9.78 | 4.89 | 9.78 | 4.89 | 15.7 | 7.10 |
| | 4.0 | 4.39 | 5.59 | 11.8 | 5.91 | 11.8 | 5.91 | 19.5 | 8.54 |
| 50 x 50 | 2.5 | 3.68 | 4.68 | 17.5 | 6.99 | 17.5 | 6.99 | 27.5 | 10.2 |
| | 3.0 | 4.35 | 5.54 | 20.2 | 8.08 | 20.2 | 8.08 | 32.1 | 11.8 |
| 60 x 60 | 3.0 | 5.29 | 6.74 | 36.2 | 12.1 | 36.2 | 12.1 | 56.9 | 17.7 |
| | 4.0 | 6.90 | 8.79 | 45.4 | 15.1 | 45.4 | 15.1 | 72.5 | 22.0 |
| | 5.0 | 8.42 | 10.7 | 53.3 | 17.8 | 53.3 | 17.8 | 86.4 | 25.7 |
| 50 x 30 | 3.0 | 3.41 | 4.34 | 13.6 | 5.43 | 5.94 | 3.96 | 13.5 | 6.51 |
| | 4.0 | 4.39 | 5.59 | 16.5 | 6.60 | 7.08 | 4.72 | 16.6 | 7.77 |
| 60 x 40 | 3.0 | 4.35 | 5.54 | 26.5 | 8.82 | 13.9 | 6.95 | 29.2 | 11.2 |
| | 4.0 | 5.64 | 7.19 | 32.8 | 10.9 | 17.0 | 8.52 | 36.7 | 13.7 |
| 80 x 40 | 4.0 | 6.90 | 8.79 | 68.2 | 17.1 | 22.2 | 11.1 | 55.2 | 18.9 |
| | 5.0 | 8.42 | 10.7 | 80.3 | 20.1 | 25.7 | 12.9 | 65.1 | 21.9 |
| | 6.0 | 9.87 | 12.6 | 90.5 | 22.6 | 28.5 | 14.2 | 73.4 | 24.2 |
| 100 x 50 | 4.0 | 8.78 | 11.2 | 140 | 27.9 | 46.2 | 18.5 | 113 | 31.4 |
| | 5.0 | 10.8 | 13.7 | 167 | 33.3 | 54.3 | 21.7 | 135 | 36.9 |

⇒ **Tube DIN EN 10210 – 60 x 60 x 5 – S355J0:** Square tube, $a = 60$ mm, $s = 5$ mm, made of S355J0

## Cold worked, welded, square and rectangular tubes

cf. DIN EN 10219-2 (1997-11)

| Nominal dimension $a \times a$ $a \times b$ mm | Wall thickness $s$ mm | Linear mass density $m'$ kg/m | Cross section $S$ cm² | Area moments and section moduli for the bending axes $x-x$ $I_x$ cm⁴ | $W_x$ cm³ | $y-y$ $I_y$ cm⁴ | $W_y$ cm³ | for torsion $I_p$ cm⁴ | $W_p$ cm³ |
|---|---|---|---|---|---|---|---|---|---|
| 30 x 30 | 2.0 | 1.68 | 2.14 | 2.72 | 1.81 | 2.72 | 1.81 | 4.54 | 2.75 |
| | 2.5 | 2.03 | 2.59 | 3.16 | 2.10 | 3.16 | 2.10 | 5.40 | 3.20 |
| | 3.0 | 2.36 | 3.01 | 3.50 | 2.34 | 3.50 | 2.34 | 6.15 | 3.58 |
| 40 x 40 | 2.0 | 2.31 | 2.94 | 6.94 | 3.47 | 6.94 | 3.47 | 11.3 | 5.23 |
| | 2.5 | 2.82 | 3.59 | 8.22 | 4.11 | 8.22 | 4.11 | 13.6 | 6.21 |
| | 3.0 | 3.30 | 4.21 | 9.32 | 4.66 | 9.32 | 4.66 | 15.8 | 7.07 |
| | 4.0 | 4.20 | 5.35 | 11.1 | 5.54 | 11.1 | 5.54 | 19.4 | 8.48 |
| 80 x 80 | 3.0 | 7.07 | 9.01 | 87.8 | 22.0 | 87.8 | 22.0 | 140 | 33.0 |
| | 4.0 | 9.22 | 11.7 | 111 | 27.8 | 111 | 27.8 | 180 | 41.8 |
| | 5.0 | 11.3 | 14.4 | 131 | 32.9 | 131 | 32.9 | 218 | 49.7 |
| 40 x 20 | 2.0 | 1.68 | 2.14 | 4.05 | 2.02 | 1.34 | 1.34 | 3.45 | 2.36 |
| | 2.5 | 2.03 | 2.59 | 4.69 | 2.35 | 1.54 | 1.54 | 4.06 | 2.72 |
| | 3.0 | 2.36 | 3.01 | 5.21 | 2.60 | 1.68 | 1.68 | 4.57 | 3.00 |
| 60 x 40 | 3.0 | 4.25 | 5.41 | 25.4 | 8.46 | 13.4 | 6.72 | 29.3 | 11.2 |
| | 4.0 | 5.45 | 6.95 | 31.0 | 10.3 | 16.3 | 8.14 | 36.7 | 13.7 |
| | 5.0 | 6.56 | 8.36 | 35.3 | 11.8 | 18.4 | 9.21 | 42.8 | 15.6 |
| 80 x 40 | 3.0 | 5.19 | 6.61 | 52.3 | 13.1 | 17.6 | 8.78 | 43.9 | 15.3 |
| | 4.0 | 6.71 | 8.55 | 64.8 | 16.2 | 21.5 | 10.7 | 55.2 | 18.8 |
| | 5.0 | 8.13 | 10.4 | 75.1 | 18.8 | 24.6 | 12.3 | 65.0 | 21.7 |
| 100 x 40 | 3.0 | 6.13 | 7.81 | 92.3 | 18.5 | 21.7 | 10.8 | 59.0 | 19.4 |
| | 4.0 | 7.97 | 10.1 | 116 | 23.1 | 26.7 | 13.3 | 74.5 | 24.0 |
| | 5.0 | 9.70 | 12.4 | 136 | 27.1 | 30.8 | 15.4 | 87.9 | 27.9 |

⇒ **Tube DIN EN 10219 – 60 x 40 x 4 – S355J0:** Rectangular tube, $a = 60$ mm, $b = 40$ mm, $s = 4$ mm, made of S355J0

# Linear mass density and area mass density

## Linear mass density[1] (Table values for steel with density $\varrho = 7.85$ kg/dm³)

$d$ diameter $m'$ linear mass density $a$ length of side SW widths across flats

**Steel wire**

| $d$ mm | $m'$ kg/1000 m | $d$ mm | $m'$ kg/1000 m | $d$ mm | $m'$ kg/1000 m |
|---|---|---|---|---|---|
| 0.10 | 0.062 | 0.55 | 1.87 | 1.1 | 7.46 |
| 0.16 | 0.158 | 0.60 | 2.22 | 1.2 | 8.88 |
| 0.20 | 0.247 | 0.65 | 2.60 | 1.3 | 10.4 |
| 0.25 | 0.385 | 0.70 | 3.02 | 1.4 | 12.1 |
| 0.30 | 0.555 | 0.75 | 3.47 | 1.5 | 13.9 |
| 0.35 | 0.755 | 0.80 | 3.95 | 1.6 | 15.8 |
| 0.40 | 0.986 | 0.85 | 4.45 | 1.7 | 17.8 |
| 0.45 | 1.25 | 0.90 | 4.99 | 1.8 | 20.0 |
| 0.50 | 1.54 | 1.0 | 6.17 | 2.0 | 24.7 |

**Round steel bar**

| $d$ mm | $m'$ kg/m | $d$ mm | $m'$ kg/m | $d$ mm | $m'$ kg/m |
|---|---|---|---|---|---|
| 3 | 0.055 | 18 | 2.00 | 60 | 22.2 |
| 4 | 0.099 | 20 | 2.47 | 70 | 30.2 |
| 5 | 0.154 | 25 | 3.85 | 80 | 39.5 |
| 6 | 0.222 | 30 | 5.55 | 100 | 61.7 |
| 8 | 0.395 | 35 | 7.55 | 120 | 88.8 |
| 10 | 0.617 | 40 | 9.86 | 140 | 121 |
| 12 | 0.888 | 45 | 12.5 | 150 | 139 |
| 15 | 1.39 | 50 | 15.4 | 160 | 158 |
| 16 | 1.58 | 55 | 18.7 | 200 | 247 |

**Flat steel bar**

| $a$ mm | $m'$ kg/m | $a$ mm | $m'$ kg/m | $a$ mm | $m'$ kg/m |
|---|---|---|---|---|---|
| 6 | 0.283 | 20 | 3.14 | 40 | 12.6 |
| 8 | 0.502 | 22 | 3.80 | 50 | 19.6 |
| 10 | 0.785 | 25 | 4.91 | 60 | 28.3 |
| 12 | 1.13 | 28 | 6.15 | 70 | 38.5 |
| 14 | 1.54 | 30 | 7.07 | 80 | 50.2 |
| 16 | 2.01 | 32 | 8.04 | 90 | 63.6 |
| 18 | 2.54 | 35 | 9.62 | 100 | 78.5 |

**Hexagonal steel bar**

| SW mm | $m'$ kg/m | SW mm | $m'$ kg/m | SW mm | $m'$ kg/m |
|---|---|---|---|---|---|
| 6 | 0.245 | 20 | 2.72 | 40 | 10.9 |
| 8 | 0.435 | 22 | 3.29 | 50 | 17.0 |
| 10 | 0.680 | 25 | 4.25 | 60 | 24.5 |
| 12 | 0.979 | 28 | 5.33 | 70 | 33.3 |
| 14 | 1.33 | 30 | 6.12 | 80 | 43.5 |
| 16 | 1.74 | 32 | 6.96 | 90 | 55.1 |
| 18 | 2.20 | 35 | 8.33 | 100 | 68.0 |

## Linear mass density of special profiles

| Profile | | Page | Profile | | Page |
|---|---|---|---|---|---|
| Tee | EN 10055 | 146 | Tubes | EN 10210-2 | 151 |
| Angles, equal legs | EN 10056-1 | 148 | Tubes | EN 10219-2 | 151 |
| Angles, unequal legs | EN 10056-1 | 147 | Aluminum round bars | DIN 1798 | 169 |
| Steel channel | DIN1026-1 | 146 | Aluminum square bars | DIN 1796 | 169 |
| I-beams IPE | DIN 1025-5 | 149 | Aluminum flat bars | DIN 1769 | 170 |
| I-beams IPB | DIN 1025-2 | 149 | Aluminum round tube | DIN 1795 | 171 |
| I-beams, narrow | DIN 1025-1 | 150 | Aluminum channel | DIN 9713 | 171 |

## Area mass density[1] (Table values for steel with density $\varrho = 7.85$ kg/dm³)

**Sheet**

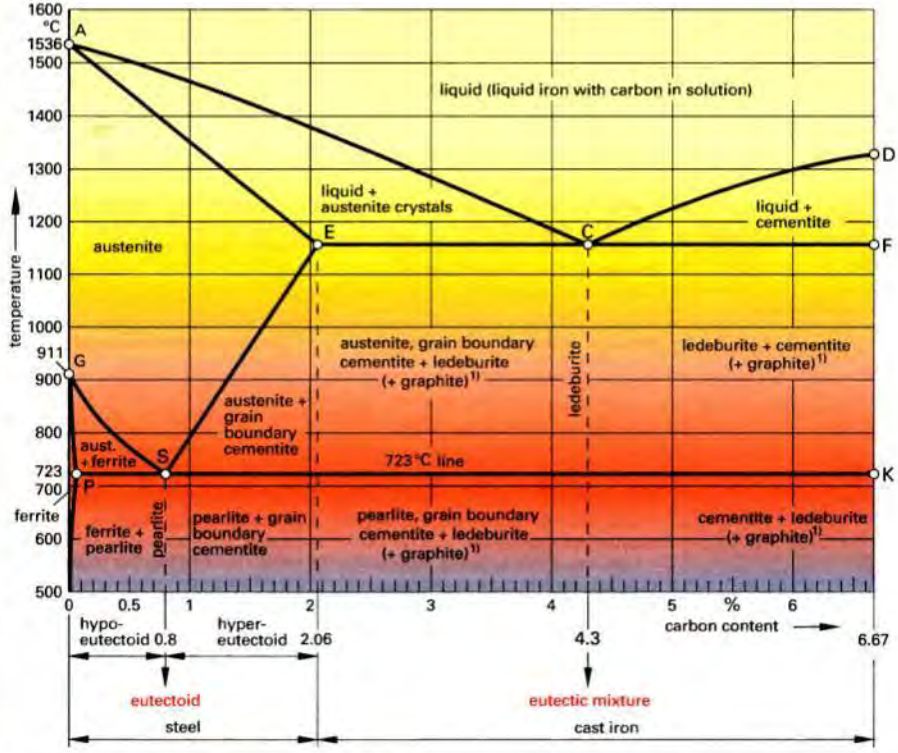
$s$ sheet thickness $m''$ area mass density

| $s$ mm | $m''$ kg/m² | $s$ mm | $m''$ kg/m² | $s$ mm | $m''$ kg/m² | $s$ mm | $m''$ kg/m² | $s$ mm | $m''$ kg/m² | $s$ mm | $m''$ kg/m² |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.35 | 2.75 | 0.70 | 5.50 | 1.2 | 9.42 | 3.0 | 23.6 | 4.75 | 37.3 | 10.0 | 78.5 |
| 0.40 | 3.14 | 0.80 | 6.28 | 1.5 | 11.8 | 3.5 | 27.5 | 5.0 | 39.3 | 12.0 | 94.2 |
| 0.50 | 3.93 | 0.90 | 7.07 | 2.0 | 15.7 | 4.0 | 31.4 | 6.0 | 47.1 | 14.0 | 110 |
| 0.60 | 4.71 | 1.0 | 7.85 | 2.5 | 19.6 | 4.5 | 35.3 | 8.0 | 62.8 | 15.0 | 118 |

[1] Table values can be calculated for a different material by taking a ratio of its density to the density of steel (7,85 kg/dm³).

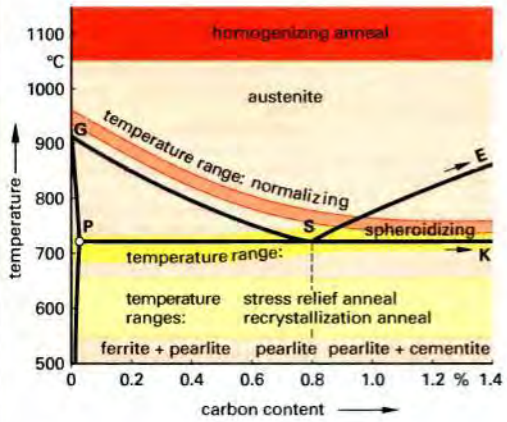
**Example:** Sheet metal with $s = 4.0$ mm of AlMg3Mn (density 2.66 kg/dm³). From the table: $m'' = 31.4$ kg/m² for steel.
$AlMg_3Mn$: $m'' = 31.4$ kg/m² · 2.66 kg/dm³/7.85 kg/dm³ = **10.64 kg/m²**

# Iron-Carbon phase diagram



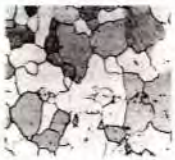

1) For iron types with a C content over 2.06% (cast iron) and additional Si content, a portion of the unalloyed precipitates in the form of graphite.

## Heat treatment of steel




## Microstructures of unalloyed steel

**Carbon content and crystalline structure**
Etchant: 3% nitric acid /alcohol solution
Magnification approx. 500 : 1



**0.1% C**
**ferrite**



**0.45% C**
**ferrite + pearlite**

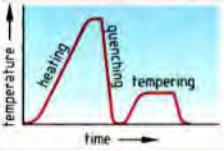
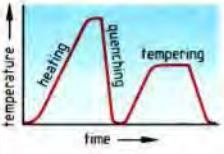
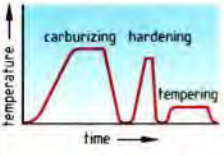
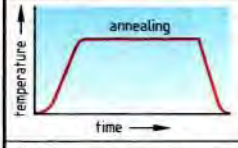


**0.8% C**
**pearlite**



**1.3% C**
**pearlite + grain boundary cementite**

# Heat treatment of steels – Overview

| Illustration | Short description | Application, information[1] |
|---|---|---|
| **Normalizing** | | |
|  | • **Heat** and hold at annealing temperature → structural transformation (austenite)<br>• Controlled **cooling** to room temperature → fine-grained normal structure | To normalize coarse grain structures in rolled, cast, welded and forged products |
| **Spheroidizing** | | |
|  | • **Heat** to annealing temperature, hold at temperature or cycle anneal → spheroidizing of the cementite<br>• **Cool down** to room temperature | To improve cold workability, machinability and hardenability; can be used for all steels |
| **Stress relief anneal** | | |
|  | • **Heat** and hold at annealing temperature (below structure transition) → stress relief by plastic deformation of the workpieces<br>• **Cool down** to room temperature | To reduce internal stresses in welded, cast and forged parts; can be used for all steels |
| **Hardening** | | |
|  | • **Heat** and hold at hardening temperature → structural transformation (austenite)<br>• **Quench** in oil, water, air → brittle hard, fine structure (martensite)<br>• **Temper** → transformation of martensite, higher toughness, working hardness | For parts subject to wear stress, e.g. tools, springs, guideways, press forms; steels suitable for heat treatment with C > 0,3%, e.g. C70U, 102Cr6, C45E, HS6-5-2C, X38CrMoV5-3 |
| **Quenching and tempering** | | |
|  | • **Heat** and hold at hardening temperature → structural transformation (austenite)<br>• **Quench** in oil, water, air → hard, brittle, fine-grain structure (martensite), for larger sized parts fine core structure (bainite)<br>• **Temper** at higher temperatures than for hardening → martensite reduction, fine structure, high strength with good toughness | Usually used for dynamically loaded workpieces with high strength and good toughness, e.g. shafts, gears, screws; quenched and tempered steels, see page 133, nitriding steels, see page 134, steels for flame and induction hardening, see page 134, steels for heat-treatable springs, see page 138 |
| **Case hardening** | | |
|  | • **Carburize** machined workpieces on the surface layer<br>• **Cool** to room temperature → normal structure (ferrite, pearlite, carbides)<br>• **Harden** (for procedure see hardening) → surface hardening: heat to surface hardening temperature<br>core hardening: heat to hardening temperature of the core area | For workpieces with wear-resistant surfaces, high fatigue strength and good core strength, e.g. gears, shafts, bolts;<br>**surface hardening:** high wear-resistance, low core strength<br>**core hardening:** high core strength, hard brittle surface;<br>case hardened steels, see page 133, free cutting steels, see page 134 |
| **Nitriding** | | |
|  | • **Anneal** usually finish-machined workpieces in nitrogen-producing atmospheres → formation of hard, wear-resistant and temperature-resistant nitrides<br>• **Cool** in still air or in nitrogen stream | For workpieces with wear-resistant surfaces, high fatigue strength and good temperature-resistance, e.g. valves, piston rods, spindles; nitriding steels, see page 134 |

[1] For annealing and tempering temperatures, quenching media and attainable hardness values, see pages 155 to 157.

# Tool steels, Case hardened steels

## Heat treatment of unalloyed cold work steels

cf. DIN EN ISO 4957 (2001-02)

| Steel type | | Hot working temperature | Spheroidizing | | Hardening | | | | Surface hardness in HRC ≈ | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Designation | Material number | | Temperature | Hardness HB | Temperature | Cooling medium | Case harden. depth[1] | Full harden. up to Ø | after hardening | after tempering[2] at 100 °C | 200 °C | 300 °C |
| | | °C | °C | max. | °C | | mm | mm | | | | |
| C45U | 1.1730 | 1000–800 | 680–710 | 207 | 800–820 | water | 3.5 | 15 | 58 | 58 | 54 | 48 |
| C70U | 1.1520 | | | 183 | 790–810 | | 3.0 | 10 | 64 | 63 | 60 | 53 |
| C80U | 1.1525 | 1050–800 | | 192 | 780–800 | | | | 64 | 64 | 60 | 54 |
| C90U | 1.1535 | 1050–800 | 680–710 | 207 | 770–790 | water | 3.0 | 10 | 64 | 64 | 61 | 54 |
| C105U | 1.1545 | 1000–800 | | 212 | 770–790 | | | | 65 | 64 | 62 | 56 |

[1] For diameters of 30 mm.

[2] The tempering temperature is set according to the application and the desired working hardness. The steels are normally delivered spheroidized.

## Heat treatment of alloy cold work steels, hot work steels and high-speed steels

cf. DIN EN ISO 4957 (2001-02)

| Steel type | | Hot working temperature | Spheroidizing | | Hardening | | Surface hardness in HRC ≈ | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Designation | Material number | | tempe-rature | Hardn. HB max. | tempe-rature[1] | cooling medium | after harden-ing | after tempering[2] at 200 °C | 300 °C | 400 °C | 500 °C | 550 °C |
| | | °C | °C | | °C | | | | | | | |
| 105V | 1.2834 | 1050–850 | 710–750 | 212 | 780–800 | water | 68 | 64 | 56 | 48 | 40 | 36 |
| X153CrMoV12 | 1.2379 | | 800–850 | 255 | 1010–1030 | air | 63 | 61 | 59 | 58 | 58 | 56 |
| X210CrW12 | 1.2436 | 1050–850 | 800–840 | 255 | 96–980 | oil | 64 | 62 | 60 | 58 | 56 | 52 |
| 90MnCrV8 | 1.2842 | | 680–720 | 229 | 780–800 | | 65 | 62 | 56 | 50 | 42 | 40 |
| 102Cr6 | 1.2067 | | 710–750 | 223 | 830–850 | | 65 | 62 | 57 | 50 | 43 | 40 |
| 60WCrV8 | 1.2550 | 1050–850 | 710–750 | 229 | 900–920 | oil | 62 | 60 | 58 | 53 | 48 | 46 |
| X37CrMoV5-1 | 1.2343 | 1100–900 | 750–800 | 229 | 1010–1030 | | 53 | 52 | 52 | 53 | 54 | 52 |
| HS6-5-2C | 1.3343 | 1100–900 | 770–840 | 269 | 1200–1220 | oil, hot bath, air | 64 | 62 | 62 | 62 | 65 | 65 |
| HS10-4-3-10 | 1.3207 | | | 302 | 1220–1240 | | 66 | 61 | 61 | 62 | 66 | 67 |
| HS2-9-1-8 | 1.3247 | | | 277 | 1180–1200 | | 66 | 62 | 62 | 61 | 68 | 69 |

[1] The austenitizing time is the holding time at hardening temperature, which is approx. 25 min for cold work steels and approx. 3 min. for high-speed steels. Heating is performed in stages.

[2] High-speed steels are tempered at least twice at 540–570 °C. Holding time at this temperature is at least 60 min.

## Heat treatment of case hardened steels

cf. DIN EN 10084 (2008-06)

| Steel type[1] | | Carburizing temperature | Hardening | | Temper-ing | Quench-ing medium | End quench test | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Designation | Material number | | Core harden. temperature | Surf. harden. temperature | | | Temp. | Hardness HRC at distance of: max.[2] | 3 mm | 5 mm | 7 mm |
| | | °C | °C | °C | °C | | °C | | | | |
| C10E | 1.1121 | 880–980 | 880–920 | 780–820 | 150–200 | water | – | – | – | – | – |
| C15E | 1.1141 | | | | | | – | – | – | – | – |
| 17Cr3 | 1.7016 | | 860–900 | | | oil | 880 | 47 | 44 | 40 | 33 |
| 16MnCr5 | 1.7131 | | | | | | 870 | 47 | 46 | 44 | 41 |
| 20MnCr5 | 1.7147 | | | | | | 870 | 49 | 49 | 48 | 46 |
| 20MoCr4 | 1.7321 | | | | | | 910 | 49 | 47 | 44 | 41 |
| 17CrNi6-6 | 1.5918 | | 830–870 | | | | 870 | 47 | 47 | 46 | 45 |
| 15NiCr13 | 1.5752 | | 840–880 | | | | 880 | 48 | 48 | 48 | 47 |
| 20NiCrMo2-2 | 1.6523 | | 860–900 | | | | 920 | 49 | 48 | 45 | 42 |
| 18CrNiMo7-6 | 1.6587 | | 830–870 | | | | 860 | 48 | 48 | 48 | 48 |

[1] The same values apply to steels with controlled sulfur content, e.g. C10R, 20MnCrS5.

[2] For steels with normal hardenability (+H) at a distance of 1.5 mm from the end face.

# Quenched and tempered steels

## Heat treatment of unalloyed quenched and tempered steels

cf. DIN EN 10083-2 (2006-10)[1]

| Steel types[2] Designation | Material number | Normalizing °C | End quench test Hardness HRC at hardening depth in mm[3] °C | 1 | 3 | 5 | Quenching and tempering Hardening[4] °C | Quenching medium | Tempering[5] °C |
|---|---|---|---|---|---|---|---|---|---|
| C22E | 1.1151 | 880–940 | – | – | – | – | 860–900 | water | 550–660 |
| C35E[1] | 1.1181 | 860–920 | 870 | 48–58 | 33–55 | 22–49 | 840–880 | water or oil | 550–660 |
| C40E | 1.1186 | 850–910 | 870 | 51–60 | 35–59 | 25–53 | 830–870 | | |
| C45E[1] | 1.1191 | 840–900 | 850 | 55–62 | 37–61 | 28–57 | 820–860 | | |
| C50E[1] | 1.1206 | 830–890 | 850 | 56–63 | 44–61 | 31–58 | 810–850 | oil or water | 550–660 |
| C55E[1] | 1.1203 | 825–885 | 830 | 58–65 | 47–63 | 33–60 | 810–850 | | |
| C60E | 1.1221 | 820–880 | 830 | 60–67 | 50–65 | 35–62 | 810–850 | | |
| 28Mn6 | 1.1170 | 850–890 | 850 | 45–54 | 42–53 | 37–51 | 840–880 | water or oil | 540–680 |

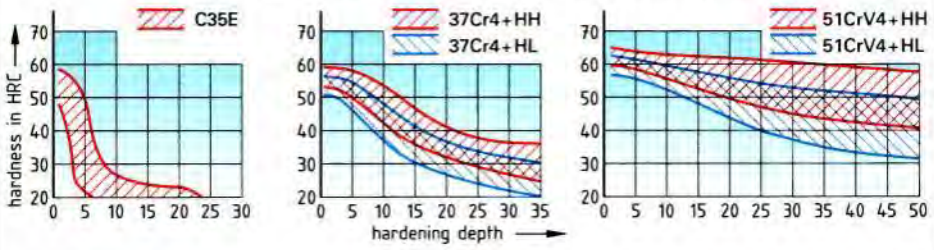
## Heat treatment of quenched and tempered alloy steels (selection)

cf. DIN EN 10083-3 (2007-01)[1]

| Steel types[2] Designation | Material number | Surface hardness[6] HRC | End quench test Hardness HRC at hardening depth in mm[3] °C | 1.5 | 5 | 15 | Quenching and tempering Hardening[4] °C | Quenching medium | Tempering[5] °C |
|---|---|---|---|---|---|---|---|---|---|
| 38Cr2 | 1.7003 | – | 850 | 51–59 | 37–54 | –35 | 830–870 | oil or water | 540–680 |
| 46Cr2[1] | 1.7006 | 54 | | 54–63 | 40–59 | 22–39 | 820–860 | oil or water | |
| 34Cr4 | 1.7033 | – | | 49–57 | 45–56 | 27–44 | 830–870 | water or oil | |
| 37Cr4[1] | 1.7034 | 51 | 850 | 51–59 | 48–58 | 31–48 | 825–865 | oil or water | 540–680 |
| 41Cr4[1] | 1.7035 | 53 | | 53–61 | 50–60 | 32–52 | 820–860 | oil or water | |
| 25CrMo4 | 1.7218 | – | | 44–52 | 40–51 | 27–41 | 840–900 | water or oil | |
| 34CrMo4 | 1.7220 | – | 850 | 49–57 | 48–57 | 34–52 | 830–890 | oil or water | 540–680 |
| 42CrMo4[1] | 1.7225 | 53 | | 53–61 | 52–61 | 37–58 | 820–880 | oil or water | |
| 50CrMo4[1] | 1.7228 | 58 | | 58–65 | 57–64 | 48–62 | 820–870 | oil | |
| 51CrV4 | 1.8159 | – | 850 | 57–65 | 56–64 | 48–62 | 820–870 | oil | 540–680 |
| 39NiCrMo3 | 1.6510 | – | | 52–60 | 50–59 | 43–56 | 820–850 | oil or water | |
| 34CrNiMo6 | 1.6582 | – | | 50–58 | 50–58 | 48–57 | 830–860 | oil or water | 540–660 |
| 30CrNiMo8 | 1.6580 | – | 850 | 48–56 | 48–56 | 46–55 | 830–860 | oil or water | 540–660 |
| 36NiCrMo16 | 1.6773 | – | | 50–57 | 48–56 | 47–55 | 865–885 | air or oil | 550–650 |
| 38MnB5 | 1.5532 | – | 850 | 52–60 | 50–59 | 31–47 | 840–880 | water/oil | 400–600 |
| 33MnCrB5-2 | 1.7185 | – | 880 | 48–57 | 47–57 | 41–54 | 860–900 | oil | 400–600 |

[1] DIN 17212 "Steels for flame and induction hardening" was withdrawn without replacement. More information about steels for flame and induction hardening on page 133 and 134 in the section "Quenched and tempered steels".
[2] Identical values apply to the high-grade steels C35 to C60 and steels with controlled sulphur content, such as C35R.
[3] Hardenability requirements: +H normal hardenability
[4] The lower temperature range applies to quenching in water, the higher range to quenching in oil.
[5] The tempering time is 60 minutes minimum.
[6] Minimum surface hardness of the steel after flame or induction hardening.

**Hardenability and hardening depth of quenched and tempered steels (scatter bands)**



# Nitriding steels, Free cutting steels, Aluminum alloys

## Heat treatment of nitriding steels

cf. DIN EN 10085 (2001-01)

| Steel type | | Heat treatment before nitriding | | | | Nitriding treatment[1] | | |
|---|---|---|---|---|---|---|---|---|
| | | | Quenching and tempering | | | | | |
| | | | Hardening | | Tempering | | | |
| Designation | Material number | Spheroid. temperature °C | Temperature[2] °C | Quenching medium | temperature[3][4] °C | Gas nitriding °C | Nitrocarburizing °C | Hardness[5] HV1 |
| 24CrMo13-6 | 1.8516 | 650–700 | 870–970 | oil or water | 580–700 | 500–600 | 570–650 | – |
| 31CrMo12 | 1.8515 | 650–700 | 870–930 | | | | | 800 |
| 32CrAlMo7-10 | 1.8505 | 650–750 | 870–930 | | | | | – |
| 31CrMoV9 | 1.8519 | 680–720 | 870–930 | | | | | 800 |
| 33CrMoV12-9 | 1.8522 | 680–720 | 870–970 | | | | | – |
| 34CrAlNi7-10 | 1.8550 | 650–700 | 870–930 | | | | | 950 |
| 41CrAlMo7-10 | 1.8509 | 650–750 | 870–930 | | | | | 950 |
| 40CrMoV13-9 | 1.8523 | 680–720 | 870–970 | | | | | – |
| 34CrAlMo5-10 | 1.8507 | 650–750 | 870–930 | | | | | 950 |

1) The nitriding time is a function of the desired nitriding hardness depth.
2) Austenitizing time at least 0.5 hours.
3) Tempering time at least 1 hour.
4) The tempering temperature should not be less than 50 °C above the nitriding temperature.
5) Hardness of the nitrided surface.

## Heat treatment of free cutting steels

cf. DIN EN 10087 (1999-01)

### Free cutting case hardened steels

| Steel type | | Carburizing temperature °C | Core hardening temperature °C | Surface harden. temperature °C | Quenching medium[1] | Tempering temperature[2] °C |
|---|---|---|---|---|---|---|
| Designation | Material number | | | | | |
| 10S20 | 1.0721 | 880–980 | 880–920 | 780–820 | water, oil, emulsion | 150–200 |
| 10SPb20 | 1.0722 | | | | | |
| 15SMn13 | 1.0725 | | | | | |

### Free cutting quenched and tempered steels

| Steel type | | Hardness temperature °C | Quenching medium[1] | Quench. and temp. temperat. °C | Quenched and tempered[3] | | |
|---|---|---|---|---|---|---|---|
| | | | | | $R_e$ | $R_m$ | $A$ |
| Designation | Material number | | | | N/mm² | N/mm² | % |
| 35S20 | 1.0726 | 860–890 | water or oil | 540–680 | 430 | 630–780 | 15 |
| 35SPb20 | 1.0756 | | | | | | |
| 36SMn14 | 1.0764 | 850–880 | | | 460 | 700–850 | 14 |
| 36SMnPb14 | 1.0765 | | | | | | |
| 38SMn28 | 1.0760 | 850–880 | oil or water | | 460 | | 15 |
| 38SMnPb28 | 1.0761 | | | | | | |
| 44SMn28 | 1.0762 | 840–870 | | | 480 | | 16 |
| 44SMnPb28 | 1.0763 | | | | | | |
| 46S20 | 1.0757 | | | | 490 | | 12 |

1) The choice of quenching medium depends on the shape of the workpiece.
2) Tempering time at least 1 hour.
3) Values apply to diameters $10 < d \leq 16$.

## Hardening of aluminum alloys

| Alloy EN AW- | | Type of age hardening[2] | Solution annealing temperature °C | Artificial aging | | Natural aging time days | Age hardened | |
|---|---|---|---|---|---|---|---|---|
| | | | | temperature °C | holding time h | | $R_m$ | $A$ |
| Designation | Material number | | | | | | N/mm² | % |
| Al Cu4MgSi | 2017 | T4 | 500 | 100–300 | 8–24 | 5–8 | 390 | 12 |
| Al Cu4SiMg | 2014 | T6 | | | | – | 420 | 8 |
| Al MgSi | 6060 | T4 | 525 | | | 5–8 | 130 | 15 |
| Al MgSi1MgMn | 6082 | T6 | | | | – | 280 | 6 |
| Al Zn4,5Mg1 | 7020 | T6 | 470 | | | – | 210 | 12 |
| Al Zn5,5MgCu | 7075 | T6 | | | | – | 545 | 8 |
| Al Si7Mg[1] | 42000[1] | T6 | 525 | | | 4 | 250 | 1 |

1) Aluminum casting alloy EN AC-Al Si7Mg or EN AC 42000.
2) T4 solution annealed and naturally aged; T6 solution annealed and artificially aged.

# Designation system for cast iron materials

## Designations and material numbers

cf. DIN EN 1560 (1997-08)

Cast iron materials are referenced either with a designation or a material number.

**Example:**

Cast iron with flake graphite, tensile strength $R_m$ = 300 N/mm²

| Designation | Material number |
|---|---|
| EN-GJL-300 | EN-JL1050 |

### Material designations

Material designations have up to six characters without spaces, beginning with **EN** (European standard) and **GJ** (cast iron; I iron)

**Designation example:**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| EN | - | GJ | L | | - | 350 | | Cast iron with flake graphite |
| EN | - | GJ | L | | - | HB155 | | Cast iron with flake graphite |
| EN | - | GJ | S | | - | 350-22U | | Cast iron with spheroidal graphite (ductile Iron) |
| EN | - | GJ | M | B | - | 450-6 | | Malleable cast iron – blackheart |
| EN | - | GJ | M | W | - | 360-12 | W | Malleable cast iron – whiteheart |
| EN | - | GJ | M | | - | HV600(XCr14) | | Wear-resistant cast iron |
| EN | - | GJ | L | A | - | XNiCuCr15-6-2 | | Austenitic cast iron |

**Graphite structure (letter)**

- L flake graphite
- S spheroidal graphite
- M temper carbon
- V vermicular graphite
- N no graphite
- Y special structure

**Microstructure or macrostructure (letter)**

- A austenite
- F ferrite
- P pearlite
- M martensite
- L ledeburite
- Q quenched
- T quenched and tempered
- B not decarburized
- W decarburized

**Mechanical properties or chemical composition (numbers/letters)**

**Mechanical properties**

- 350 minimum tensile strength $R_m$ in N/mm²
- 350-22 additional elongation at fracture *EL* in %
- S **Test specimen** cast separately
- U cast-on
- C taken from the casting
- HB155 max. hardness

**Chemical composition**

Data are based on steel designations, see page 125

**Additional requirements**

- D rough casting
- H heat treated casting
- W weldable
- Z additional requirements

### Material numbers

Material numbers have seven characters without spaces, beginning with **EN** (European standard) and **J** (iron; I iron)

**Designation examples:**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| EN | - | J | L | 2 | 04 | 7 | Cast iron with flake graphite and hardness as characteristic |
| EN | - | J | S | 1 | 02 | 2 | spheroidal graphite casting with cast-on test specimen, characteristic $R_m$ |
| EN | - | J | M | 1 | 13 | 0 | Malleable cast iron without special requirements, characteristic $R_m$ |

**Graphite structure (letter)**

- L flake graphite
- S spheroidal graphite
- M temper carbon
- V vermicular graphite
- N no graphite
- Y special structure

**Main characteristic (number)**

- 1 tensile strength
- 2 hardness
- 3 chemical composition

**Material characteristic number**

Every cast iron material is assigned a two-digit number.
A higher number indicates a higher strength.

**Material requirements (number)**

- 0 no special requirements
- 1 separately cast test specimen
- 2 cast-on test specimen
- 3 test specimen taken from the casting
- 4 toughness at room temperature
- 5 toughness at low temperature
- 6 specified weldability
- 7 rough casting
- 8 heat treated casting
- 9 additional requirements

## Classification of Cast Iron Materials

| Type | Standard | Examples/ material number | Tensile strength $R_m$ N/mm² | Properties | Application examples |
|---|---|---|---|---|---|
| **Cast iron** | | | | | |
| with flake graphite (gray iron) | DIN EN 1561 | EN-GJL-150 (GG-15)[1] EN-JL1020 | 100 to 450 | Very good castability, good compression strength, damping capacity, emergency running properties, and good corrosion resistance | For complex workpieces with many contours; very versatile in its applications. Machine frames, gear housings |
| with spheroidal graphite | DIN EN 1563 | EN-GJS-400 (GGG-40)[1] EN-JS1030 | 350 to 900 | Very good castability, high strength even with dynamic loading, surface hardenable | Wear stressed workpieces; clutch parts, fittings, engine/motor construction |
| with vermicular graphite | ISO 16112 | ISO 16112/JV/300 | 300 to 500 | Very good castability, high strength without expensive alloying additions | Automotive parts, engine/motor construction, gear housings |
| bainitic cast iron | DIN EN 1564 | EN-GJS-800-8 EN-JS1100 | 800 to 1400 | Heat treatment and controlled cooling produce bainite and austenite for high strength and good toughness | Highly stressed parts, e.g. wheel hubs, gear rings, ADI castings[2] |
| wear-resistant castings, white cast iron | DIN EN 12513 | EN-GJN-HV350 EN-JN2019 | > 1000 | Wear-resistant due to martensite and carbides, also alloyed with Cr and Ni | Wear-resistant cast iron, e.g. dressing rolls, dredging shovels, impellers for pumps |
| **Malleable cast iron** | | | | | |
| decarburized (whiteheart) | DIN EN 1562 | EN-GJMW-350 (GTW-35)[1] EN-JM1010 | 270 to 570 | Decarburization of the surface by tempering. High strength and toughness, ductile | True to shape, thin-walled, impact-loaded parts; levers, brake drums |
| not decarburized (blackheart) | DIN EN 1562 | EN-GJMB-450 (GTS-45)[1] EN-JM1140 | 300 to 800 | Cluster graphite in entire cross-section due to malleablizing. High strength and toughness in larger wall thickness | True to shape, thick walled, impact stressed parts; levers, universal joint yokes |
| **Cast steel** | | | | | |
| for general use | DIN EN 10293[3] | GE240 1.0446 | 380 to 600 | Unalloyed and low alloy cast steel for general use | Minimum mechanical values from –10 °C to 300 °C |
| with improved weldability | DIN EN 10293[4] | G20Mn5 1.6220 | 430 to 650 | Lower carbon content with manganese and microalloy | Welded assembly construction, fine-grain structural steels with larger wall thickness |
| quenched and tempered cast steel | DIN EN 10293[5] | G30CrMoV6-4 1.7725 | 500 to 1250 | Fine quenched and tempered structure with high toughness | Chains, plating |
| for pressure vessels | DIN EN 10213 | GP280GH 1.0625 | 420 to 960 | Types with high strength and toughness at low and high temperatures | Pressure vessels for hot or cold media, high temperature resistant and tough at low temperatures; rustproof |
| stainless | DIN EN 10283 | GX6CrNi26-7 1.4347 | 450 to 1100 | Resistant to chemical attack and corrosion | Pump impellers in acids, duplex steel |
| heat-resistant | DIN EN 10295 | GX25CrNiSi18-9 1.4825 | 400 to 550 | Resistant to scaling gases | Turbine parts, furnace grates |

[1] previous designation [2] ADI → Austempered Ductile Iron
[3] Replaces DIN 1681 [4] Replaces DIN 17182 [5] Replaces DIN 17205

# Cast iron with flake graphite, Cast iron with spheroidal graphite

## Cast iron with flake graphite (gray iron)

cf. DIN EN 1561 (1997-08)

**Tensile strength $R_m$ as identifying characteristic**

| Type | | Wall thickness | Tensile strength $R_m$ |
|---|---|---|---|
| Designation | Material number | mm | N/mm² |
| EN-GJL-100 | EN-JL1010 | 5–40 | 100–200 |
| EN-GJL-150 | EN-JL1020 | 2.5–300 | 150–250 |
| EN-GJL-200 | EN-JL1030 | 2.5–300 | 200–300 |
| EN-GJL-250 | EN-JL1040 | 5–300 | 250–350 |
| EN-GJL-300 | EN-JL1050 | 10–300 | 300–400 |
| EN-GJL-350 | EN-JL1060 | 10–300 | 350–450 |

⇒ **EN-GJL-100**: Cast iron with flake graphite (gray iron), minimum tensile strength $R_m$ = 100 N/mm²

**Hardness HB as identifying characteristic**

| Type | | Wall thickness | Brinell hardness |
|---|---|---|---|
| Designation | Material number | mm | HB30 |
| EN-GJL-HB155 | EN-JL2010 | 40–80 | max. 155 |
| EN-GJL-HB175 | EN-JL2020 | 40–80 | 100–175 |
| EN-GJL-HB195 | EN-JL2030 | 40–80 | 120–195 |
| EN-GJL-HB215 | EN-JL2040 | 40–80 | 145–215 |
| EN-GJL-HB235 | EN-JL2050 | 40–80 | 165–235 |
| EN-GJL-HB255 | EN-JL2060 | 40–80 | 185–255 |

⇒ **EN-GJL-HB215**: Cast iron with flake graphite (gray iron), maximum Brinell hardness = 215 HB

**Properties**

Good castability and machinability, vibration damping, corrosion resistance, high compression strength, good sliding properties.

**Application examples**

Machine frames, bearing housings, plain bearings, pressure-resistant parts, turbine housings.
Hardness as characteristic property provides information on the machinability.

## Cast iron with spheroidal (nodular) graphite

cf. DIN EN 1563 (2005-10)

**Tensile strength $R_m$ as identifying characteristic**

| Type | | Tensile strength $R_m$ | Yield strength $R_{p0.2}$ | Elongation $EL$ | Properties, application examples |
|---|---|---|---|---|---|
| Designation | Material number | N/mm² | N/mm² | % | |
| EN-GJS-350-22-LT[1] | EN-JS1015 | 350 | 220 | 22 | Good machinability, low wear resistance; housings |
| EN-GJS-350-22-RT[2] | EN-JS1014 | 350 | 220 | 22 | |
| EN-GJS-350-22 | EN-JS1010 | 350 | 220 | 22 | |
| EN-GJS-400-18-LT[1] | EN-JS1025 | 400 | 250 | 18 | |
| EN-GJS-400-18-RT[2] | EN-JS1024 | 400 | 250 | 18 | |
| EN-GJS-400-18 | EN-JS1020 | 400 | 250 | 18 | |
| EN-GJS-400-15 | EN-JS1030 | 400 | 250 | 15 | |
| EN-GJS-450-10 | EN-JS1040 | 450 | 310 | 10 | Good machinability, average wear resistance; fittings, press frames |
| EN-GJS-500-7 | EN-JS1050 | 500 | 320 | 7 | |
| EN-GJS-600-3 | EN-JS1060 | 600 | 370 | 3 | |
| EN-GJS-700-2 | EN-JS1070 | 700 | 420 | 2 | Good surface hardness; gears, steering and clutch parts, chains |
| EN-GJS-800-2 | EN-JS1080 | 800 | 480 | 2 | |
| EN-GJS-900-2 | EN-JS1090 | 900 | 600 | 2 | |

[1] LT for low temperatures [2] RT for room temperature

⇒ **EN-GJS-400-18**: Cast iron with spheroidal (nodular) graphite, minimum tensile strength $R_m$ = 400 N/mm²; elongation at fracture $EL$ = 18%

**Hardness HB as identifying characteristic**

| Type | | Tensile strength $R_m$ | Yield strength $R_{p0.2}$ | Brinell hardness | Properties, application examples |
|---|---|---|---|---|---|
| Designation | Material number | N/mm² | N/mm² | HB | |
| EN-GJS-HB130 | EN-JS2010 | 350 | 220 | < 160 | By specifying hardness values the purchaser can better adapt process parameters to machining of the cast parts. Applications as above. |
| EN-GJS-HB150 | EN-JS2020 | 400 | 250 | 130–175 | |
| EN-GJS-HB155 | EN-JS2030 | 400 | 250 | 135–180 | |
| EN-GJS-HB185 | EN-JS2040 | 450 | 310 | 160–210 | |
| EN-GJS-HB200 | EN-JS2050 | 500 | 320 | 170–230 | |
| EN-GJS-HB230 | EN-JS2060 | 600 | 370 | 190–270 | |
| EN-GJS-HB265 | EN-JS2070 | 700 | 420 | 225–305 | |
| EN-GJS-HB300 | EN-JS2080 | 800 | 480 | 245–335 | |
| EN-GJS-HB330 | EN-JS2090 | 900 | 600 | 270–360 | |

⇒ **EN-GJS-HB130**: Cast iron with spheroidal (nodular) graphite, Brinell hardness HB 130, maximum hardness

# Malleable cast iron, Cast steel

## Malleable cast iron[1)]

cf. DIN EN 1562 (2006-08)

| Type: Designation | Material number | Tensile strength $R_m$ N/mm² | Yield strength $R_{p0.2}$ N/mm² | Elongation at fracture $EL$ % | Brinell hardness HB | Properties, application examples |
|---|---|---|---|---|---|---|
| **Decarburizing annealed malleable cast iron (whiteheart malleable cast iron)** | | | | | | |
| EN-GJMW-350-4 | EN-JM1010 | 350 | – | 4 | 230 | All types have good castability and good machinability. Workpieces with low wall thickness, e. g. levers, chain links |
| EN-GJMW-400-5 | EN-JM1030 | 400 | 220 | 5 | 220 | |
| EN-GJMW-450-7 | EN-JM1040 | 450 | 260 | 7 | 250 | |
| EN-GJMW-550-4 | EN-JM1050 | 550 | 340 | 4 | 250 | |
| EN-GJMW-360-12 | EN-JM1020 | 360 | 190 | 12 | 200 | Especially well suited for welding. |
| ⇒ **EN-GJMW-350-4:** Whiteheart malleable cast iron, $R_m$ = 350 N/mm², $EL$ = 4% | | | | | | |
| **Non-decarburizing annealed malleable iron (blackheart malleable cast iron)** | | | | | | |
| EN-GJMB-300-6 | EN-JM1110 | 300 | – | 6 | ~150 | High pressure tightness |
| EN-GJMB-350-10 | EN-JM1130 | 350 | 200 | 10 | ~150 | All types have good castability and good machinability. Workpieces with high wall thickness, e. g. housings, universal joint yokes pistons |
| EN-GJMB-450-6 | EN-JM1140 | 450 | 270 | 6 | 150–200 | |
| EN-GJMB-500-5 | EN-JM1150 | 500 | 300 | 5 | 165–215 | |
| EN-GJMB-550-4 | EN-JM1160 | 550 | 340 | 4 | 180–230 | |
| EN-GJMB-600-3 | EN-JM1170 | 600 | 390 | 3 | 195–245 | |
| EN-GJMB-650-2 | EN-JM1180 | 650 | 430 | 2 | 210–260 | |
| EN-GJMB-700-2 | EN-JM1190 | 700 | 530 | 2 | 240–290 | |
| EN-GJMB-800-1 | EN-JM1200 | 800 | 600 | 1 | 270–320 | |
| ⇒ **EN-GJMB-350-10:** Non-decarburizing annealed malleable cast iron, $R_m$ = 350 N/mm², $EL$ = 10% | | | | | | |

[1)] Previous designations: page 159

## Cast steel for general applications (selection)

cf. DIN EN 10293 (2005-06)[1)]

| Type: Designation | Material number | Tensile strength $R_m$ N/mm² | Yield strength $R_{p0.2}$ N/mm² | Elongation $EL$ % | Notch impact energy $K_v$ J | Properties, application examples |
|---|---|---|---|---|---|---|
| GE200[2)] | 1.0420 | 380–530 | 200 | 25 | 27 | For workpieces with average dynamic loading; wheel spiders, levers |
| GE240[2)] | 1.0445 | 450–600 | 240 | 22 | 31 | |
| GE300[2)] | 1,0558 | 600–750 | 300 | 15 | 27 | |
| G17Mn5[3)] | 1.1131 | 450–600 | 240 | 24 | 70 | Improved weldability; composite welded structures |
| G20Mn5[2)] | 1.6220 | 480–620 | 300 | 20 | 60 | |
| GX4CrNiMo16-5-1[3)] | 1.4405 | 760–960 | 540 | 15 | 60 | |
| G28Mn6[2)] | 1.1165 | 520–670 | 260 | 18 | 27 | For workpieces with high dynamic loading; shafts |
| G10MnMoV6-3[3)] | 1.5410 | 600–750 | 500 | 18 | 60 | |
| G34CrMo4[3)] | 1.7230 | 620–770 | 480 | 10 | 35 | |
| G32NiCrMo8-5-4[3)] | 1.6570 | 850–1000 | 700 | 16 | 50 | For corrosion-protected workpieces with high dynamic loading |
| GX23CrMoV12-1[3)] | 1.4931 | 740–880 | 540 | 15 | 27 | |

[1)] DIN 17182 "Steel cast types with improved weldability and toughness" was withdrawn without replacement.
[2)] normalized [3)] quenched and tempered

## Cast steel for pressure vessels (selection)

cf. DIN EN 10213 (2004-03)

| Type: Designation | Material number | Tensile strength[1)] $R_m$ N/mm² | Yield strength[1)] $R_{p0.2}$ N/mm² | Elongation at fracture $EL$ % | Notch impact energy $K_v$ J | Properties, application examples |
|---|---|---|---|---|---|---|
| GP240GH | 1.0619 | 420 | 240 | 22 | 27 | For high and low temperatures, e. g. steam turbines, super heated steam armatures, also corrosion resistant |
| G17CrMo5-5 | 1.7357 | 490 | 315 | 20 | 27 | |
| GX8CrNi12 | 1.4107 | 540 | 355 | 18 | 45 | |
| GX4CrNiMo16-5-1 | 1.4405 | 760 | 540 | 15 | 60 | |

[1)] Values for a wall thickness up to 40 mm

# Patterns, Pattern equipment and core boxes

cf. DIN EN 12890 (2000-06)

## Materials and grades

| Characteristics | Materials | | |
|---|---|---|---|
| | Wood | Plastic | Metal |
| Type of material | Plywood, particle board or sandwich board, hard and soft wood | Epoxy resins or polyurethane with fillers | Cu, Sn, Zn alloys<br>Al alloys<br>Cast iron or steel |
| Application | Recurring individual pieces and smaller lots, low precision requirements; normally hand molding | Jobbing work and volume production with higher precision requirements; hand and machine molding | Moderate to large volumes with high precision requirements; machine molding |
| Max. production run for molding | approx. 750 | approx. 10000 | approx. 150000 |
| Quality classes[1] | W1[2], W2, H3 | P1[2], P2 | M1[2], M2 |
| Surface quality | Sand paper 60–80 grit | *Ra* = 12.5 µm | *Ra* = 3.2–6.3 µm |

[1] Classification system for the manufacture and use of patterns, pattern equipment and core boxes, according to their application, quality and service life: W wood; P plastic; M metal

[2] best grade

## Mold draft for sand casting

| Height *h* | Mold draft *T* in mm | | | | | |
|---|---|---|---|---|---|---|
| | Small draft surfaces | | | Large draft surfaces | | |
| | Hand molding | | Machine molding | Hand molding | | Machine molding |
| mm | Molding sand clay bonded | Molding sand chem. bonded | | Molding sand clay bonded | Molding sand chem. bonded | |
| –30 | 1.0 | 1.0 | 1.0 | 1.5 | 1.0 | 1.0 |
| > 30–80 | 2.0 | 2.0 | 2.0 | 2.5 | 2.0 | 2.0 |
| > 80–180 | 3.0 | 2.5 | 2.5 | 3.0 | 3.0 | 3.0 |
| > 180–250 | 3.5 | 3.0 | 3.0 | 4.0 | 4.0 | 4.0 |
| > 250–1000 | + 1.0 mm each 250 mm | | | | | |
| > 1000–4000 | + 2.0 mm each 1 000 mm | | | | | |

## Paint and color codes on patterns

| Surface or partial surface | Cast steel | Nodular cast iron | Gray cast iron | Malleable iron | Heavy metal castings | Light alloy castings |
|---|---|---|---|---|---|---|
| Basic color for areas that should remain unmachined on the casting | blue | purple | red | gray | yellow | green |
| Areas to be machined on the casting | yellow stripes | yellow stripes | yellow stripes | yellow stripes | red stripes | yellow stripes |
| Locations of loose parts and their attachments | framed in black | | | | | |
| Locations of chill plates | red | red | blue | red | blue | blue |
| Core marks | black | | | | | |
| Risers | yellow stripes | | | | | |

# Shrinkage allowances, Dimensional tolerances, Molding and casting methods

## Shrinkage allowances

cf. DIN EN 12890 (2000-06)

| Cast iron | Shrinkage allowance in % | Other casting materials | Shrinkage allowance in % |
|---|---|---|---|
| with flake graphite | 1.0 | Cast steel | 2.0 |
| with spheroidal graphite, annealed | 0.5 | Austenitic manganese cast steel | 2.3 |
| with spheroidal graphite, not annealed | 1.2 | Al, Mg, CuZn alloys | 1.2 |
| austenitic | 2.5 | CuSnZn, Zn alloys | 1.3 |
| malleable cast iron, decarburizing anneal | 1.6 | CuSn alloys | 1.5 |
| malleable cast iron, no decarburizing anneal | 0.5 | Cu | 1.9 |

## Dimensional tolerances and machining allowances, RMA

cf. DIN ISO 8062 (1998-08)

**Examples of tolerance specifications in a drawing:**

1. **ISO 8062-CT12-RMA6 (H)**
   Tolerance grade 12, material allowance 6 mm
2. Individual tolerances and machining allowances are given directly after a dimension.

*R* rough casting – nominal dimension
*F* dimension after finishing
*CT* casting tolerance grade
*T* total casting tolerance
*RMA* material allowance for machining

$$R = F + 2 \cdot RMA + T/2$$

### Casting tolerances

| Nominal dimensions in mm | Total casting tolerance *T* in mm for casting tolerance grade *CT* | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
| –10 | 0.09 | 0.13 | 0.18 | 0.26 | 0.36 | 0.52 | 0.74 | 1.0 | 1.5 | 2.0 | 2.8 | 4.2 | – | – | – | – |
| > 10–16 | 0.10 | 0.14 | 0.20 | 0.28 | 0.38 | 0.54 | 0.78 | 1.1 | 1.6 | 2.2 | 3.0 | 4.4 | – | – | – | – |
| > 16–25 | 0.11 | 0.15 | 0.22 | 0.30 | 0.42 | 0.58 | 0.82 | 1.2 | 1.7 | 2.4 | 3.2 | 4.6 | 6 | 8 | 10 | 12 |
| > 25–40 | 0.12 | 0.17 | 0.24 | 0.32 | 0.46 | 0.64 | 0.9 | 1.3 | 1.8 | 2.6 | 3.6 | 5 | 7 | 9 | 11 | 14 |
| > 40–63 | 0.13 | 0.18 | 0.26 | 0.36 | 0.50 | 0.70 | 1.0 | 1.4 | 2.0 | 2.8 | 4.0 | 5.6 | 8 | 10 | 12 | 16 |
| > 63–100 | 0.14 | 0.20 | 0.28 | 0.40 | 0.56 | 0.78 | 1.1 | 1.6 | 2.2 | 3.2 | 4.4 | 6 | 9 | 11 | 14 | 18 |
| > 100–160 | 0.15 | 0.22 | 0.30 | 0.44 | 0.62 | 0.88 | 1.2 | 1.8 | 2.5 | 3.6 | 5 | 7 | 10 | 12 | 16 | 20 |
| > 160–250 | – | 0.24 | 0.34 | 0.50 | 0.70 | 1.0 | 1.4 | 2.0 | 2.8 | 4.0 | 5.6 | 8 | 11 | 14 | 18 | 22 |
| > 250–400 | – | – | 0.40 | 0.56 | 0.78 | 1.1 | 1.6 | 2.2 | 3.2 | 4.4 | 6.2 | 9 | 12 | 16 | 20 | 25 |
| > 400–630 | – | – | – | 0.64 | 0.90 | 1.2 | 1.8 | 2.6 | 3.6 | 5 | 7 | 10 | 14 | 18 | 22 | 28 |
| > 630–1000 | – | – | – | – | 1.0 | 1.4 | 2.0 | 2.8 | 4 | 6 | 8 | 11 | 16 | 20 | 25 | 32 |

## Molding and casting methods

| Method | Application | Advantages and disadvantages | Casting material | Relative dimensional accuracy[1] in mm/mm | Achievable roughness *Ra* in µm |
|---|---|---|---|---|---|
| Hand molding | large castings, small lots | all sizes, expensive, low dimensional accuracy | GJL, GJS, GS, GJM, Al and Cu alloys | 0.00–0.10 | 40–320 |
| Machine molding | small to medium sized parts, volume | dimensionally accurate, good surface | GJL, GJS, GS, GJM, Al alloys | 0.00–0.06 | 20–160 |
| Vacuum molding | medium to large parts, volumes | dimensionally accurate, good surface, high investment costs | GJL, GJS, GS, GJM, Al and Cu alloys | 0.00–0.08 | 40–160 |
| Shell molding | small parts, large volumes | dimensionally accurate, high mold costs | GJL, GS, Al and Cu alloys | 0.00–0.06 | 20–160 |
| Investment casting | small parts, large volumes | complex parts, high mold costs | GS, Al alloys | 0.00–0.04 | 10–80 |
| Die casting | small to medium sized parts, large volumes | dimensionally accurate even with thin walls, fine-grain structure, high investment costs | hot chamber: Zn, Pb, Sn, Mg cold chamber: Cu, Al | 0.00–0.04 | 10–40 |

[1] The ratio of largest relative deviation to the nominal dimension is called the relative dimensional accuracy.

# Aluminum, Aluminum alloys – Overview

| Alloy group | Material number | Main characteristics | Main areas of application | Product shapes[1] S | B | T |
|---|---|---|---|---|---|---|
| **Pure aluminum** | | | | | | page 166 |
| Al (Al content > 99.00%) | AW-1000 to AW-1990 (Series1000) | • very good cold workability<br>• weldable and brazable<br>• difficult for cutting machining<br>• corrosion resistant<br>• anodized for decorative purposes | Containers, conduits and equipment for the food and chemical industry, electrical conductors, reflectors, trims, license plates in automotive manufacturing | • | • | • |
| **Aluminum, wrought aluminum alloys,** non-heat treatable (selection) | | | | | | page 166 |
| AlMn | AW-3000 to AW-3990 (Series 3000) | • cold workable<br>• weldable and solderable<br>• good machinability in work-hardened condition<br>Compared to Series 1000:<br>• higher strength<br>• improved lye resistivity | Roofing, siding, and supporting structures in the construction industry, parts for radiators and air conditioning units in automotive manufacturing, drink and food cans in the packaging industry | • | • | • |
| AlMg | AW-5000 to AW-5990 (Series 5000) | • good cold workability with high work hardening<br>• limited weldability<br>• good machinability in work-hardened condition and with higher alloy contents<br>• weather and saltwater resistant | Lightweight material for superstructures of commercial vehicles, tank and silo trucks, metal signs, traffic sign, rolling shutters and doors, windows, doors, hardware in the construction industry, machine frames, parts in the construction of jigs and fixtures and mold making | • | • | • |
| AlMgMn | | • good cold workability with high work hardening<br>• good weldability<br>• good cutting machinability<br>• saltwater resistant | | • | • | • |
| **Aluminum, wrought aluminum alloys,** heat treatable (selection) | | | | | | page 167 |
| AlMgSi | AW-6000 to AW-6990 (Series 6000) | • good cold and hot workability<br>• corrosion resistant<br>• good weldability<br>• good cutting machinability in heat treated condition | Load-bearing structures in the construction industry, windows, doors, machine beds, hydraulic and pneumatic parts;<br>with Pb, Sn or Bi additions: very good cutting machinable free cutting alloys | •[2] | •[2] | •[2] |
| AlCuMg | AW-2000 to AW-2990 (Series 2000) | • high-strength values<br>• good high-temperature strength<br>• limited corrosion resistance<br>• limited weldability<br>• good cutting machinability in heat treated condition | Lightweight material in automotive and aircraft construction;<br>with Pb, Sn or Bi additions: very good cutting machinable free cutting alloys | •[2] | •[2] | •[2] |
| AlZnMgCu | AW-7000 to AW-7990 (Series 7000) | • highest strength of all Al alloys<br>• best corrosion resistance in artificially aged condition<br>• limited weldability<br>• good cutting machinability in heat treated condition | High-strength lightweight material in aircraft industry, machine construction, tools and molds for plastic molding, screws, extruded parts | • | • | • |

[1] Product forms: S sheet; B bars; T tubes

[2] Free machining alloys are only delivered as bars or tubes.

# Aluminum, wrought aluminum alloys: Designations and material numbers

## Designations for aluminum and wrought aluminum alloys

cf. DIN EN 573-2 (1994-12)

The designations apply to wrought products, e.g. sheet, bars, tubes, wires and for wrought parts.

**Designation examples:**

**EN AW - Al 99,98**
**EN AW - Al Mg1SiCu - H111**

| | |
|---|---|
| EN | European standard |
| AW | Aluminum wrought products |

| **Chemical composition, purity** | | |
|---|---|---|
| Al 99.98 | → | pure aluminum, degree of purity 99,98% Al |
| Mg1SiCu | → | 1% Mg, low percentage of Si and Cu |

**Material condition** (excerpt)

cf. DIN EN 515 (1993-12)

| Condition | Symbol | Meaning of the symbol | Meaning of the material conditions |
|---|---|---|---|
| manufactured condition | F | Wrought products are manufactured without specifying mechanical limits, e.g. tensile strength, yield strength, elongation at fracture | Wrought products without secondary operations |
| spheroidized | O<br>O1<br>O2 | Spheroidizing can be replaced by hot working<br>Solution annealed, cooled slowly to room temperature<br>Thermomechanically formed, highest workability | To restore workability after cold working |
| Work hardened | H12 to H18 | Work hardened with the following hardness grades:<br>H12 H14 H16 H18<br>1/4 hard 1/2 hard 3/4 hard 4/4 hard | To assure guaranteed mechanical values, e.g. tensile strength, yield strength |
| | H111<br>H112 | Annealed with subsequent slight work hardening<br>Slight work hardening | |
| Heat treated | T1<br>T2<br>T3 | Solution annealed, stress relieved and naturally age hardened, not redressed<br>Quenched like T1, cold worked and naturally aged<br>Solution heat treated, cold worked and naturally age hardened | To increase in tensile strength, yield strength and hardness, reduction of the cold workability |
| | T3510<br>T3511 | Solution annealed, stress relieved and naturally aged<br>Like T3510, redressed to hold the limit deviations | |
| | T4<br>T4510 | Solution annealed, naturally age hardened<br>Solution annealed, stress relieved and naturally age hardened, not redressed | |
| | T6<br>T6510 | Solution annealed, artificially aged<br>Solution annealed, stress relieved and artificially aged, not redressed | |
| | T8<br>T9 | Solution annealed, cold worked, artificially aged<br>Solution annealed, artificially aged, cold worked | |

## Material numbers for aluminum and wrought aluminum alloys

cf. DIN EN 573-1 (1994-12)

Material numbers apply to wrought products, e.g. sheet, bars, tubes, wires and for wrought parts.

**Designation examples:**

**EN AW - 1050A**
**EN AW - 5154**

| | |
|---|---|
| EN | European standard |
| AW | Aluminum wrought products |

Indicates that country-specific limits deviate from the original alloy.

**Alloy groups**

| Number | Group | Number | Group |
|---|---|---|---|
| 1<br>2 | pure Al<br>AlCu | 5<br>6 | AlMg<br>AlMgSi |
| 3<br>4 | AlMn<br>AlSi | 7<br>8 | AlZn<br>other |

**Alloy modifications**

| | | |
|---|---|---|
| 0 | → | Original alloy |
| 1–9 | → | Alloys that deviate from the original alloy |

**Type number**

Within an alloy group, e.g. AlMgSi, each type is assigned its own number.

# Aluminum, wrought aluminum alloys

## Aluminum and wrought aluminum alloys, non-heat treatable (selection)

cf. DIN EN 485-2 (2004-09), DIN EN 754-2, 755-2 (2008-06)

| Designation (material-number)[1] | Delivery forms[2] R | S | DC[3] | Material condition[4] | Thickness/ diameter mm | Tensile strength $R_m$ N/mm² | Yield strength $R_{p\,0.2}$ N/mm² | Elong. at fracture $EL$ % | Applications, Examples |
|---|---|---|---|---|---|---|---|---|---|
| Al 99.5 (1050A) | • | – | p | F, H112 | ≤ 200 | ≥ 60 | ≥ 20 | 25 | Equipment manufacturing, pressure vessels, signs, packaging, trim |
| | | | z | O, H111 | ≤ 80 | 60–95 | – | 25 | |
| | | | z | H14 | ≤ 40 | 100–135 | ≥ 70 | 6 | |
| | – | • | w | O, H111 | 0,5–1,4 | 65–95 | ≥ 20 | 22 | |
| | | | | | 1,5–2,9 | 65–95 | ≥ 20 | 26 | |
| | | | | | 3,0–5,9 | 65–95 | ≥ 20 | 29 | |
| Al Mn1 (3103) | • | – | p | F, H112 | ≤ 200 | ≥ 95 | ≥ 35 | 25 | Equipment manufacturing, extruded parts, vehicle superstructures, heat exchangers |
| | | | z | O, H111 | ≤ 60 | 95–130 | ≥ 35 | 25 | |
| | | | z | H14 | ≤ 10 | 130–165 | ≥ 110 | 6 | |
| | – | • | w | O, H111 | 0.5–1.4 | 90–130 | ≥ 35 | 19 | |
| | | | | | 1.5–2.9 | 90–130 | ≥ 35 | 21 | |
| | | | | | 3.0–5.9 | 90–130 | ≥ 35 | 24 | |
| Al Mn1Cu (3003) | • | – | p | F, H112 | ≤ 200 | ≥ 95 | ≥ 35 | 25 | Roofing, facades, load-bearing structures in metal working |
| | | | z | O, H111 | ≤ 80 | 95–130 | ≥ 35 | 25 | |
| | | | z | H14 | ≤ 40 | 130–165 | ≥ 110 | 6 | |
| | – | • | w | O, H111 | 0.5–1.4 | 95–135 | ≥ 35 | 17 | |
| | | | | | 1.5–2.9 | 95–135 | ≥ 35 | 20 | |
| | | | | | 3.0–5.9 | 95–135 | ≥ 35 | 23 | |
| Al Mg1 (5005) | • | – | p | F, H112 | ≤ 200 | ≥ 100 | ≥ 40 | 18 | Roofing, facades, windows, doors, hardware |
| | | | z | O, H111 | ≤ 80 | 100–145 | ≥ 40 | 18 | |
| | | | z | H14 | ≤ 40 | ≥ 140 | ≥ 110 | 6 | |
| | – | • | w | O, H111 | 0.5–1.49 | 100–145 | ≥ 35 | 19 | |
| | | | | | 1.5–2.9 | 100–145 | ≥ 35 | 20 | |
| | | | | | 3.0–5.9 | 100–145 | ≥ 35 | 22 | |
| Al Mg2Mn0.3 (5251) | • | – | p | F, H112 | ≤ 200 | ≥ 160 | ≥ 60 | 16 | Equipment and devices for the food industry |
| | | | z | O, H111 | ≤ 80 | 150–200 | ≥ 60 | 17 | |
| | | | z | H14 | ≤ 30 | 200–240 | ≥ 160 | 5 | |
| | – | • | w | O, H111 | 0.5–1.4 | 160–200 | ≥ 60 | 14 | |
| | | | | | 1.5–2.9 | 160–200 | ≥ 60 | 16 | |
| | | | | | 3.0–5.9 | 160–200 | ≥ 60 | 18 | |
| Al Mg3 (5754) | • | – | p | F, H112 | ≤ 150 | ≥ 180 | ≥ 80 | 14 | Equipment manufacturing, aircraft industry, body parts, mold making |
| | | | z | O, H111 | ≤ 80 | 180–250 | ≥ 80 | 16 | |
| | | | z | H14 | ≤ 25 | 240–290 | ≥ 180 | 4 | |
| | – | • | w | O, H111 | 0.5–1.4 | 190–240 | ≥ 80 | 14 | |
| | | | | | 1.5–2.9 | 190–240 | ≥ 80 | 16 | |
| | | | | | 3.0–5.9 | 190–240 | ≥ 80 | 18 | |
| Al Mg5 (5019) | • | – | p | F, H112 | ≤ 200 | ≥ 250 | ≥ 110 | 14 | Optical equipment, packaging |
| | | | z | O, H111 | ≤ 80 | 250–320 | ≥ 110 | 16 | |
| | | | z | H14 | ≤ 40 | 270–350 | ≥ 180 | 8 | |
| Al Mg3Mn (5454) | • | – | p | F, H112 | ≤ 200 | ≥ 200 | ≥ 85 | 10 | Container construction, including pressure vessels, conduits, tank and silo trucks |
| | | | | O, H111 | | 200–275 | ≥ 85 | 18 | |
| | – | • | w | O, H111 | 0.5–1.4 | 215–275 | ≥ 85 | 13 | |
| | | | | | 1.5–2.9 | 215–275 | ≥ 85 | 15 | |
| | | | | | 3.0–5.9 | 215–275 | ≥ 85 | 17 | |
| Al Mg4.5Mn0.7 (5083) | • | – | p | F, H111 | ≤ 200 | ≥ 270 | ≥ 110 | 12 | Mold making and construction of jigs and fixtures, machine frames |
| | | | z | O, H111 | ≤ 80 | 270–350 | ≥ 110 | 16 | |
| | | | z | H12 | ≤ 30 | ≥ 280 | ≥ 200 | 6 | |

[1] For simplification all designations and material numbers are written without the addition "EN AW-".
[2] Delivery forms: R round bar; S sheet, strip
[3] DC Delivery condition: p extruded; z drawn; w cold-rolled
[4] Material condition, see page 165

# Wrought aluminum alloys

**Wrought aluminum alloys,** heat treatable (selection)

cf. DIN EN 485-2 (2004-09), DIN EN 754-2, 755-2 (2008-06)

| Designation (material-number)[1] | Delivery forms[2] R | S | DC[3] | Material condition[4] | Thickness/ diameter mm | Tensile strength $R_m$ N/mm² | Yield strength $R_{p\,0.2}$ N/mm² | Elong. at fracture $EL$ % | Application, Examples |
|---|---|---|---|---|---|---|---|---|---|
| Al Cu4PbMgMn (2007) | • | – | p | T4, T4510 | ≤ 80 | ≥ 370 | ≥ 250 | 8 | Free cutting alloys, also good machinability at high machining outputs, e. g. for turned parts, milled parts |
| | | | z | T3 | ≤ 30 | ≥ 370 | ≥ 240 | 7 | |
| | | | z | T3 | 30–80 | ≥ 340 | ≥ 220 | 6 | |
| Al Cu4PbMg (2030) | • | – | p | T4, T4510 | ≤ 80 | ≥ 370 | ≥ 250 | 8 | |
| | | | z | T3 | ≤ 30 | ≥ 370 | ≥ 240 | 7 | |
| | | | z | T3 | 30–80 | ≥ 340 | ≥ 220 | 6 | |
| Al MgSiPb (6012) | • | – | p | T5, T6510 | ≤ 150 | ≥ 310 | ≥ 260 | 8 | |
| | | | z | T3 | ≤ 80 | ≥ 200 | ≥ 100 | 10 | |
| | | | z | T6 | ≤ 80 | ≥ 310 | ≥ 260 | 8 | |
| Al Cu4SiMg (2014) | • | – | p | O, H111 | ≤ 200 | ≤ 250 | ≤ 135 | 12 | Parts in hydraulic, pneumatic, automotive and aircraft manufacturing, load-bearing structures in metal manufacturing |
| | | | z | T3 | ≤ 80 | ≥ 380 | ≥ 290 | 8 | |
| | | | z | T4 | ≤ 80 | ≥ 380 | ≥ 220 | 12 | |
| | – | • | w | O | 0.5–1.4 | ≤ 220 | ≤ 140 | 12 | |
| | | | | | 1.5–2.9 | ≤ 220 | ≤ 140 | 13 | |
| | | | | | 3.0–5.9 | ≤ 220 | ≤ 140 | 16 | |
| Al Cu4Mg1 (2024) | • | – | p | O, H111 | ≤ 200 | ≤ 250 | ≤ 150 | 12 | Parts in automotive and aircraft manufacturing, load-bearing structures in metal working |
| | | | z | T3 | 10–80 | ≥ 425 | ≥ 290 | 9 | |
| | | | z | T6 | ≤ 80 | ≥ 425 | ≥ 315 | 5 | |
| | – | • | w | O | 0.5–1.4 | ≤ 220 | ≤ 140 | 12 | |
| | | | | | 1.5–2.9 | ≤ 220 | ≤ 140 | 13 | |
| | | | | | 3.0–5.9 | ≤ 220 | ≤ 140 | 13 | |
| Al MgSi (6060) | • | – | p | T4 | ≤ 150 | ≤ 120 | ≤ 60 | 16 | Windows, doors, vehicle superstructures, machine beds, optical equipment |
| | | | z | T4 | ≤ 80 | ≥ 130 | ≥ 65 | 15 | |
| | | | z | T6 | ≤ 80 | ≥ 215 | ≥ 160 | 12 | |
| Al Si1MgMn (6082) | • | – | p | O, H111 | ≤ 200 | ≤ 160 | ≤ 110 | 14 | Hardware, parts in mold making and manufacturing of jigs and fixtures, machine beds, equipment in the food industry |
| | | | z | T4 | ≤ 80 | ≥ 205 | ≥ 110 | 14 | |
| | | | z | T6 | ≤ 80 | ≥ 310 | ≥ 255 | 10 | |
| | – | • | w | O | 0.5–1.4 | ≤ 150 | ≤ 85 | 14 | |
| | | | | | 1.5–2.9 | ≤ 150 | ≤ 85 | 16 | |
| | | | | | 3.0–5.9 | ≤ 150 | ≤ 85 | 18 | |
| Al Zn4.5Mg1 (7020) | • | – | p | T6 | ≤ 50 | ≥ 350 | ≥ 290 | 10 | Parts in automotive and aircraft manufacturing, machine beds, superstructures of rail cars |
| | | | z | T6 | ≤ 80 | ≥ 350 | ≥ 280 | 10 | |
| | – | • | w | O | 0.5–1.4 | ≤ 220 | ≤ 140 | 12 | |
| | | | | | 1.5–2.9 | ≤ 220 | ≤ 140 | 13 | |
| | | | | | 3.0–5.9 | ≤ 220 | ≤ 140 | 15 | |
| Al Zn5Mg3Cu (7022) | • | – | p | T6, T6510 | ≤ 80 | ≥ 490 | ≥ 420 | 7 | Parts in hydraulic, pneumatic and aircraft manufacturing, screws |
| | | | z | T6 | ≤ 80 | ≥ 460 | ≥ 380 | 8 | |
| | – | • | w | T6 | 3.0–12 | ≥ 450 | ≥ 370 | 8 | |
| | | | | | 12.5–24 | ≥ 450 | ≥ 370 | 8 | |
| | | | | | 25–50 | ≥ 450 | ≥ 370 | 7 | |
| Al Zn5.5MgCu (7075) | • | – | p | O, H111 | ≤ 200 | ≤ 275 | ≤ 165 | 10 | Parts in automotive and aircraft manufacturing, mold making and manufacturing of jigs and fixtures, screws |
| | | | z | T6 | ≤ 80 | ≥ 540 | ≥ 485 | 7 | |
| | | | z | T73 | ≤ 80 | ≥ 455 | ≥ 385 | 10 | |
| | – | • | w | O | 0.4–0.75 | ≥ 275 | ≥ 145 | 10 | |
| | | | | | 0.8–1.45 | ≥ 275 | ≥ 145 | 10 | |
| | | | | | 1.5–2.9 | ≥ 275 | ≥ 145 | 10 | |

[1] For simplification all designations and material numbers are written without the addition "EN AW-".
[2] Delivery forms: R round bar; S sheet, strip
[3] DC Delivery condition: p extruded; z drawn; w cold-rolled
[4] Material condition, see page 165

# Aluminum casting alloys

## Designation of aluminum castings

cf. DIN EN 1780-1...3 (2003-01), DIN EN 1706 (1998-06)

Aluminum castings are identified by designations or material numbers.

**Designation examples:**

**Designation**
EN AC - Al Mg5KF

EN European standard
AC Aluminum casting

K → casting method
F → material condition
(table below)

**Material number**
EN AC - 51300KF

K → casting method
F → material condition
(table below)

| Chemical composition | |
|---|---|
| Example | Alloy percentage |
| AlMg5<br>AlSi6Cu | 5% Mg<br>6% Si, additions of Cu |
| AlCu4MgTi | 4% Cu, additions of Mg and Ti |

| Alloy groups | | | |
|---|---|---|---|
| No. | Group | No. | Group |
| 21<br>41 | AlCu<br>AlSiMgTi | 46<br>47 | AlSi9Cu<br>AlSi(Cu) |
| 42<br>44 | AlSi7Mg<br>AlSi | 51<br>71 | AlMg<br>AlZnMg |

**Type number**

Within one alloy group each type has its own number.

| Casting method | | Material condition | |
|---|---|---|---|
| Letter | Casting method | Letter | Meaning |
| S<br>K<br>D<br>L | Sand casting<br>Permanent mold casting<br>Die casting<br>Investment casting | F<br>O | Casting condition, without subsequent processing<br>Spheroidized |
| | | T1<br>T4 | Controlled cooling after pouring, naturally aged<br>Solution annealed and naturally aged |
| | | T5<br>T6 | Controlled cooling after pouring, artificially aged<br>Solution annealed and artificially aged |

## Aluminum casting alloys

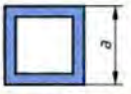
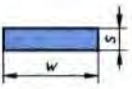
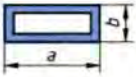
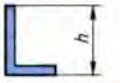
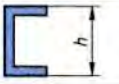
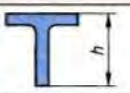
cf. DIN EN 1706 (1998-06)

| Designation (material-number)[1] | C[2] | M[3] | Strength values in casting condition (F) Hardn. strength HB | Tensile strength $R_m$ N/mm² | Yield $R_{p\,0,2}$ N/mm² | Elongation at fracture $EL$ % | Properties[4] C | P | M | Application |
|---|---|---|---|---|---|---|---|---|---|---|
| AC-AlMg3<br>(AC-51000) | S<br>K | F<br>F | 50<br>50 | 140<br>150 | 70<br>70 | 3<br>5 | – | – | • | Corrosion resistant, polishable, anodized for decorative purposes; fittings, household appliances, ship building, chemical industry |
| AC-AlMg5<br>(AC-51300) | S<br>K | F<br>F | 55<br>60 | 160<br>180 | 90<br>100 | 3<br>4 | – | – | • | |
| AC-AlMg5(Si)<br>(AC-51400) | S<br>K | F<br>F | 60<br>65 | 160<br>180 | 100<br>110 | 3<br>3 | – | – | • | |
| AC-AlSi12<br>(AC-44100) | S<br>K<br>L | F<br>F<br>F | 50<br>55<br>60 | 150<br>170<br>160 | 70<br>80<br>80 | 4<br>5<br>1 | • | • | ○ | Resistant to weather influences, for complex, thin-walled and pressure-tight parts; pump and motor housings, cylinder heads, parts in aircraft manufacturing |
| AC-AlSi7Mg<br>(AC-42000) | S<br>K<br>L | T6<br>T6<br>T6 | 75<br>90<br>75 | 220<br>260<br>240 | 180<br>220<br>190 | 2<br>1<br>1 | ○ | • | ○ | |
| AC-AlSi12(Cu)<br>(AC-47000) | S<br>K | F<br>F | 50<br>55 | 150<br>170 | 80<br>90 | 1<br>2 | • | • | – | |
| AC-AlCu4Ti<br>(AC-21100) | S<br>K | T6<br>T6 | 95<br>95 | 300<br>330 | 200<br>220 | 3<br>7 | – | – | • | Highest strength values, vibration and high temp. resistance; simple castings |

[1] For simplification all designations and material numbers are written without "EN", e.g. AC-AlMg3 instead of EN AC-AlMg3 or AC-51000 instead of EN AC-51000.
[2] C casting method (table above)
[3] M material condition (table above)
[4] C castability, P pressure tightness, M machinability; • very good, ○ good, – conditionally good

# Aluminum profiles – Overview, Round bars, Flat bars

## Aluminum sections, Overview

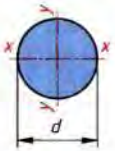
| Illustration | Fabrication, dimensions | Standard | Illustration | Fabrication, dimensions | Standard |
|---|---|---|---|---|---|
| **Round bars** | | | **Round tubes** | | |
|  | extruded<br>$d$ = 3–100 mm | DIN EN 755-3 |  | seamless extruded<br>$d$ = 20–250 mm | DIN EN 755-7 |
| | drawn<br>$d$ = 8–320 mm | DIN EN 754-3 | | cold-drawn seamless<br>$d$ = 3–270 mm | DIN EN 754-7 |
| **Square bars** | | | **Square tubes** | | |
|  | extruded<br>$s$ = 10–220 mm | DIN EN 755-4 |  | extruded<br>$a$ = 15–100 mm | DIN EN 754-4 |
| | drawn<br>$s$ = 3–100 mm | DIN EN 754-4 | | | |
| **Flat bars** | | | **Flat tubes** | | |
|  | extruded<br>$w$ = 10–600 mm<br>$s$ = 2–240 mm | DIN EN 755-4 |  | extruded seamless<br>$a$ = 15–250 mm<br>$b$ = 10–100 mm | DIN EN 755-7 |
| | drawn<br>$w$ = 5–200 mm<br>$s$ = 2–60 mm | DIN EN 754-4 | | cold-drawn seamless<br>$a$ = 15–250 mm<br>$b$ = 10–100 mm | DIN EN 754-7 |
| **Sheet and strip** | | | **L profiles** | | |
|  | rolled<br>$s$ = 0.4–15 mm | DIN EN 485 |  | sharp corners or round corners<br>$h$ = 10–200 mm | DIN 1771[1] |
| **Channels** | | | **Tees** | | |
|  | sharp corners or round corners<br>$h$ = 10–160 mm | DIN 9713[1] |  | sharp corners or round corners<br>$h$ = 15–100 mm | DIN 9714[1] |

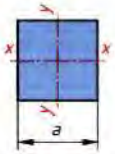
[1] Standards were withdrawn without replacement.

## Round bars, Flat bars, drawn

cf. DIN EN 754-3, 754-4 (1996-01), DIN 1798[1], DIN 1796[1]

$S$ cross-sectional area
$m'$ linear mass density
$W$ axial section modulus
$I$ axial moment of inertia




| $d$, $a$ mm | $S$ cm² ○ | $S$ cm² □ | $m'$ kg/m ○ | $m'$ kg/m □ | $W_x = W_y$ cm³ ○ | $W_x = W_y$ cm³ □ | $I_x = I_y$ cm⁴ ○ | $I_x = I_y$ cm⁴ □ |
|---|---|---|---|---|---|---|---|---|
| 10 | 0.79 | 1.00 | 0.21 | 0.27 | 0.10 | 0.17 | 0.05 | 0.08 |
| 12 | 1.13 | 1.44 | 0.31 | 0.39 | 0.17 | 0.29 | 0.10 | 0.17 |
| 16 | 2.01 | 2.56 | 0.54 | 0.69 | 0.40 | 0.68 | 0.32 | 0.55 |
| 20 | 3.14 | 4.00 | 0.85 | 1.08 | 0.79 | 1.33 | 0.79 | 1.33 |
| 25 | 4.91 | 6.25 | 1.33 | 1.69 | 1.53 | 2.60 | 1.77 | 3.26 |
| 30 | 7.07 | 9.00 | 1.91 | 2.43 | 2.65 | 4.50 | 3.98 | 6.75 |
| 35 | 9.62 | 12.25 | 2.60 | 3.31 | 4.21 | 7.15 | 7.37 | 12.51 |
| 40 | 12.57 | 16.00 | 3.40 | 4.32 | 6.28 | 10.68 | 12.57 | 21.33 |
| 45 | 15.90 | 20.25 | 4.30 | 5.47 | 8.95 | 15.19 | 20.13 | 34.17 |
| 50 | 19.64 | 25.00 | 5.30 | 6.75 | 12.28 | 20.83 | 30.69 | 52.08 |
| 55 | 23.76 | 30.25 | 6.42 | 8.17 | 16.33 | 27.73 | 44.98 | 76.26 |
| 60 | 28.27 | 36.00 | 7.63 | 9.72 | 21.21 | 36.00 | 63.62 | 108.00 |
| Materials | Wrought aluminum alloys, see pages 166 and 167. | | | | | | | |

[1] DIN 1796 und DIN 1798 were replaced by DIN EN 754-3 or DIN EN 754-4. The DIN EN standards contain no dimensions. However, dealers continue to offer DIN 1798 and DIN 1796 round and square bars.

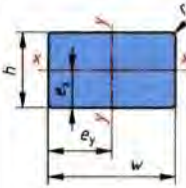
○ round bars; □ square bars

# Flat bars from aluminum alloys

**Flat bars, drawn** (selection) — cf. DIN EN 754-5 (1996-01), replaces DIN 1769[1)]

$S$ cross-sectional area
$m'$ linear mass density
$e$ distance to edge
$W$ axial section modulus
$I$ axial moment of inertia

| $w \times h$ mm | $S$ cm² | $m'$ kg/m | $e_x$ cm | $e_y$ cm | $W_x$ cm³ | $I_x$ cm⁴ | $W_y$ cm³ | $I_y$ cm⁴ |
|---|---|---|---|---|---|---|---|---|
| 10 × 3 | 0.30 | 0.08 | 0.15 | 0.5 | 0.015 | 0.0007 | 0.033 | 0.016 |
| 10 × 6 | 0.60 | 0.16 | 0.3 | 0.5 | 0.060 | 0.018 | 0.100 | 0.050 |
| 10 × 8 | 0.80 | 0.22 | 0.4 | 0.5 | 0.106 | 0.042 | 0.133 | 0.066 |
| 15 × 3 | 0.45 | 0.12 | 0.15 | 0.75 | 0.022 | 0.003 | 0.112 | 0.084 |
| 15 × 5 | 0.75 | 0.24 | 0.25 | 0.75 | 0.090 | 0.027 | 0.225 | 0.168 |
| 15 × 8 | 1.20 | 0.32 | 0.4 | 0.75 | 0.230 | 0.064 | 0.300 | 0.225 |
| 20 × 5 | 1.00 | 0.27 | 0.25 | 1.0 | 0.083 | 0.020 | 0.333 | 0.333 |
| 20 × 8 | 1.60 | 0.43 | 0.4 | 1.0 | 0.213 | 0.085 | 0.533 | 0.533 |
| 20 × 10 | 2.00 | 0.54 | 0.5 | 1.0 | 0.333 | 0.166 | 0.666 | 0.666 |
| 20 × 15 | 3.00 | 0.81 | 0.75 | 1.0 | 0.750 | 0.562 | 1.000 | 1.000 |
| 25 × 5 | 1.25 | 0.34 | 0.25 | 1.25 | 0.104 | 0.026 | 0.520 | 0.651 |
| 25 × 8 | 2.00 | 0.54 | 0.4 | 1.25 | 0.266 | 0.106 | 0.833 | 1.041 |
| 25 × 10 | 2.50 | 0.67 | 0.5 | 1.25 | 0.416 | 0.208 | 1.041 | 1.302 |
| 25 × 15 | 3.75 | 1.01 | 0.75 | 1.25 | 0.937 | 0.703 | 1.562 | 1.953 |
| 25 × 20 | 5.00 | 1.35 | 1.0 | 1.25 | 1.666 | 1.666 | 2.083 | 2.604 |
| 30 × 10 | 3.00 | 0.81 | 0.5 | 1.5 | 0.500 | 0.250 | 1.500 | 2.250 |
| 30 × 15 | 4.50 | 1.22 | 0.75 | 1.5 | 1.125 | 0.843 | 2.250 | 3.375 |
| 30 × 20 | 6.00 | 1.62 | 1.0 | 1.5 | 2.000 | 2.000 | 3.000 | 4.500 |
| 40 × 10 | 4.00 | 1.08 | 0.5 | 2.0 | 0.666 | 0.333 | 2.666 | 5.333 |
| 40 × 15 | 6.00 | 1.62 | 0.75 | 2.0 | 1.500 | 1.125 | 4.000 | 8.000 |
| 40 × 20 | 8.00 | 2.16 | 1.0 | 2.0 | 2.666 | 2.666 | 5.333 | 10.666 |
| 40 × 25 | 10.00 | 2.70 | 1.25 | 2.0 | 4.166 | 5.208 | 6.666 | 13.333 |
| 40 × 30 | 12.00 | 3.24 | 1.5 | 2.0 | 6.000 | 9.000 | 8.000 | 16.000 |
| 40 × 35 | 14.00 | 3.78 | 1.75 | 2.0 | 8.166 | 14.291 | 9.333 | 18.666 |
| 50 × 10 | 5.00 | 1.35 | 0.5 | 2.5 | 0.833 | 0.416 | 4.166 | 10.416 |
| 50 × 15 | 7.50 | 2.03 | 0.75 | 2.5 | 1.875 | 1.406 | 6.250 | 15.625 |
| 50 × 20 | 10.00 | 2.70 | 1.0 | 2.5 | 3.333 | 3.333 | 8.333 | 20.833 |
| 50 × 25 | 12.50 | 3.37 | 1.25 | 2.5 | 5.208 | 6.510 | 10.416 | 26.041 |
| 50 × 30 | 15.00 | 4.05 | 1.5 | 2.5 | 7.500 | 11.250 | 12.500 | 31.250 |
| 50 × 35 | 17.50 | 4.73 | 1.75 | 2.5 | 10.208 | 17.864 | 14.583 | 36.458 |
| 50 × 40 | 20.00 | 5.40 | 2.0 | 2.5 | 13.333 | 26.666 | 16.666 | 41.668 |
| 60 × 10 | 6.00 | 1.62 | 0.5 | 3.0 | 1.000 | 0.500 | 6.000 | 18.000 |
| 60 × 15 | 9.00 | 2.43 | 0.75 | 3.0 | 2.250 | 1.687 | 9.000 | 27.000 |
| 60 × 20 | 12.00 | 3.24 | 1.0 | 3.0 | 4.000 | 4.000 | 12.000 | 36.000 |
| 60 × 25 | 15.00 | 4.05 | 1.25 | 3.0 | 6.250 | 7.812 | 15.000 | 45.000 |
| 60 × 30 | 18.00 | 4.86 | 1.5 | 3.0 | 9.000 | 13.500 | 18.000 | 54.000 |
| 60 × 35 | 21.00 | 5.67 | 1.75 | 3.0 | 12.250 | 21.437 | 21.000 | 63.000 |
| 60 × 40 | 24.00 | 6.48 | 2.0 | 3.0 | 16.000 | 32.000 | 24.000 | 72.000 |
| 80 × 10 | 8.00 | 2.16 | 0.5 | 4.0 | 1.333 | 0.666 | 10.666 | 42.666 |
| 80 × 15 | 12.00 | 3.24 | 0.75 | 4.0 | 3.000 | 2.250 | 16.000 | 64.000 |
| 80 × 20 | 16.00 | 4.52 | 1.0 | 4.0 | 5.433 | 5.333 | 21.333 | 85.333 |
| 80 × 25 | 20.00 | 5.40 | 1.25 | 4.0 | 8.333 | 10.416 | 26.666 | 106.66 |
| 80 × 30 | 24.00 | 6.48 | 1.5 | 4.0 | 12.000 | 18.000 | 32.000 | 128.00 |
| 80 × 35 | 28.00 | 7.56 | 1.75 | 4.0 | 16.333 | 28.583 | 37.333 | 149.33 |
| 80 × 40 | 32.00 | 8.64 | 2.0 | 4.0 | 21.333 | 42.666 | 42.666 | 170.66 |
| 100 × 20 | 20.00 | 5.40 | 1.0 | 5.0 | 6.666 | 3.666 | 33.333 | 166.66 |
| 100 × 30 | 30.00 | 8.10 | 1.5 | 5.0 | 15.000 | 22.500 | 50.000 | 250.00 |
| 100 × 40 | 40.00 | 10.8 | 2.0 | 5.0 | 26.666 | 53.333 | 66.666 | 333.33 |




**Edge radii $r$**

| $h$ mm | $r_{max}$ mm |
|---|---|
| ≤ 10 | 0.6 |
| > 10–30 | 1.0 |
| > 30–60 | 2.0 |

Material: Wrought aluminum alloys, see pages 166 and 167.

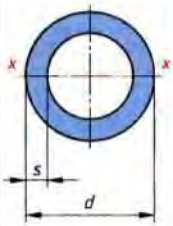
[1)] DIN EN 754-5 contains no dimensions. Specialized dealers still offer flat bars in dimensions according to DIN 1769.

# Round tubes, Channels from aluminum alloys

## Round tubes, cold-drawn seamless (selection)

cf. DIN EN 754-7 (1998-10), replaces DIN 1795[1)]

*d* outside diameter
*s* wall thickness
*S* cross-sectional area
*m'* linear mass density
*W* axial section modulus
*I* axial moment of inertia




| *d* × *s* mm | *S* cm² | *m'* kg/m | $W_x$ cm³ | $I_x$ cm⁴ | *d* × *s* mm | *S* cm² | *m'* kg/m | $W_x$ cm³ | $I_x$ cm⁴ |
|---|---|---|---|---|---|---|---|---|---|
| 10 × 1 | 0.281 | 0.076 | 0.058 | 0.029 | 35 × 3 | 3.016 | 0.814 | 2.225 | 3.894 |
| 10 × 1.5 | 0.401 | 0.108 | 0.075 | 0.037 | 35 × 5 | 4.712 | 1.272 | 3.114 | 5.449 |
| 10 × 2 | 0.503 | 0.136 | 0.085 | 0.043 | 35 × 10 | 7.854 | 2.121 | 4.067 | 7.118 |
| 12 × 1 | 0.346 | 0.093 | 0.088 | 0.053 | 40 × 3 | 3.487 | 0.942 | 3.003 | 6.007 |
| 12 × 1.5 | 0.495 | 0.134 | 0.116 | 0.070 | 40 × 5 | 5.498 | 1.484 | 4.295 | 8.590 |
| 12 × 2 | 0.628 | 0.170 | 0.136 | 0.082 | 40 × 10 | 9.425 | 2.545 | 5.890 | 11.781 |
| 16 × 1 | 0.471 | 0.127 | 0.133 | 0.133 | 50 × 3 | 4.430 | 1.196 | 4.912 | 12.281 |
| 16 × 2 | 0.880 | 0.238 | 0.220 | 0.220 | 50 × 5 | 7.069 | 1.909 | 7.245 | 18.113 |
| 16 × 3 | 1.225 | 0.331 | 0.273 | 0.273 | 50 × 10 | 12.566 | 3.393 | 10.681 | 26.704 |
| 20 × 1.5 | 0.872 | 0.235 | 0.375 | 0.375 | 55 × 3 | 4.901 | 1.323 | 6.044 | 16.201 |
| 20 × 3 | 1.602 | 0.433 | 0.597 | 0.597 | 55 × 5 | 7.854 | 2.110 | 9.014 | 24.789 |
| 20 × 5 | 2.356 | 0.636 | 0.736 | 0.736 | 55 × 10 | 14.137 | 3.817 | 13.655 | 37.552 |
| 25 × 2 | 1.445 | 0.390 | 0.770 | 0.963 | 60 × 5 | 8.639 | 2.333 | 10.979 | 32.938 |
| 25 × 3 | 2.073 | 0.560 | 1.022 | 1.278 | 60 × 10 | 15.708 | 4.241 | 17.017 | 51.051 |
| 25 × 5 | 3.142 | 0.848 | 1.335 | 1.669 | 60 × 16 | 22.117 | 4.890 | 20.200 | 60.600 |
| 30 × 2 | 1.759 | 0.475 | 1.155 | 1.733 | 70 × 5 | 10.210 | 2.757 | 15.498 | 54.242 |
| 30 × 4 | 3.267 | 0.882 | 1.884 | 2.826 | 70 × 10 | 18.850 | 5.089 | 24.908 | 87.179 |
| 30 × 6 | 4.524 | 1.220 | 2.307 | 3.461 | 70 × 16 | 27.143 | 7.331 | 30.750 | 107.62 |

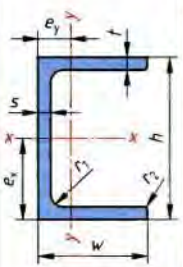
| Material | e.g. aluminum alloys, non-heat treatable, see page 166<br>aluminum alloys, heat-treatable, see page 167 |
|---|---|

[1)] DIN EN 754-7 contains no dimensions. Specialized dealers still offer round tubes in dimensions according to DIN 1795.

## Extruded channel sections (selection)

cf. DIN 9713 (1981-09)[1)]

*w* width
*h* height
*S* cross-sectional area
*m'* linear mass density
*W* axial section modulus
*I* axial moment of inertia




| *h* × *w* × *s* × *t* mm | *S* cm² | *m'* kg/m | $e_x$ cm | $e_y$ cm | $W_x$ cm³ | $I_x$ cm⁴ | $W_y$ cm³ | $I_y$ cm⁴ |
|---|---|---|---|---|---|---|---|---|
| 20 × 20 × 3 × 3 | 1.62 | 0.437 | 1.00 | 0.780 | 0.945 | 0.945 | 0.805 | 0.628 |
| 30 × 30 × 3 × 3 | 2.52 | 0.687 | 1.50 | 1.10 | 2.43 | 3.64 | 2.06 | 2.29 |
| 35 × 35 × 3 × 3 | 2.97 | 0.802 | 1.75 | 1.28 | 3.44 | 6.02 | 2.91 | 3.73 |
| 40 × 15 × 3 × 3 | 1.92 | 0.518 | 2.0 | 0.431 | 2.04 | 4.07 | 0.810 | 0.349 |
| 40 × 20 × 3 × 3 | 2.25 | 0.608 | 2.0 | 0.610 | 2.59 | 5.17 | 1.30 | 0.795 |
| 40 × 30 × 3 × 3 | 2.85 | 0.770 | 2.0 | 3.62 | 7.24 | 2.49 | 2.49 | 2.52 |
| 40 × 30 × 4 × 4 | 3.71 | 1.00 | 2.0 | 1.05 | 4.49 | 8.97 | 3.03 | 3.17 |
| 40 × 40 × 4 × 4 | 4.51 | 1.22 | 2.0 | 1.49 | 5.80 | 11.6 | 4.80 | 7.12 |
| 40 × 40 × 5 × 5 | 5.57 | 1.50 | 2.0 | 1.52 | 6.80 | 13.6 | 5.64 | 8.59 |
| 50 × 30 × 3 × 3 | 3.15 | 0.851 | 2.5 | 0.929 | 4.88 | 12.2 | 2.91 | 2.70 |
| 50 × 30 × 4 × 4 | 4.91 | 1.33 | 2.5 | 1.38 | 7.83 | 19.6 | 5.65 | 7.80 |
| 50 × 40 × 5 × 5 | 6.07 | 1.64 | 2.5 | 1.42 | 9.32 | 23.3 | 6.54 | 9.26 |
| 60 × 30 × 4 × 4 | 4.51 | 1.22 | 3.0 | 0.896 | 7.90 | 23.7 | 4.12 | 3.69 |
| 60 × 40 × 4 × 4 | 5.31 | 1.43 | 3.0 | 1.29 | 10.1 | 30.3 | 6.35 | 8.20 |
| 60 × 40 × 5 × 5 | 6.57 | 1.77 | 3.0 | 1.33 | 12.0 | 36.0 | 7.47 | 9.94 |
| 80 × 40 × 6 × 6 | 8.95 | 2.42 | 4.0 | 1.22 | 20.6 | 82.4 | 10.6 | 20.6 |
| 80 × 45 × 6 × 8 | 11.2 | 3.02 | 4.0 | 1.57 | 27.1 | 108 | 13.9 | 21.8 |
| 100 × 40 × 6 × 6 | 10.1 | 2.74 | 5.0 | 1.11 | 28.3 | 142 | 12.5 | 13.8 |
| 100 × 50 × 6 × 9 | 14.1 | 3.80 | 5.0 | 1.72 | 43.4 | 217 | 19.9 | 34.3 |
| 120 × 55 × 7 × 9 | 17.2 | 4.64 | 6.0 | 1.74 | 61.9 | 295 | 28.2 | 49.1 |
| 140 × 60 × 4 × 6 | 12.35 | 3.35 | 7.0 | 1.83 | 56.4 | 350 | 24.7 | 45.2 |

**Rounded edges $r_1$ and $r_2$**

| *t* mm | $r_1$ mm | $r_2$ mm |
|---|---|---|
| 3, 4 | 2.5 | 0.4 |
| 5, 6 | 4 | 0.6 |
| 8, 9 | 6 | 0.6 |

| Materials | AlMgSi0.5; AlMgSi1; AlZn4.5Mg1 |
|---|---|

[1)] DIN 9713 was withdrawn without replacement. Specialized dealers still offer channels according to this standard.

# Magnesium alloys, Titanium, Titanium alloys

## Wrought magnesium alloys (selection)

cf. DIN 9715 (1982-08)

| Designation | Material-number | Delivery form[1] B | T | D | M[2] | Bar diameter mm | Tensile strength $R_m$ N/mm² | Yield strength $R_{p0,2}$ N/mm² | Elong. at fracture $EL$ % | Properties, application |
|---|---|---|---|---|---|---|---|---|---|---|
| MgMn2 | 3.3520 | • | • | • | F20 | ≤ 80 | 200 | 145 | 15 | Corrosion resistant, weldable, cold workable; cladding, containers |
| MgAl3Zn | 3.5312 | | | | F24 | ≤ 80 | 240 | 155 | 10 | |
| MgAl6Zn | 3.5612 | • | • | • | F27 | ≤ 80 | 270 | 195 | 10 | Higher strength, limited weldability; lightweight material in automotive, machine and aircraft manufacturing |
| MgAl8Zn | 3.5812 | • | • | • | F29 | ≤ 80 | 290 | 205 | 10 | |
| | | | | | F31 | ≤ 80 | 310 | 215 | 6 | |

[1] Delivery forms: B bars, e.g. round bars; T tubes; D stamped part
[2] M material condition F20 → $R_m = 10 \cdot 20 = 200$ N/mm²

## Magnesium casting alloys (selection)

cf. DIN EN 1753 (1997-08)

| Designation[1] | Material-number[1] | M[2] | Material-condition[3] | Hardness HB | Tensile strength $R_m$ N/mm² | Yield strength $R_{p0,2}$ N/mm² | Elong. at fracture $EL$ % | Properties, application |
|---|---|---|---|---|---|---|---|---|
| MCMgAl8Zn1 | MC21110 | S | F | 50–65 | 160 | 90 | 2 | Very good castability, dynamically loadable, weldable; gear and motor housings |
| | | | T6 | 50–65 | 240 | 90 | 8 | |
| | | K | F | 50–65 | 160 | 90 | 2 | |
| | | K | T4 | 50–65 | 160 | 90 | 8 | |
| | | D | F | 60–85 | 200–250 | 140–160 | ≤ 7 | |
| MCMgAl9Zn1 | MC21120 | S | F | 55–70 | 160 | 90 | 6 | High-strength, good sliding properties, weldable; automotive and aircraft manufacturing, armatures |
| | | | T6 | 60–90 | 240 | 150 | 2 | |
| | | K | F | 55–70 | 160 | 110 | 2 | |
| | | K | T6 | 60–90 | 240 | 150 | 2 | |
| | | D | F | 65–85 | 200–260 | 140–170 | 1–6 | |
| MCMgAl6Mn | MC21230 | D | F | 55–70 | 190–250 | 120–150 | 4–14 | Fatigue resistant, dynamically loadable, high temperature resistant, gear and motor housings |
| MCMgAl7Mn | MC21240 | D | F | 60–75 | 200–260 | 130–160 | 3–10 | |
| MCMgAl4Si | MC21320 | D | F | 55–80 | 200–250 | 120–150 | 3–12 | |

[1] For simplification, designations and material numbers are written without the "EN-" prefix, e.g. MCMgAlBZn1 instead of EN-MCMgAl8Zn1.
[2] M casting method: S sand casting; K permanent mold casting; D die casting
[3] Material condition, see designation of aluminum casting alloys, page 168

## Titanium, titanium alloys (selection)

cf. DIN 17860 (1990-11)

| Designation | Material-number | Delivery form[1] S | B | T | Sheet thickness s mm | Hardness HB | Tensile-strength $R_m$ N/mm² | Yield strength $R_{p0,2}$ N/mm² | Elong. at fracture $EL$ % | Properties, application |
|---|---|---|---|---|---|---|---|---|---|---|
| Ti1 | 3.7025 | • | • | • | 0.4–35 | 120 | 290–410 | 180 | 30 | Weldable, solderable, glueable, machinable, cold and hot workable, fatigue resistant, corrosion resistant; weight saving designs in machine construction, electrical engineering, precision engineering, optics and medical technology, chemical industry, food industry, aircraft manufacturing |
| Ti2 | 3.7035 | | | | | 150 | 390–540 | 250 | 22 | |
| Ti3 | 3.7055 | | | | | 170 | 460–590 | 320 | 18 | |
| Ti1Pd | 3.7225 | • | • | • | 0.4–35 | 120 | 290–410 | 180 | 30 | |
| Ti2Pd | 3.7235 | | | | | 150 | 390–540 | 250 | 22 | |
| TiAl6V6Sn2 | 3.7175 | • | • | • | < 6 | 320 | ≥ 1070 | 1000 | 10 | |
| | | | | | 6–50 | 320 | ≥ 1000 | 950 | 8 | |
| TiAl6V4 | 3.7165 | • | • | • | < 6 | 310 | ≥ 920 | 870 | 8 | |
| | | | | | 6–100 | 310 | ≥ 900 | 830 | 8 | |
| TiAl4Mo4Sn2 | 3.7185 | • | • | • | 6–65 | 350 | ≥ 1050 | 1050 | 9 | |

[1] Delivery forms: S sheet and strip; B bars, e.g. round bars; T tubes

# Overview of the heavy non-ferrous metals

**Heavy non-ferrous metals have a density $\varrho > 5$ kg/dm³.** However, in technical literature $\varrho \geq 4.5$ kg/dm³ is also used as limit for non-ferrous metals.

- Construction materials in machine and plant construction: copper, tin, zinc, nickel, lead and their alloys
- Metals used for alloys: chromium, vanadium, cobalt (for effects of alloying metals, see page 129)
- Precious metals: gold, silver, platinum

**Pure metals**: Homogeneous structure; low strengths, lesser importance as a construction material; usually used based on material typical properties, e.g. good electrical conductivity.

**Heavy non-ferrous metal alloys:** Improved properties compared to base metals, such as higher strength, higher hardness, better machinability and corrosion resistance, construction materials for various application. Classified according to **manufacture into wrought alloys and** casting alloys.

## Overview of common heavy non-ferrous metals and alloys

| Metal, alloy group | Main characteristics | Application examples |
|---|---|---|
| **Copper (Cu)** | High electrical conductivity and thermal conductivity, inhibits bacteria, viruses and molds, corrosion resistant, good appearance, easily recyclable | Pipes in heating and plumbing equipment, cooling and heating coils, electrical wiring, electrical parts, cookware, building facades |
| CuZn (brass) | Wear-resistant, corrosion-resistant, good hot and cold workability, good machinability, polishable, shiny golden, medium strengths | • Wrought alloys: deep-drawn parts, screws, springs, pipes, instrument parts<br>• Casting alloys: armature housings, plain bearings, precision mechanical parts |
| CuZnPb | Very good machinability, limited cold workability, very good hot workability | Automatic screw machine parts, precision mechanical parts, fittings, hot-pressed parts |
| CuZn multi-alloy | Good hot workability, high strengths, wear-resistant, weather-resistant | Armature housings, plain bearings, flanges, valve parts, water housings |
| CuSn (bronze) | Very corrosion-resistant, good sliding properties, good wear-resistance, strength resulting from cold working is highly variable | • Wrought alloys: hardware, screws, springs, metal hoses<br>• Casting alloys: spindle nuts, worm gears, solid plain bearings |
| CuAl | High strength and toughness, very corrosion resistant, salt water resistant, heat resistant, highly cavitation resistant | • Wrought alloys: highly stressed lock nuts, ratchet wheels<br>• Casting alloys: armatures in the chemical industry, pump bodies, propellers |
| CuNi(Zn) | Extremely corrosion resistant, silvery appearance, good machinability, polishable, cold workable | Coins, electrical resistors, heat exchangers, pumps, valves in salt water cooling systems, ship building |
| **Zinc (Zn)** | Resistant to atmospheric corrosion | Corrosion protection of steel parts |
| ZnTi | Good workability, joinable by soft soldering | Roofing, gutters, downspouts |
| ZnAlCu | Very good castability | Thin walled, finely articulated die castings |
| **Tin (Sn)** | Good chemical resistance, non-toxic | Coating of steel sheet |
| SnPb | Low viscosity | Soft solder |
| SnSb | Good dry running properties | Small, dimensionally precise die castings, plain bearings with average loading |
| **Nickel (Ni)** | Corrosion resistant, high temperature resistant | Corrosion protection layer on steel parts |
| NiCu | Extremely corrosion resistant and high temp. resist. | Equipment, condensers, heat exchangers |
| NiCr | Extremely corrosion resistant and very high temperature resistant and nonscaling, e.g. age hardenable | Chemical installations, heating tubes, boiler internals in power plants, gas turbines |
| **Lead (Pb)** | Shields against x-ray and gamma rays, corrosion resistant, toxic | Shielding, cable sheathing, tubes for chemical equipment |
| PbSn | Low viscosity, soft, good dry running properties | Soft solder, sliding sheaths |
| PbSbSn | Low viscosity, corrosion resistant, good running and sliding properties (low friction) | plain bearings, small, dimensionally precise die castings such as pendulums, parts for measuring equipment, meters |

# Designation of heavy non-ferrous metals

## Designation system (excerpt)

cf. DIN 1700 (1954-07)[1]

**Example:** NiCu30Fe F45
GD - Sn80Sb

**Manufacture, application**

| | |
|---|---|
| E | Electrical material |
| G | Sand casting |
| GC | Continuous casting |
| GD | Die casting |
| GK | Permanent mold casting |
| GZ | Centrifugal casting |
| L | Solder |
| S | Welding filler alloys |

**Chemical composition**

| Example | Comment |
|---|---|
| NiCu30Fe | Ni-Cu alloy, 30% Cu, trace iron |
| Sn80Sb | Sn-Sb alloy, 80% Sn, approx. 20% Sb |

**Special properties**

| | |
|---|---|
| F45 | minimum tensile strength $R_m$ = 10 · 45 N/mm² = 450 N/mm² |
| a | age hardened |
| g | annealed |
| h | hard |
| ka | naturally aged |
| ku | cold worked |
| ta | partially age hardened |
| wa | artificially aged |
| wu | hot worked |
| zh | drawn hard |

[1] The standard has been withdrawn. However the material designations are still used in individual standards.

## Designation system for copper alloys

cf. DIN EN 1982 (2008-08) and 1173 (2008-08)

**Examples:** CuZn31Si - R620
CuZn38Pb2
CuSn11Pb2 - C - GS

**Chemical composition**

| Example | Meaning |
|---|---|
| CuZn31Si | Cu alloy, 31% Zn, trace Si |
| CuZn38Pb2 | Cu alloy 38% Zn, 2% Pb |
| CuSn11Pb2 | Cu alloy 11% Sn, 2% Pb |

**Casting method**

GS Sand casting
GM Permanent mold casting
GZ Centrifugal casting
GC Continuous casting
GP Die casting

**Product form**

C Material in the form of castings
B Material in ingot form
Wrought alloys (without code letter)

**Material condition (selection)**

| Example | Meaning | Example | Meaning |
|---|---|---|---|
| A007 | Elongation at fracture *EL* = 7% | Y450 | Yield strength $R_p$ = 450 N/mm² |
| D | Drawn, without specified mechanical properties | M | Manufactured condition, without specified mechanical properties |
| H160 | Vickers hardness HV = 160 | R620 | Minimum tensile strength $R_m$ = 620 N/mm² |

## Material numbers for copper and copper alloys

cf. DIN EN 1412 (1995-12)

**Example:** C W 024 A

C Copper material

C Cast material
B Material in ingots
W Wrought material

Number between 000 and 999 without specified meaning (sequential number)

**Code letters for material groups**

| Letter | Material group | Letter | Material group |
|---|---|---|---|
| A or B | Copper | H | Copper-nickel alloys |
| C or D | Copper alloys, percentage of the alloying element < 5% | J<br>K | Copper-zinc alloys<br>Copper-tin alloys |
| E or F | Copper alloys, percentage of the alloying elements ≥ 5% | L or M<br>N or P | Copper-zinc binary alloys<br>Copper-zinc-lead alloys |
| G | Copper-aluminum alloys | R or S | Copper-zinc multi-alloys |

## Material numbers for castings of zinc alloys

cf. DIN EN 12844 (1999-01)

**Example:** Z P 04 1 0

Z Zinc alloy

P Casting

Al content
04 ≙ 4% aluminum

Cu content
1 ≙ 1% copper

Content of the next higher alloying element
0 = next higher alloying element < 1%

# Copper alloys

## Wrought copper alloys

| Designation, Material number[1] | C[2] | Bars $D$[3] mm | Hardness HB | Tensile strength $R_m$ N/mm² | Yield strength $R_{p0.2}$ N/mm² | Elong. at fracture $EL$ % | Properties, application examples |
|---|---|---|---|---|---|---|---|
| **Copper-zinc alloys** | | | | | | | cf. DIN EN 12163 (1998-04) |
| CuZn28 (CW504L) | R310 | 4–80 | – | 310 | 120 | 27 | Very good cold workability, good hot workability, machinable, very easily polished; instrument parts, bushings |
| | R460 | 4–10 | – | 460 | 420 | – | |
| | H085 | 4–80 | 85–115 | – | – | – | |
| | H145 | 4–10 | ≥ 145 | – | – | – | |
| CuZn37 (CW508L) | R310 | 2–80 | – | 310 | 120 | 30 | Very good cold workability, good hot workability, machinable, very easily polished; deep-drawn parts, screws, springs, press rollers |
| | R440 | 2–10 | – | 440 | 400 | – | |
| | H070 | 4–80 | 70–100 | – | – | – | |
| | H140 | 4–10 | ≥ 140 | – | – | – | |
| CuZn40 (CW509L) | R340 | 2–80 | – | 340 | 260 | 25 | Very good hot workability, machinable; rivets, screws |
| | H080 | | ≥ 80 | – | – | – | |
| **Copper-zinc alloys** (multi-alloys) | | | | | | | cf. DIN EN 12163 (1998-04) |
| CuZn31Si (CW708R) | R460 | 5–40 | – | 460 | 250 | 22 | Good cold workability; hot workable, machinable, good sliding properties; sliding parts, bearing bushings, guides |
| | R530 | 5–14 | – | 530 | 330 | 12 | |
| | H115 | 5–40 | 115–145 | – | – | – | |
| | H140 | 5–14 | ≥ 140 | – | – | – | |
| CuZn38Mn1Al (CW716R) | R490 | 5–40 | – | 490 | 210 | 18 | Good hot workability, cold workable, machinable, sliding properties, weather resistant; sliding elements, guides |
| | R550 | 5–14 | – | 550 | 280 | 10 | |
| | H120 | 5–40 | 120–150 | – | – | – | |
| | H150 | 5–14 | ≥ 150 | – | – | – | |
| CuZn40Mn2Fe1 (CW723R) | R460 | 5–40 | – | 460 | 270 | 20 | Good hot workability, cold workable, machinable, average strength, weather resistant; equipment manufacturing, architecture |
| | R540 | 5–14 | – | 540 | 320 | 8 | |
| | H110 | 5–40 | 110–140 | – | – | – | |
| | H150 | 5–14 | ≥ 150 | – | – | – | |
| **Copper-zinc-lead alloys** | | | | | | | cf. DIN EN 12164 (2000-09) |
| CuZn36Pb3 (CW603N) | R340 | 40–80 | 90 | 340 | 160 | 20 | Excellent machinability, limited cold workability; automatic lathe parts |
| | R550 | 2–4 | 150 | 550 | 450 | – | |
| CuZn38Pb2 (CW608N) | R360 | 40–80 | 90 | 360 | 150 | 25 | Excellent machinability, good cold and hot workability; screw machine parts |
| | R550 | 2–6 | 150 | 550 | 420 | – | |
| CuZn40Pb2 (CW617N) | R360 | 40–80 | 90 | 360 | 150 | 20 | Excellent machinability, good hot workability; stamping blanks, gears |
| | R550 | 2–4 | 150 | 550 | 420 | – | |
| **Copper-tin alloys** | | | | | | | cf. DIN EN 12163 (1998-04) |
| CuSn6 (CW452K) | R340 | 2–60 | – | 340 | 230 | 45 | High chemical resistance, good strength; springs, metal hoses, pipes and bushings for suspension bodies |
| | R550 | 2–6 | – | 550 | 500 | – | |
| | H085 | 2–60 | 85–115 | – | – | – | |
| | H180 | 2–6 | ≥ 180 | – | – | – | |
| CuSn8 (CW453K) | R390 | 2–60 | – | 390 | 260 | 45 | High chemical resistance, high-strength, good sliding properties; plain bearings, rolled bearing bushings, contact springs |
| | R620 | 2–6 | – | 620 | 550 | – | |
| | H090 | 2–60 | 90–120 | – | – | – | |
| | H185 | 2–6 | ≥ 185 | – | – | – | |
| CuSn8P (CW459K) | R390 | 2–60 | – | 390 | 260 | 45 | Excellent sliding properties, high wear-resistance, endurance strength; highly stressed plain bearings in automotive and machine manufacturing |
| | R620 | 2–6 | – | 620 | 550 | – | |
| | H090 | 2–60 | 90–120 | – | – | – | |
| | H185 | 2–6 | ≥ 185 | – | – | – | |

[1] Material numbers according to DIN EN 1412, see page 174.

[2] C Material condition according to DIN EN 1173, see page 174. In manufactured condition M all alloys can be delivered up to diameter $D = 80$ mm.

[3] $D$ Diameter for round bars, width across flats for square bars and hexagonal bars, thickness for flat bars.

# Copper and refined zinc alloys

| Designation, Material number[1] | C[2] | Bars $D$[3] mm | Hardness HB | Tensile strength $R_m$ N/mm² | Yield strength $R_{p0.2}$ N/mm² | Elong. at fracture $EL$ % | Properties, application examples |
|---|---|---|---|---|---|---|---|
| **Copper-aluminum alloys** | | | | | | | cf. DIN EN 12163 (1998-04) |
| CuAl10Fe3Mn2 (CW306G) | R590 | 10–80 | – | 590 | 330 | 12 | Corrosion-resistant, wear-resistant, fatigue-resistant, high-temperature resistant; screws, shafts, gears, worm gears, valve seats |
| | R690 | 10–50 | – | 690 | 510 | 6 | |
| | H140 | 10–80 | 140–180 | – | – | – | |
| | H170 | 10–50 | ≥ 170 | – | – | – | |
| CuAl10Ni5Fe4 (CW307G) | R680 | 10–80 | – | 680 | 480 | 10 | Corrosion resistant, wear-resistant, nonscaling, fatigue resistant, high temperature resistant; capacitor bases, control parts for hydraulics |
| | R740 | | – | 740 | 530 | 8 | |
| | H170 | 10–80 | 170–210 | – | – | – | |
| | H200 | | ≥ 200 | – | – | – | |
| **Copper-nickel-zinc alloys** | | | | | | | cf. DIN EN 12163 (1998-04) |
| CuNi12Zn24 (CW430J) | R380 | 2–50 | – | 380 | 270 | 38 | Extremely good cold workability, machinable, easily polished; deep-drawn parts, flatware, applied arts, architecture, spring contacts |
| | R640 | 2–4 | – | 640 | 550 | – | |
| | H090 | 2–50 | 90–130 | – | – | – | |
| | H190 | 2–4 | ≥ 190 | – | – | – | |
| CuNi18Zn20 (CW409J) | R400 | 2–50 | – | 400 | 280 | 35 | Good cold workability, machinable, non-tarnishing, easily polished; membranes, spring contacts, flatware |
| | R650 | 2–4 | – | 650 | 580 | – | |
| | H100 | 2–50 | 100–140 | – | – | – | |
| | H200 | 2–4 | ≥ 200 | – | – | – | |

[1] Material numbers according to DIN EN 1412, see page 174. [2] C Material condition according to DIN EN 1173, see page 174.
[3] $D$ Diameter for round bars, width across flats for flat bars and hexagonal bars, thickness for flat bars.

## Cast copper alloys

cf. DIN EN 1982 (1998-12)

| Designation, Material number[1] | Tensile strength $R_m$ N/mm² | Yield strength $R_{p0.2}$ N/mm² | Elong. at fracture $A$ % | Hardness HB | Properties, application |
|---|---|---|---|---|---|
| CuZn15As-C (CC760S) | 160 | 70 | 20 | 45 | Excellent soft and hard solderability, salt water resistant; flanges |
| CuZn32Pb2-C (CC750S) | 180 | 70 | 12 | 45 | Good machinability, resistant to industrial water up to 90°C; armatures |
| CuZn25Al5Mn4Fe-C (CC762S) | 750 | 450 | 8 | 180 | Very high strength and hardness, good machinability; plain bearings |
| CuSn12-C (CC483K) | 260 | 140 | 7 | 80 | High wear-resistance; spindle nuts, worm gears |
| CuSn11Pb2-C (CC482K) | 240 | 130 | 5 | 80 | Wear-resistant, good dry running properties; plain bearings |
| CuAl10Fe2-C (CC331G) | 500 | 180 | 18 | 100 | Mechanically stressed parts; levers, housings, bevel gears |
| CuAl10Ni3Fe2-C (CC332G) | 500 | 180 | 18 | 130 | Corrosion stressed parts; armatures, propellers |
| CuAl10Fe5Ni5-C (CC333G) | 600 | 250 | 13 | 140 | Strength and corrosion stressed parts; pumps |

1) Material numbers according to DIN EN 1412, see page 174. More cast Cu alloys for plain bearings, see page 261. Strength values apply to separately sand-cast test specimens.

## High-grade cast zinc alloys

cf. DIN EN 12844 (1999-01)

| | | | | | |
|---|---|---|---|---|---|
| ZP3 (ZP0400) | 280 | 200 | 10 | 83 | Very good castability; preferred alloys for die castings |
| ZP5 (ZP0410) | 330 | 250 | 5 | 92 | |
| ZP2 (ZP0430) | 335 | 270 | 5 | 102 | Good castability; very good machinability, universally applicable |
| ZP8 (ZP0810) | 370 | 220 | 8 | 100 | |
| ZP12 (ZP1110) | 400 | 300 | 5 | 100 | Injection, blow, and deep-draw molds for plastics, sheet metal working tools |
| ZP27 (ZP2720) | 425 | 300 | 2.5 | 120 | |

# Composite materials, Ceramic materials

## Composite materials

| Composite material | Base material[1] | Fiber content % | Density $\varrho$ g/cm³ | Tensile strength $\sigma_B$ N/mm² | Elong. at tear $\varepsilon_R$ % | Modulus of elasticity $E$ N/mm² | Service temperature up to °C | Application examples |
|---|---|---|---|---|---|---|---|---|
| FRP (Fiberglass reinforced plastic) | EP | 60 | – | 365 | 3.5 | – | – | Shafts, joints, connecting bars, ship hulls, rotor blades |
| | UP | 35 | 1.5 | 130 | 3.5 | 10800 | 50 | Containers, tanks, pipes, dome lights, body parts |
| | PA 66 | 35 | 1.4 | 160[2] | 5[3] | 5000 | 190 | Large-area, stiff housing parts, power plugs |
| | PC | 30 | 1.42 | 90[2] | 3.5[3] | 6000 | 145 | Housings for printers, computers, televisions |
| | PPS | 30 | 1.56 | 140 | 3.5 | 11200 | 260 | Lamp sockets and coils in electrical equipment |
| | PAI | 30 | 1.56 | 205 | 7 | 11700 | 280 | Bearings, valve seat rings, seals, piston rings |
| | PEEK | 30 | 1.44 | 155 | 2.2 | 10300 | 315 | Light construction materials in aerospace applications, metal substitute |
| CFRP (Carbon fiber reinforced plastic) | PPS | 30 | 1.45 | 190 | 2.5 | 17150 | 260 | Like FRP-PPS |
| | PAI | 30 | 1.42 | 205 | 6 | 11700 | 180 | Like FRP-PAI |
| | PEEK | 30 | 1.44 | 210 | 1.3 | 13000 | 315 | Like FRP-PEEK |

[1] EP epoxide; UP unsaturated polyester; PA 66 polyamide 66, semi-crystalline; PC polycarbonate; PPS polyphenylene sulfide; PAI polyamideimide; PEEK polyetheretherketone

[2] $\sigma_y$ yield stress

[3] $\varepsilon_S$ elongation at yield stress

## Ceramic materials

| Material: Name | Material: Designation | Density $\varrho$ g/cm³ | Flexural strength $\sigma_b$ N/mm² | Modulus of elasticity $E$ N/mm² | Coefficient of linear expansion $\alpha$ 1/K | Properties, application examples |
|---|---|---|---|---|---|---|
| Aluminum silicate | C130 | 2.5 | 160 | 100000 | 0.000005 | Hard, wear-resistant, chemical and heat resistant, high insulating resistance; insulators, catalytic converters, refractory housings |
| Aluminum oxide | C799 | 3.7 | 300 | 300000 | 0.000007 | Hard, wear-resistant, chemical and heat resistant; ceramic inserts, wire drawing dies, biomedicine |
| Zirconium oxide | $ZrO_2$ | 5.5 | 800 | 210000 | 0.000010 | High stability, high strength, heat and chemical resistant, wear-resistant; drawing dies, extrusion dies |
| Silicon carbide | SiC | 3.1 | 600 | 440000 | 0.000005 | Hard, wear-resistant, thermal-shock resistance, corrosion-resistant even at high temperatures; abrasives, valves, bearings, combustion chambers |
| Silicon nitride | $Si_3N_4$ | 3.2 | 900 | 330000 | 0.000004 | High stability, thermal-shock resistance, high strength; cutting ceramics, guide and runner blades for gas turbines |
| Aluminum nitride | AlN | 3.0 | 200 | 300000 | 0.000005 | High thermal conductivity, high electrical insulation property; semiconductors, housings, heatsinks, insulating parts |

# Sintered metals

## Designation system for sintered metals

cf. DIN 30910-1 (1990-10)

**Designation example:** Sint - A 1 0 sintered smooth

- Sint: Sintered metal
- A: Code letter for material class
- 1: 1st number for chemical composition
- 0: 2. 2nd number for further differentiation without systematics

### Code letters for material class

| Code letter | Volume ratio $R_x$ in % | Area of application |
|---|---|---|
| AF | < 73 | Filter |
| A | 75 ± 2.5 | plain bearings |
| B | 80 ± 2.5 | plain bearings<br>Formed parts with sliding properties |
| C | 85 ± 2.5 | plain bearing, formed parts |
| D | 90 ± 2.5 | Formed parts |
| E | 94 ± 1.5 | Formed parts |
| F | > 95.5 | Sintered forged formed parts |

### 1. 1st number for chemical composition

| Number | Chemical composition mass fraction in % |
|---|---|
| 0 | **Sintered iron, sint. steel,** Cu < 1% with or without C |
| 1 | **Sintered steel,** 1% to 5% Cu, with or without C |
| 2 | **Sintered steel,** Cu > 5%, with or without C |
| 3 | **Sintered steel,** with or without Cu or C, other alloying elements < 6%, e.g. Ni |
| 4 | **Sintered steel,** with or without Cu or C, other alloying elements > 6%, e.g. Ni, Cr |
| 5 | **Sintered alloys,** Cu > 60%, e.g. sintered CuSn |
| 6 | Sintered nonferrous heavy metals, except for no. 5 |
| 7 | Sintered light alloys, e.g. sintered aluminum |
| 8, 9 | Reserved numbers |

### Treatment condition

| Treatment condition of the material | | Treatment condition of the surface | |
|---|---|---|---|
| • sintered | • steam treated | • sintered smooth | • machined |
| • calibrated | • sintered forged | • calibrated smooth | • surface treated |
| • heat treated | • isostatically pressed | • sized and coined smooth | |

## Sintered metals (selection, soft magnetic sintered metals not included)

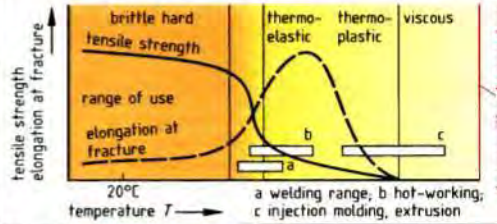
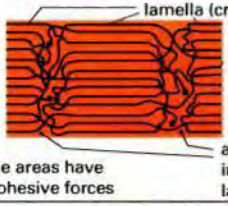
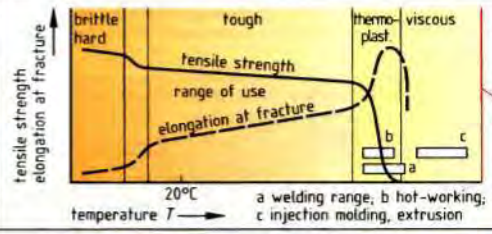
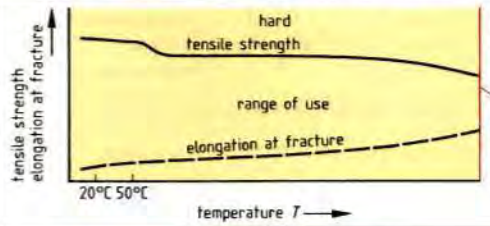
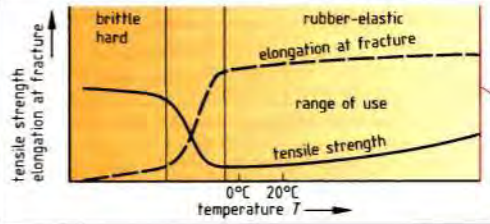
cf. DIN 30910-2-6 (1990-10)

| Designation | Hardness $HB_{min}$ | Tensile strength $R_m$ N/mm² | Chemical composition | Properties, application examples |
|---|---|---|---|---|
| Sint-AF 40 | – | 80–200 | Sintered steel, Cr 16–19%, Ni 10–14% | Filter parts for gas and liquid filters |
| Sint-AF 50 | – | 40–160 | Sintered bronze, Sn 9–11%, rem. Cu | |
| Sint-A 00 | > 25 | > 60 | Sintered iron, C < 0.3%, Cu < 1% | Bearing materials with exceptionally large pore volume for the best emergency running properties; bearing liners, bearing bushings |
| Sint-A 20 | > 40 | > 150 | Sintered steel, C < 0.3%, Cu 15–25% | |
| Sint-A 50 | > 25 | > 70 | Sintered bronze, C < 0.2%, Sn 9–1%, rem. Cu | |
| Sint-A 51 | > 18 | > 60 | Sintered bronze, C 0.2–2%, Sn 9–11%, rem. Cu | |
| Sint-B 00 | > 30 | > 80 | Sintered iron, C < 0.3%, Cu < 1% | Plain bearings with very good dry running properties, low stressed formed parts |
| Sint-B 10 | > 40 | > 150 | Sintered steel, C < 0.3%, Cu 1–5% | |
| Sint-B 50 | > 30 | > 90 | Sintered bronze, C < 0.2%, Sn 9–11%, rem. Cu | |
| Sint-C 00 | > 45 | > 150 | Sintered iron, C < 0.3%, Cu < 1% | Plain bearings, formed parts with average stress with good sliding properties; auto parts, levers, clutch parts |
| Sint-C 10 | > 60 | > 200 | Sintered steel, C < 0.3%, Cu 1–1,5% | |
| Sint-C 40 | > 100 | > 300 | Sintered steel, Cr 16–19%, Ni 10–14%, Mo 2% | |
| Sint-C 50 | > 35 | > 140 | Sintered bronze, C < 0.2%, Sn 9–11%, rem. Cu | |
| Sint-D 00 | > 50 | > 250 | Sintered iron, C < 0.3%, Cu < 1% | Formed parts for higher stresses; wear-resistant pump parts, gears, some are corrosion-resistant |
| Sint-D 10 | > 80 | > 300 | Sintered steel, C < 0.3%, Cu 1–5% | |
| Sint-D 30 | > 110 | > 550 | Sintered steel, C < 0.3%, Cu 1–5%, Ni 1–5% | |
| Sint-D 40 | > 100 | > 450 | Sintered steel, Cr 16–19%, Ni 10–14%, Mo 2% | |
| Sint-E 00 | > 60 | > 200 | Sintered iron, C < 0.3%, Cu < 1% | Formed parts for precision engineering, for household appliances, for the electrical industry |
| Sint-E 10 | > 100 | > 350 | Sintered steel, C < 0.3%, Cu 1–5% | |
| Sint-E 73 | > 55 | > 200 | Sintered aluminum Cu 4–6% | |
| Sint-F 00 | > 140 | > 600 | Sinter forged steel, containing C and Mn | Sealing rings, flanges for muffler systems |
| Sint-F 31 | > 180 | > 770 | Sinter forged steel, containing C, Ni, Mn, Mo | |

# Overview of plastics

| General properties | Advantages: | Disadvantages: |
|---|---|---|
| | • low density<br>• electrically insulating<br>• heat and sound absorbing<br>• decorative surface<br>• economical forming<br>• weather and chemical resistance | • lower strength and heat resistance in comparison to metals<br>• some are combustible<br>• some are nonresistant to solvents<br>• limited material reutilization |

| Classification | Thermoplastics | Thermosets | Elastomers |
|---|---|---|---|
| Processing | Hot workable<br>Weldable<br>Generally glueable<br>Machinable | Not workable<br>Non-weldable<br>Glueable<br>Machinable | Not workable<br>Non-weldable<br>Glueable<br>Machinable at low temperatures |
| Fabrication | Injection molding<br>Injection blow molding<br>Extruding | Pressing<br>Transfer molding<br>Injection molding, molding | Pressing<br>Injection molding<br>Extruding |
| Recycling | Easily recyclable | Not recyclable,<br>possible reuse as filler | Not recyclable |

| Structure | Temperature behavior |
|---|---|
| **Amorphous thermoplastics**<br>  <br>Filamentary macromolecules without cross-linking |  |
| **Semi-crystalline thermoplastic**<br>  <br>Crystalline areas have greater cohesive forces |  |
| **Filamentary thermoset plastics**<br>  <br>Macromolecules with many cross-links |  |
| **Filamentary elastomers**<br>  <br>Macromolecules in random condition with few cross-linkages |  |

# Basic polymers, fillers and reinforcing materials

## Designations for basic polymers

cf. DIN EN ISO 1043-1 (2002-06)

| Designation | Meaning | Type[1] | Designation | Meaning | Type[1] | Designation | Meaning | Type[1] |
|---|---|---|---|---|---|---|---|---|
| ABS | Acrylonitrile butadiene styrene | T | PAK | Polyacrylate | T | PTFE | Polytetrafluoroethylene | T |
| AMMA | Acrylonitrile-methyl-methacrylate | T | PAN | Polyacrylonitrile | T | PUR | Polyurethane | D |
| | | | PB | Polybutene | T | PVAC | Polyvinyl acetate | T |
| | | | PBT | Polybutylene terephthalate | T | PVB | Polyvinyl butyral | T |
| ASA | Acrylonitrile-styrene-acrylate | T | PC | Polycarbonate | T | PVC | Polyvinyl chloride | T |
| CA | Cellulose acetate | T | PCTFE | Polychlorotrifluoroethylene | T | PVDC | Polyvinylidene chloride | T |
| CAB | Cellulose acetate butyrate | T | PE | Polyethylene | T | PVF | Polyvinyl fluoride | T |
| CF | Cresol-formaldehyde | D | PET | Polyethyleneterephthalate | T | PVFM | Polyvinyl formaldehyde | T |
| CMC | Carboxymethyl cellulose | MNM | PF | Phenol formaldehyde | D | PVK | Poly-N-vinylcarbazole | T |
| CN | Cellulose nitrate | MNM | PIB | Polyisobutene | T | SAN | Styrene-acrylonitrile | T |
| CP | Cellulose propionate | T | PMMA | Polymethylmethacrylate | T | SB | Styrene-butadiene | T |
| EC | Ethyl cellulose | MNM | POM | Polyoxymethylene; Polyformaldehyde | T | SI | Silicone | D |
| EP | Epoxide | D | | | | SMS | Styrene-α-methylstyrene | T |
| EVAC | Ethylene-vinyl acetate | E | PP | Polypropylene | T | UF | Urea-formaldehyde | D |
| MF | Melamine formaldehyde | D | PS | Polystyrene | T | UP | Unsaturated polyester | D |
| PA | Polyamide | T | PSU | Polysulfone | T | VCE | Vinyl chloride-ethylene | T |

[1] MNM modified natural materials; E elastomers; D thermoset plastics; T thermoplastics

## Code letters for designation of special properties

cf. DIN EN ISO 1043-1 (2002-06)

| CL[1] | Special properties | CL[1] | Special properties | CL[1] | Special properties | CL[1] | Special properties |
|---|---|---|---|---|---|---|---|
| B | block, brominated | F | flexible; liquid | N | normal; novolak | T | temperature |
| C | chlorinated; crystalline | H | high; homo | O | oriented | U | ultra; no plasticizers |
| D | density | I | impact tough | P | plasticized | V | very |
| E | foamed; elastomer | L | linear, low | R | raised; resol; hard | W | weight |
| | | M | moderate, molecular | S | saturated; sulphonated | X | cross-linked, cross-linkable |

⇒ **PVC-P:** Polyvinylchloride, plasticized; **PE-LLD:** Linear Polyethylene low density

[1] code letter

## Code letters and abbreviations for fillers and reinforcing materials

cf. DIN EN ISO 1043-2 (2002-04)

### Abbreviation for material[1]

| Designation | Material | Designation | Material | Designation | Material | Designation | Material |
|---|---|---|---|---|---|---|---|
| B | Boron | G | Glass | P | Mica | T | Talc |
| C | Carbon | K | Calcium carbonate | Q | Silicate | W | Wood |
| D | Aluminum trihydrate | L | Cellulose | R | Aramid | X | not specified |
| E | Clay | M | Mineral, metal[2] | S | Synthetic materials | Z | other |

### Abbreviations for shape and structure

| Designation | Shape, structure | Designation | Shape, structure | Designation | Shape, structure | Designation | Shape, structure |
|---|---|---|---|---|---|---|---|
| B | pearls, balls, beads | G | ground stock | N | nonwoven (thin) | VV | veneer |
| C | chips, shavings | H | whiskers | P | paper | W | woven |
| D | powder | K | knitwear | R | roving | X | not specified |
| F | fibers | L | laminates | S | peelings, flakes | Y | yarn |
| | | M | matted, thick | T | spun yarn, cord | Z | other |

⇒ **GF:** glass fiber; **CH:** carbon whisker; **MD:** mineral powder

[1] The materials can be further designated, e.g. by its chemical symbol or another symbol from relevant international standards.

[2] For metals (M) the type of metal must be specified by the chemical symbol.

# Identification, Distinguishing characteristics

## Methods for identifying plastics

| Floating test: Solution density in g/cm³ | Floating test: Plastics floating | Solubility in solvents | Visual test: Appearance of the specimen is transparent | Visual test: Appearance of the specimen is cloudy | Behavior when heated |
|---|---|---|---|---|---|
| 0.9–1.0 | PB, PE, PIB, PP | Thermosets and PTFE are not soluble. Other thermoplastics are soluble in certain solvents; e.g. PS is soluble in benzene or acetone. | CA, CAB, CP, EP, PC, PS, PMMA, PVC, SAN | ABS, ASA, PA, PE, POM, PP, PTFE | • Thermopl. soften and melt<br>• Thermosets and elastomers decompose without softening |
| 1.0–1.2 | ABS, ASA, CAB, CP, PA, PC, PMMA, PS, SAN, SB | | | | |
| 1.2–1.5 | CA, PBT, PET, POM, PSU, PUR | | **Touch** | | **Burning test** |
| 1.5–1.8 | Organically filled molding material | | Waxy to the touch: PE, PTFE, POM, PP | | • flame color<br>• fire behavior<br>• soot formation<br>• odor of the smoke |
| 1.8–2.2 | PTFE | | | | |

## Distinguishing characteristics of plastics

| Designation[1] | Density g/cm³ | Burning behavior | Other characteristics |
|---|---|---|---|
| ABS | ≈ 1.05 | Yellow flame, soots strongly, smells like coal gas | Tough elastic, is not dissolved by carbon tetrachloride, sounds dull |
| CA | 1.31 | Yellow, sputtering flame, drips, smells like distilled vinegar and burnt paper | Pleasant to the touch, sounds dull |
| CAB | 1.19 | Yellow, sputtering flame, drips burning, smells like rancid butter | Sounds dull |
| MF | 1.50 | Very flammable, chars with white edges, smells like ammonia | Very brittle, rattling sound (compare to UF) |
| PA | ≈ 1.10 | Blue flame with yellow edges, drips in fibers, smells like burnt horn | Tough elastic, not brittle, sounds dull |
| PC | 1.20 | Yellow flame, goes out after flame is removed, soots, smells like phenol | Tough hard, not brittle, rattling sound |
| PE | 0.92 | Light flame with blue core, drips off burning, odor like paraffin, smoke hardly visible (compare with PP) | Wax like surface, can be scratched with the fingernail, not brittle, working temperature > 230 °C |
| PF | 1.40 | Very flammable, yellow flame, chars, smells like phenol and burnt wood | Very brittle, rattling sound |
| PMMA | 1.18 | Luminous flame, fruity odor, crackles, drips | Clear when uncolored, sounds dull |
| POM | 1.42 | Bluish flame, drips, smells like formaldehyde | Not brittle, rattling sound |
| PP | 0.91 | Light flame with blue core, drips off burning, odor like paraffin, smoke hardly visible (compare with PE) | Cannot mark with fingernail, not brittle |
| PS | 1.05 | Yellow flame, soots strongly, smells sweet like coal gas, drips off burning | Brittle, sounds like tinny metal, is dissolved by carbon tetrachloride among others |
| PTFE | 2.20 | Nonflammable, strong odor when red hot | Waxy surface |
| PUR | 1.26 | Yellow flame, very strong odor | Polyurethane, rubber elastic |
| | ≈ 0.05 | | Polyurethane foam |
| PVC-U | 1.38 | Very flammable, extinguishes after the flame is removed, smells like hydrochloric acid, chars | Rattling sound (U = hard) |
| PVC-P | 1.20–1.35 | Can be more flammable than PVC-U, depending on plasticizer, smells like hydrochloric acid, chars | Rubbery flexible, no sound (P = soft) |
| SAN | 1.08 | Yellow flame, soots strongly, smells like coal gas, drips off burning | Tough elastic, is not dissolved by carbon tetrachloride |
| SB | 1.05 | Yellow flame, soots strongly, smells like coal gas and rubber, drips off burning | Not as brittle as PS, is dissolved by carbon tetrachloride among other things |
| UF | 1.50 | Very flammable, chars with white edges, smells like ammonia | Very brittle, rattling sound (compare to MF) |
| UP | 2.00 | Luminous flame, chars, soots, smells like styrene, glass fiber residue | Very brittle, rattling sound |

[1] Compare to page 180

## Thermoplastics (selection)

| Abbreviation | Designation | Trade name | Density g/cm³ | Tensile strength[1] N/mm² | Impact toughness mJ/mm² | Working temperature, long-term[2] °C | Application examples |
|---|---|---|---|---|---|---|---|
| ABS | Acrylonitrile-butadiene-styrene | Terluran, Novodur | ≈ 1.05 | 35–56 | 80–n.f.[3] | 85–100 | Telephone housings, instrument panels, surf boards |
| PA 6 | Polyamide 6 | Durethan, Maranyl, Resistane, Ultramid, Rilsan | 1.14 | 43 | n.f.[3] | 80–100 | Gears, plain bearings, screws, cables, housings |
| PA 66 | Polyamide 66 | | 1.14 | 57 | 21[4] | 80–100 | |
| PE-HD | Polyethylene, high density | Hostalen, Lupolen, Vestolen A | 0.96 | 20–30 | n.f.[3] | 80–100 | Battery cases, fuel containers, garbage cans, pipes, cable insulation, films, bottles |
| PE-LD | Polyethylene, low density | | 0.92 | 8–10 | n.f.[3] | 60–80 | |
| PMMA | Polymethyl-methacrylate | Plexiglas, Degalan, Lucryl | 1.18 | 70–76 | 18 | 70–100 | Optical lenses, warning lights, dials, lighted letters |
| POM | Polyoxy-methylene; | Delrin, Hostaform, Ultraform | 1.42 | 50–70 | 100 | 95 | Gears, plain bearings, valve bodies, housing parts |
| PP | Polypropylene | Hostalen PP, Novolen, Procom, Vestolen P | 0.91 | 21–37 | n.f.[3] | 100–110 | Heating ducts, washing machine parts, fittings, pump housings |
| PS | Polystyrene | Styropor, Polystyrol, Vestyron | 1.05 | 40–65 | 13–20 | 55–85 | Packaging material, flatware, film cartridges, insulating boards |
| PTFE | Polytetrafluor-ethylen | Hostaflon, Teflon, Fluon | 2.20 | 15–35 | n.f.[3] | 280 | Maintenance free bearings, piston rings, seals, pumps |
| PVC-P | Polyvinylchloride, plasticized | Hostalit, Vinoflex, Vestolit, Vinnolit, Solvic | 1.20 –1.35 | 20–29 | 2[4] | 60–80 | Hoses, seals, cable sheathing, pipes, fittings, containers |
| PVC-U | Polyvinylchloride no plasticizers | | 1.38 | 35–60 | n.f.[3] | < 60 | |
| SAN | Styrene-acrylnitrile copolymer | Luran, Vestyron, Lustran | 1.08 | 78 | 23–25 | 85 | Graduated dials, battery housings, headlight housings |
| SB | Styrene-butadiene copolymer | Vestyron, Styrolux | 1.05 | 22–50 | 40 - n.f.[3] | 55–75 | Television housings, packaging material, clothes hangers, distribution boxes |

[1] Values depend on temperature and test speed.
[2] Duration of temperature application has a significant effect.
[3] n.f. ≙ no fracture of the specimen
[4] Impact toughness

# Designation of thermoplastic molding materials

**Polyethylene PE**
**Polypropylene PP**

cf. DIN EN ISO 1872-1 (1999-10)
cf. DIN EN ISO 1873-1 (1995-12)

**Designation system**

| Name block: | Standard number block | Data block 1 | Data block 2 | Data block 3 | Data block 4 | Data block 5[1] |
|---|---|---|---|---|---|---|
| Example: | | | | | | |
| Thermoplastic | ISO 1873 – | PP-R | , EL | , 06-16-003 | „[2] | ISO 8773 |

**Data block 1**

In data block 1 the molding material is designated by its abbreviation PE or PP after the hyphen.
For polypropylene the additional information follows: **PP-H** homopolymers of the propylene, **PP-B** thermoplastic, impact tough PP (so-called block-copolymer); **PP-R** thermoplastic, static copolymers of the propylene.

**Data block 2**

| **Intended applications and/or processing methods for PE and PP** | | | | **Important properties, additives and coloring for PE and PP** | | | |
|---|---|---|---|---|---|---|---|
| Symbol | Position 1 | Symbol | Position 1 | Symbol | Positions 2 to 8 | Symbol | Positions 2 to 8 |
| B<br>C | Blow molding<br>Calendering | L<br>M | Monofilam. extrusion<br>Injection molding | A<br>B | Process stabilizer<br>Anti-blocking agent | L<br>N | Light stabilizer<br>Natural colors |
| E<br>F | Extrusion<br>Extrusion (films) | Q<br>R | Stamping<br>Rotomolding | C<br>D | Artificial color<br>Powder | P<br>R | Impact tough<br>Mold release agent |
| C<br>H | General use<br>Coating | S<br>X | Powder sintered<br>Unspecified | E<br>F | Blowing agent<br>Fire extinguisher | S<br>T | Sliding and lubricating agent<br>Increased transparency |
| K | Cable insulation | Y | Fiber production[3] | C<br>H | Pellets<br>Thermal aging stabilizer | X<br>Y<br>Z | Cross-linkable<br>Increased electr. conductivity<br>Static inhibitor |

**Data block 3**

| **Density of PE in kg/m³** | | **Modulus of elasticity for PP in MPa (N/mm²)** | | **Melting mass flow rate in g/10 min** | | | | |
|---|---|---|---|---|---|---|---|---|
| Symbol | above–to | Symbol | above–to | Conditions for PE | Temp. in °C | Load in kg | Symbol | for PP and PE above–to |
| 00<br>03<br>08 | –901<br>901–906<br>906–911 | 02<br>06<br>10 | –400<br>400–800<br>800–1200 | E<br>D<br>T<br>G | 190<br>190<br>190<br>190 | 0.325<br>2.16<br>5.00<br>21.6 | 000<br>001<br>003 | –0.1<br>0.1–0.2<br>0.2–0.4 |
| 13<br>18<br>23 | 911–916<br>916–921<br>921–925 | 16<br>28<br>40 | 1200–2000<br>2000–3500<br>3500 | | | | 006<br>012<br>022<br>0,45<br>090<br>200<br>400<br>700 | 0.4–0.8<br>0.8–1.5<br>1.5–3.0<br>3.0–6.0<br>6–12<br>12–25<br>25–50<br>50 |
| 27<br>33<br>40 | 925–930<br>930–936<br>936–942 | Impact toughness for PP in kJ/m² | | – | | | | |
| | | 02<br>05 | –3<br>3–6 | | | | | |
| 45<br>50<br>57<br>62 | 942–948<br>948–954<br>954–960<br>960 | 09<br>15<br>25<br>35 | 6–12<br>12–20<br>20–30<br>30 | – | | | | |

**Data block 4 for PE and PP**

**Position 1:** Symbol for filler/reinforcer grade

| Symbol | Material | Symbol | Material |
|---|---|---|---|
| B<br>C<br>G | Boron<br>Carbon<br>Glass | S<br><br>T | Synthetic, organic<br>Talcum |
| K<br>L<br>M | Chalk<br>Cellulose<br>Mineral, metal | W<br>X<br>Z | Wood<br>Not specified<br>Other |

**Position 2:** Symbol for physical form

| Symbol | Form | Symbol | Form |
|---|---|---|---|
| B<br>D<br>F | Pearls, balls<br>Powder<br>Fiber | S<br><br>X | Lamina<br>Flakes<br>Not specified |
| G<br>H | Ground stock<br>Whiskers | Z | Other |

**Position 3:** Mass percentage of the filler material

⇒ **Thermoplastic ISO 1873-PP-H, M 40-02-045, TD40:** Polypropylene molding material, homopolymer, fabricated by injection molding, modulus of elasticity 3500 MPa; Impact toughness 3 kJ/m², melting mass flow rate 4.5 g/10 min, filler 40% talcum powder

[1] **Data block 5** optional - entry of additional requirements [2] 2 commas - data block missing [3] only for PP

# Thermoset molding materials, Laminated material

## Designation and properties of thermoset plastic molding materials

| Type DIN 7708-2 (old standard) | Type ISO 14526 cf. page 180 | Resin | Filler | Flexural strength[1] N/mm² | Impact toughness[1] kJ/m² | Water absorption mg |
|---|---|---|---|---|---|---|
| **Pourable phenolic plastic molding materials (PF PMC)** | | | | | cf. DIN EN ISO 14526-3 (2000-08) | |
| 31 | PF (WD30+ MD20) | Phenolic (formaldehyde)-resin (PF) | 30% wood flour 20% mineral flour | Q: ≥ 40 M: ≥ 50 | Q: ≥ 4.5 M: ≥ 5.0 | ≤ 100 |
| 51 | PF (LF20+ MD25) | | 20% cellulose fibers 25% mineral flour | Q: ≥ 40 M: ≥ 50 | Q: ≥ 4.5 M: ≥ 5.0 | ≤ 150 |
| 84 | PF (SC20+ LF15) | | 20% synthetic chips 15% cellulose fibers | Q: ≥ 35 M: ≥ 45 | Q: ≥ 5.5 M: ≥ 6.5 | ≤ 150 |
| 74 | PF (SS40 to SS50) | | 40% (to 50%) flaky organ. synthesis product | Q: ≥ 30 M: ≥ 45 | Q: ≥ 7.0 M: ≥ 9.0 | ≤ 200 |
| 13 | PF (PF40 to PF60) | | 40% (to 60%) mica fibers | Q: ≥ 30 M: ≥ 40 | Q: ≥ 2.5 M: ≥ 3.5 | ≤ 30 |
| 83 | PF (LF20+ MD25) | | 20% cellulose fibers 25% mineral fibers | Q: ≥ 35 M: ≥ 45 | Q: ≥ 5.5 M: ≥ 6.0 | ≤ 150 |
| 12 | PF (GF20+ GG30) | | 20% fiber glass 30% glass grist | Q: ≥ 50 M: ≥ 60 | Q: ≥ 6.0 M: ≥ 7.0 | ≤ 30 |
| ⇒ | **PMC ISO 14526 – PF(WD30+MD20), M:** Pourable molding compound (PMC), phenolic (formaldehyde) resin (PF), approx. 30% of wood flour (WD30), approx. 20% of mineral flour (MD20); recommended machining process: injection molding (M)[1] | | | | | |
| **Urea formaldehyde molding materials (UF PMC) and urea/melamine formaldehyde molding materials (UF/MF-PMC) (UF/MF-PMC)** | | | | | cf. DIN EN ISO 14527-3 (2000-08) | |
| 131.5 | UF(LD10+ MD30),X,E[2] | Urea (formaldehyde) resin (UF) | 20% cellulose powder 30% mineral flour | Q: ≥ 45 M: ≥ 55 | Q: ≥ 5.0 M: ≥ 7.5 | ≤ 150 |
| 131 | UF(LD10+ MD30) | | 20% cellulose fibers 30% mineral flour | Q: ≥ 45 M: ≥ 55 | Q: ≥ 5.0 M: ≥ 7.5 | ≤ 150 |
| 130 | UF(WD30+ MD20) | | 30% wood flour 20% mineral flour | Q: ≥ 35 M: ≥ 40 | Q: ≥ 4.5 M: ≥ 5.0 | ≤ 200 |
| – | UF/MF (LF20+S10) | Urea/melamine (formaldehyde) resin | 20% cellulose fibers 10% organic synthesis product | – | Q: ≥ 6.5 M: – | ≤ 100 |
| ⇒ | **PMC ISO 14527 – UF(LD20+MD20), M:** Pourable molding compound (PMC), urea formaldehyde resin (UF), approx. 20% of cellulose powder (LD20), approx. 20% of mineral flour (MD20); recommended machining process: injection molding (M)[1] | | | | | |

## Laminated materials[3]

cf. DIN EN 60893 (2004-12)

| Resin types | | Types of reinforcing materials | |
|---|---|---|---|
| Type of resin | Designation | Abbreviation | Designation |
| EP | Epoxy resin | CC | Cotton fabric |
| MF | Melamine (formaldehyde) resin | CP | Cellulose paper |
| PF | Phenolic (formaldehyde) resin | CR | Combined reinforcing material |
| UP | Unsaturated polyester resin | GC | Glass fiber fabric |
| SI | Silicone resin | GM | Fiber glass mat |
| PI | Polyimide resin | WV | Wood veneer |
| Nominal thicknesses $t$ in mm | 0.4; 0.5; 0.6; 0.8; 1.0; 1.2; 1.5; 2; 2.5; 3; 4; 5; 6; 8; 10; 12; 14; 16; 20; 25; 30; 35; 40; 45; 50; 60; 70; 80; 90; 100 | | |
| ⇒ | **Board IEC 60893 – 3 – 4 – PF CP 201, 10 x 500 x 1000:** Board made of phenolic (formaldehyde) resin/cellulose paper (PF CP 201) according to IEC standard[4] 60893-3-4 with $t$ = 10 mm, $w$ = 500 mm, $l$ = 1000 mm. | | |

[1] Q = compression molding compound; M = injection molding compound
[2] X = machining process not specified; A = free of ammonia; E = specific electric properties
[3] Applications: insulators for electrical equipment, for instance, or bearing liners, rollers and gears for machine construction
[4] IEC = International Electrotechnical Commission (international standard)

# Elastomers, Foam materials

## Elastomers (rubber)

| Abbreviation[1] | Designation | Density g/cm³ | Tensile strength[2] N/mm² | Elong: at fracture % | Working temperature °C | Properties, application examples |
|---|---|---|---|---|---|---|
| BR | Butadiene rubber | 0.94 | 2 (18) | 450 | −60 to +90 | High abrasion resistance; tires, belts, V-belts |
| CO | Epichlorhydrin rubber | 1.27<br>−1.36 | 5 (15) | 250 | −30 to +120<br>−10 to +120 | Vibration damping, oil and gasoline resistant; seals, heat resistant dampers |
| CR | Chloroprene rubber | 1.25 | 11 (25) | 400 | −30 to +110 | Oil and acid resistant, very flammable, seals, hoses, V-belts |
| CSM | Chlorosulfonated polyethylene | 1.25 | 18 (20) | 300 | −30 to +120 | Aging and weather resistant, oil resistant; insulating material, molded goods, films |
| EPDM | Ethylene-propylene rubber | 0.86 | 4 (25) | 500 | −50 to +120 | Good electrical insulator, not resistant against oil and gasoline; seals, profiles, bumpers, cold water hoses |
| FKM | Fluoro rubber | 1.85 | 2 (15) | 450 | −10 to +190 | Abrasion resistant, best thermal resistance; aerospace and automotive industries; rotary shaft seals, O-rings |
| IIR | Isobutene-Isoprene rubber | 0.93 | 5 (21) | 600 | −30 to +120 | Weather and ozone resistant; cable insulation, automotive hoses |
| IR | Isoprene rubber | 0.93 | 1 (24) | 500 | −60 to +60 | Low resistance to oil, high strength; truck tires, spring elements |
| NBR | Acrylonitrile-butadiene rubber | 1.00 | 6 (25) | 450 | −20 to +110 | Abrasion resistant, oil and gasoline resistant, electr. conductors, O-rings, hydraulic hoses, rotary shaft seals, axial seal |
| NR | Natural rubber Isoprene rubber | 0.93 | 22 (27) | 600 | −60 to +70 | Low resistance to oil, high strength; truck tires, spring elements |
| PUR | Polyurethane rubber | 1.25 | 20 (30) | 450 | −30 to +100 | Elastic, wear-resistant; timing belts, seals, couplings |
| SIR | Styrene-Isoprene rubber | 1.25 | 1 (8) | 250 | −80 to +180 | Good electr. insulator, water repellant O-rings, spark plug caps, cylinder head and joint sealing |
| SBR | Styrene-Butadiene rubber | 0.94 | 5 (25) | 500 | −30 to +80 | Low resistance to oil and gasoline; tires, hoses, cable sheathing |

[1] cf. DIN ISO 1629 (1992-03) [2] Value in parentheses = with additive or filler reinforced elastomer

## Foam materials

cf. DIN 7726 (1982-05)

Foam materials consist of open cells, closed cells or a mixture of closed and open cells.
Their raw density is lower than that of the structural substance. A distinction is made between hard, medium hard, soft, elastic, soft elastic and integral foam material.

| Stiffness, hardness | Raw material base of the foam material | Cell structure | Density kg/m³ | Max. working temperature °C[1] | Thermal conductivity W/(K · m) | Water absorption in 7 days Vol.-% |
|---|---|---|---|---|---|---|
| Hard | Polystyrene | Predominantly closed cell | 15–30 | 75 (100) | 0.035 | 2–3 |
| | Polyvinylchloride | | 50–130 | 60 (80) | 0.038 | <1 |
| | Polyethersulfone | | 45–55 | 180 (210) | 0.05 | 15 |
| | Polyurethane | | 20–100 | 80 (150) | 0.021 | 1–4 |
| | Phenolic resin | Open cell | 40–100 | 130 (250) | 0.025 | 7–10 |
| | Urea-formaldehyde resin | | 5–15 | 90 (100) | 0.03 | 20 |
| Medium-hard to soft-elastic | Polyethylene | Predominantly closed cell | 25–40 | up to 100 | 0.036 | 1–2 |
| | Polyvinylchloride | | 50–70 | −60 to +50 | 0.036 | 1–4 |
| | Melamine resin | | 10.5–11.5 | up to 150 | 0.033 | approx. 1 |
| | Polyurethane polyester type | Open cell | 20–45 | −40 to +100 | 0.045 | – |
| | Polyurethane polyether type | | | | | |

[1] Long-term working temperature, short-term in parentheses

# Plastics processing

## Injection molding and extrusion

| Abbreviation | Injection molding temperature in °C | | Injection pressure in bar | Extrusion process temperature in °C | Shrinkage in % | Tolerance group[1] for | | |
|---|---|---|---|---|---|---|---|---|
| | Substance | Mold | | | | General tolerances | Dimensions with deviations Series 1[2] | Series 2[2] |
| PE | 160–300 | 20–70 | 500 | 190–230 | 1.5–3.5 | 150 | 140 | 130 |
| PP | 170–300 | 20–100 | 1200 | 235–270 | 0.8–2[3] | 150 | 140 | 130 |
| PVC, hard | 170–210[4] | 30–60 | 1000–1800 | 170–190 | 0.2–0.5 | 130 | 120 | 110 |
| PVC, soft | 170–200[4] | 20–60 | 300 | 150–200 | 1–2.5 | – | – | – |
| PS | 180–250 | 30–60 | – | 180–220 | 0.3–0.7 | 130 | 120 | 110 |
| SB | 180–250 | 20–70 | – | 180–220 | 0.4–0.7 | 130 | 120 | 110 |
| SAN | 200–260 | 40–80 | – | 180–200 | 0.5–0.6 | 130 | 120 | 110 |
| ABS | 200–240 | 40–85 | 800–1800 | 180–220 | 0.4–0.7 | 130 | 120 | 110 |
| PMMA | 200–250 | 50–90 | 400–1200 | 180–250 | 0.3–0.8 | 130 | 120 | 110 |
| PA | 210–290 | 80–120 | 700–1200 | 230–275 | 1–2 | 130 | 120 | 110 |
| POM | 180–230[4] | 50–120 | 800–1700 | 180–220 | 1–3.5 | 140 | 130 | 120 |
| PC | 280–320[4] | 80–120 | > 800 | 240–290 | 0.7–0.8 | 130 | 120 | 110 |
| PF[5] | 90–110[4] | 170–190 | 800–2500 | – | 0.5–1.5[3] | 140 | 130 | 120 |
| MF[6] | 95–110[4] | 160–180 | 1500–2500 | – | 0.6–1.7[3] | 130 | 120 | 110 |
| UF[5] | 95–110 | 150–160 | 1500–2500 | – | 0.4–0.6 | 140 | 130 | 120 |

[1] See table below [2] Series 1: Can be maintained without special effort, Series 2: Requires high finishing effort
[3] Transverse and longitudinal shrinkage may differ [4] With screw injection molding machine
[5] With organic filler material [6] With inorganic filler material

## Tolerances for plastic molded parts

cf. DIN 16901 (1982-11)

| Tolerance group from table above | Code-letter[1] | Nominal dimension range over – up to in mm | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0–1 | 1–3 | 3–6 | 6–10 | 10–15 | 15–22 | 22–30 | 30–40 | 40–53 | 53–70 | 70–90 | 90–120 | 120–160 |
| General tolerances | | | | | | | | | | | | | | |
| 150 | A | ±0.23 | ±0.25 | ±0.27 | ±0.30 | ±0.34 | ±0.38 | ±0.43 | ±0.49 | ±0.57 | ±0.68 | ±0.81 | ±0.97 | ±1.20 |
| | B | ±0.13 | ±0.15 | ±0.17 | ±0.20 | ±0.24 | ±0.28 | ±0.33 | ±0.39 | ±0.47 | ±0.58 | ±0.71 | ±0.87 | ±1.10 |
| 140 | A | ±0.20 | ±0.21 | ±0.22 | ±0.24 | ±0.27 | ±0.30 | ±0.34 | ±0.38 | ±0.43 | ±0.50 | ±0.60 | ±0.70 | ±0.85 |
| | B | ±0.10 | ±0.11 | ±0.12 | ±0.14 | ±0.17 | ±0.20 | ±0.24 | ±0.28 | ±0.33 | ±0.40 | ±0.50 | ±0.60 | ±0.75 |
| 130 | A | ±0.18 | ±0.19 | ±0.20 | ±0.21 | ±0.23 | ±0.25 | ±0.27 | ±0.30 | ±0.34 | ±0.38 | ±0.44 | ±0.51 | ±0.60 |
| | B | ±0.08 | ±0.09 | ±0.10 | ±0.11 | ±0.13 | ±0.15 | ±0.17 | ±0.20 | ±0.24 | ±0.28 | ±0.34 | ±0.41 | ±0.50 |
| Tolerances for dimensions with deviations | | | | | | | | | | | | | | |
| 140 | A | 0.40 | 0.42 | 0.44 | 0.48 | 0.54 | 0.60 | 0.68 | 0.76 | 0.86 | 1.00 | 1.20 | 1.40 | 1.70 |
| | B | 0.20 | 0.22 | 0.24 | 0.28 | 0.34 | 0.40 | 0.48 | 0.56 | 0.66 | 0.80 | 1.00 | 1.20 | 1.50 |
| 130 | A | 0.36 | 0.38 | 0.40 | 0.42 | 0.46 | 0.50 | 0.54 | 0.60 | 0.68 | 0.76 | 0.88 | 1.02 | 1.20 |
| | B | 0.16 | 0.18 | 0.20 | 0.22 | 0.26 | 0.30 | 0.34 | 0.40 | 0.48 | 0.56 | 0.68 | 0.82 | 1.00 |
| 120 | A | 0.32 | 0.34 | 0.36 | 0.38 | 0.40 | 0.42 | 0.46 | 0.50 | 0.54 | 0.60 | 0.68 | 0.78 | 0.90 |
| | B | 0.12 | 0.14 | 0.16 | 0.18 | 0.20 | 0.22 | 0.26 | 0.30 | 0.34 | 0.40 | 0.48 | 0.58 | 0.70 |
| 110 | A | 0.18 | 0.20 | 0.22 | 0.24 | 0.26 | 0.28 | 0.30 | 0.32 | 0.36 | 0.40 | 0.44 | 0.50 | 0.58 |
| | B | 0.08 | 0.10 | 0.12 | 0.14 | 0.16 | 0.18 | 0.20 | 0.22 | 0.26 | 0.30 | 0.34 | 0.40 | 0.48 |

[1] A For dimensions which do not depend on mold dimensions; B For dimensions which depend on mold dimensions

# High-temperature plastics, Polyblends, Reinforcing fibers

## High-temperature plastics

| Abbreviation | Designation | Tensile strength N/mm² | Working temperature from to | Special properties | Application examples |
|---|---|---|---|---|---|
| PTFE | Polytetrafluoretylene trade name "Teflon" | 10 | −20 to 260 °C, short-term to 300 °C | High-temperature strength and chemical resistance, low strength, hardness and coefficient of friction | Bearings, seals, coatings, high-frequency cable, chemical equipment |
| PEEK | Polyether-etherketone | 97 | −65 to 250 °C, short-term to 300 °C | High-temperature strength and chemical resistance, good sliding behavior | Bearings, gears, seals, air and space travel (instead of metals) |
| PPS | Polyphenylen-sulfide | 70 | −200 to 220 °C, short-term to 260 °C | High strength, hardness, stiffness, high chemical, weather and radiation resistance | Pump housings, bearing bushings, space travel, nuclear power stations |
| PSU | Polysulfone | 140–240 | −40 to 150 °C, short-term to 200 °C | High strength, hardness, stiffness, high chemical and radiation resistance, clear | Microwave dishes, spools, circuit boards, oil level indicators, needle bearing cages |
| PI | Polyimide trade name "Vespel" | 75–100 | −240 to 360 °C, short-term to 400 °C | High strength in large temperature range, radiation resistant, dark, non-transparent | Jet engines, aircraft noses, piston rings, valve seats, seals, electronic connection components |

## Polyblends

Polyblends (also known as "blends") are mixtures of different thermoplastics. The special properties of these copolymers result from numerous possible combinations of the properties of the original materials.

| Abbreviation | Designation | Components | Special properties | Application examples |
|---|---|---|---|---|
| S/B | Styrene/butadiene | 90% polystyrene, 10% butadiene rubber | Brittle hard, at low temperatures not impact tough | Stacking boxes, fan housings, radio housings |
| ABS | Acrylonitrile/butadiene/styrene | 90% styrene-acrylonitrile, 10% nitrile rubber | Brittle hard, impact tough even at low temperatures | Telephones, dash-boards, hub caps |
| PPE + PS | Polyphenylenether + Polystyrene | various compositions; possibly can be reinforced with 30% glass fiber | High hardness, high cold impact toughness to −40 °C, physiologically harmless | Radiator grill, computer parts, medical equipment, solar panels, trims |
| PC + ABS | Polycarbonate + Acrylnitrile/Butadiene/Styrene | various compositions | High strength, hardness, toughness, dimensional stability under heat, impact tough, shock-proof | Instrument panels, fenders, office machine housings, lamp housings in motor vehicles |
| PC + PET | Polycarbonate + Polyethyleneterephthalate | different compositions | Exceptional impact toughness and shock resistance | Motorcycle helmets, automotive parts |

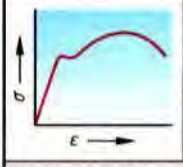
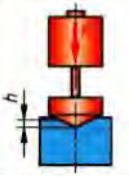
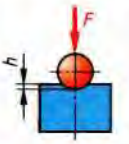
## Reinforcing fibers

| Designation | Density kg/dm³ | Tensile strength N/mm² | Elongation at fracture % | Special properties | Application examples |
|---|---|---|---|---|---|
| Glass fiber GF | 2.52 | 3400 | 4.5 | Isotropic[1], good strength, high-temp. strength, inexpensive | Body parts, aircraft manufacturing, sailboats |
| Aramide fibers AF[3] | 1.45 | 3400 – 3800 | 2.0–4.0 | Lightest reinforcing fiber, ductile, fracture tough, strongly anisotropic[1], radar-penetrable | Highly stressed light parts, crash helmets, bulletproof vests |
| Carbon fiber CF | 1.6–2.0 | 1750 – 5000[2] | 0.35–2.1[2] | Extremely anisotropic[1], high-strength, light, corrosion resistant, good electr. conductor | Parts for racing cars, sails for racing yachts, aerospace applications |

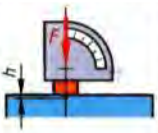
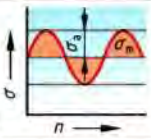
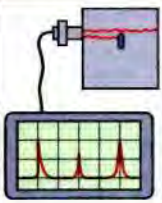
Thermosets (e.g. UP and EP resins) and thermoplastics with high working temperatures (e.g. PSU, PPE, PPS, PEEK, PI) are used as embedding materials (so-called **matrix**).

[1] Isotropic = the same material properties in all directions; anisotropic = material properties in the direction of the fibers are different from those transverse to fibers
[2] Depends significantly on the fiber defect sites occurring during the manufacturing process
[3] Trade name "Kevlar"

# Material testing methods – Overview

| Illustration | Process | Application, information |
|---|---|---|
| **Tensile test** | | page 190 |
|  | Standard tensile test specimens are pulled to fracture.<br>The changes in tensile force and strain are measured and plotted on a graph. This is converted to a stress-strain curve. | Determination of material characteristic values, for example<br>– calculation of static load strength<br>– prediction of forming behavior<br>– obtaining data for machining processes |
| **Hardness test by Brinell HB** | | page 192 |
|  | • Indenter ball is loaded with standardized test load *F*<br>– test load depends on ball diameter *D* and on the material group<br>→ Degree of loading, see page 192<br>• Indentation diameter *d* is measured<br>• Hardness is determined based on the test load and the surface area of indentation | Hardness test, e.g. on steels, cast iron materials, non-ferrous metals, which<br>– are not hardened<br>– have a metallic bright testing surface<br>– are softer than 650 HB |
| **Hardness test by Rockwell** | | page 193 |
|  | • Indenter (diamond cone, carbide ball) is loaded with minor test load → measurement baseline<br>• Impact with major test load<br>→ permanent deformation of the test piece<br>• Removal of the major load<br>• Hardness is displayed directly on the test device and is based on the depth of penetration *h* | Hardness testing by different methods, e.g. on steels and non-ferrous metals,<br>– in soft or hardened condition<br>– with small thicknesses<br>**Methods HRA, HRC:**<br>hardened and high-strength metals<br>**Methods HRB, HRF:**<br>soft steel, non-ferrous metals |
| **Hardness test by Vickers** | | page 193 |
|  | • The diamond pyramid is loaded with variable loads<br>– test load is a function of parameters such as test piece thickness or grain size in matrix structure<br>• The diagonals of the indentation are measured<br>• Hardness is determined based on the test load and surface area of indentation | Universal method for testing<br>– soft and hardened materials<br>– thin layers<br>– individual microstructural components of metals |
| **Hardness test by penetrant testing** (Martens hardness) | | page 194 |
|  | • Diamond pyramid is loaded with variable loads<br>– test load is based on parameters such as test piece thickness or grain size<br>• The load is logged continuously as a function of penetration depth<br>• Martens hardness is determined **during** loading | Method for testing all materials, e.g.<br>– soft and hardened metals<br>– thin layers, also carbide coatings and paint coating<br>– individual microstructure components<br>– ceramic, hard material, etc. |
| **Hardness test by ball penetration test** | | page 195 |
|  | • The test ball is loaded with initial load → measurement baseline<br>• Impact with established test load<br>– test load must produce a penetration depth of 0.15–0.35 mm<br>• The penetration depth is measured after 30 s loading time<br>• Ball indentation hardness is determined | Testing of plastics and hard rubber.<br>Ball indentation hardness provides comparison values for research, development and quality control. |

# Material testing methods – Overview

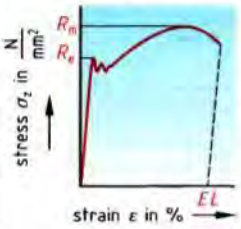
| Illustration | Process | Applications, notes |
|---|---|---|
| **Hardness test by Shore** | | page 195 |
|  | • The testing device (durometer) is pressed on the test piece with contact pressure $F$<br>• The spring loaded indenter penetrates into the test piece<br>• Working time 15 s<br>• The shore hardness is displ. directly on the device | Control of plastics (elastomers).<br>It is hardly possible to derive any relationships to other material properties from the shore hardness. |
| **Shear test** | | page 191 |
|  | • Cylindrical specimens are loaded in standardized equipment until fractured due to shearing<br>• Breaking strength is determined from the maximum shearing force and cross-sectional area of the test specimen | Used to determine the shear strength $\tau_{sB}$, e.g.<br>– for strength calculations of shear loaded parts, e.g. pins<br>– to predict cutting forces in forming |
| **Notched-bar impact bending test** | | page 191 |
|  | • Notched test specimens are subjected to bending load by pendulum impact and are fractured<br>• Notch impact toughness = energy required to deform and fracture the test specimen | – To test metallic materials for behavior after impact bending loads<br>– To monitor heat treatment results, e.g. with quenching and tempering<br>– To test the temperature behavior of steels |
| **Erichsen cupping test** | | page 191 |
|  | • Sheet metal clamped on all sides is deformed until crack formation by a ball<br>• The deformation depth until crack propagation is a measure of deep drawing capability | – For testing of sheet metal and strip for their deep drawing capability<br>– Evaluation of the sheet surface for changes during cold working |
| **Fatigue test** | | |
|  | • Cylindrical specimens with polished surface are alternately loaded with constant mean stress $\sigma_m$ and variable alternating stress amplitude $\sigma_A$, until fracture. The graphical representation of the series of tests yields the Wöhler (S-N) curve | Used to determine material properties with dynamic loading, e.g.<br>– fatigue strength, fatigue endurance and fatigue strength under alternating stresses<br>– endurance limit |
| **Ultrasonic testing** | | |
|  | • A transducer sends ultrasonic signals through the workpiece. The waves are reflected by the front wall, the back wall and by defects of a certain size<br>• The screen of the testing device displays the echoes<br>• The test frequency determines the detectable defect size which is limited by the grain size of the test specimen | – Nondestructive testing of parts, e.g. for cracks, cavities, gas holes, inclusions, lack of fusion, differences in microstructure<br>– To determine the type of defect, the size and the location of the defect<br>– To measure wall and layer thicknesses |
| **Metallography** | | |
|  | Etching metallographic test specimens (microsections) develops the microstructure which can then be observed under the metallographic microscope.<br>Specimen preparation:<br>Removal → avoid structural transformation<br>Embedding → sharp edged microsections<br>Grinding → removal of layers of deformation<br>Polishing → high surface quality<br>Etching → structural development | – To check the crystalline structure<br>– To monitor heat treatments, forming and joining processes<br>– To determine grain distribution and grain size<br>– Defect testing |

# Tensile test, Tensile test specimens

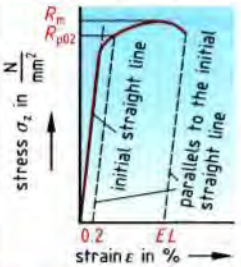
## Tensile test

cf. DIN EN 10002-1 (2001-12)

**Stress-strain diagram with distinct yield point, e.g. for soft steel**




**Stress-strain diagram without distinct yield point, e.g. for quenched and tempered steel**




- $EL$ elongation at fracture
- $F$ tensile force
- $F_m$ maximum force
- $F_e$ force at yield strength limit
- $F_{p0.2}$ force at yield strength limit at 0.2% strain offset
- $L_0$ initial gage length
- $L_u$ gage length after fracture
- $d_0$ initial diameter of the test specimen
- $S_0$ initial cross section of the test specimen
- $S_u$ smallest test specimen cross section after fracture
- $\varepsilon$ normal strain
- $Z$ reduction of area at fracture
- $\sigma_z$ tensile stress
- $R_m$ tensile strength
- $R_e$ yield strength
- $R_{p0.2}$ yield strength at 0.2% strain offset
- $V_s$ yield strength ratio

**Tensile test specimens**

Normally, round proportional bars with an initial gage length of $L_0 = 5 \cdot d_0$ are used.

Unmachined specimens are allowed with
- uniform cross sections, e.g. for specimens of sheet metal, profiles, wires
- cast test specimens, e.g. of cast iron materials or non-ferrous casting alloys

**Elongation at fracture** $EL$

If tensile test specimens are used that contract during the test, the initial gage length $L_0$ has an effect on the elongation at fracture $EL$.

Smaller initial gage length $L_0$ → greater elongation at fracture $EL$

**Yield strength ratio:** $V_s = R_e\,(R_{p0.2})/R_m$
It provides information about the heat treatment condition of the steels:

| | |
|---|---|
| normalized | $V_s \approx 0.5-0.7$ |
| quenched & tempered | $V_s \approx 0.7-0.95$ |

**Tensile stress**

$$\sigma_z = \frac{F}{S_0}$$

**Tensile strength**

$$R_m = \frac{F_m}{S_0}$$

**Yield strength**

$$R_e = \frac{F_e}{S_0}$$

**Yield strength at 0.2 % strain offset**

$$R_{p0.2} = \frac{F_{p0.2}}{S_0}$$

**Normal strain**

$$\varepsilon = \frac{L - L_0}{L_0} \cdot 100\%$$

**Elongation at fracture**

$$EL = \frac{L_u - L_0}{L_0} \cdot 100\%$$

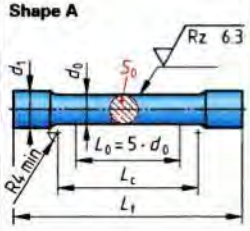
**Reduction of area at fraction**

$$Z = \frac{S_0 - S_u}{S_0} \cdot 100\%$$

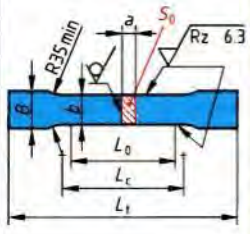
## Tensile test specimens

cf. DIN 50125 (2004-01)

**Shape A**




**Shape E**




**Round tensile test specimens with smooth cylindrical ends, shapes A and B**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $d_0$ | 4 | 5 | 6 | 8 | 10 | 12 | 14 | Shapes, application |
| $L_0$ | 20 | 25 | 30 | 40 | 50 | 60 | 70 | **Shape A:** Machined test specimens for clamping in the tensioning wedge<br>**Shape B:** Machined test specimens with threaded heads produce more precise measurement of the elongation |
| $L_c$ | 24 | 30 | 36 | 48 | 60 | 72 | 84 | |
| Shape A $d_1$ | 5 | 6 | 8 | 10 | 12 | 15 | 17 | |
| Shape A $L_t$ | 65 | 80 | 95 | 115 | 140 | 160 | 185 | |
| Shape B $d_1$ | M6 | M8 | M10 | M12 | M16 | M18 | M20 | |
| Shape B $L_t$ | 40 | 50 | 60 | 75 | 90 | 110 | 125 | |

**Tensile test specimens, other shapes**

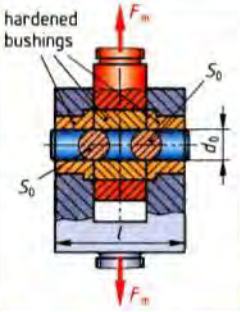
| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $a$ | 3 | 4 | 5 | 6 | 7 | 8 | 10 | Shapes, application |
| Shape E $b$ | 8 | 10 | 10 | 20 | 22 | 25 | 25 | Flat specimens with heads for tensioning wedges, tensile test specimens of strips, sheets, flat bars and profiles |
| Shape E $L_0$ | 30 | 35 | 40 | 60 | 70 | 80 | 90 | |
| Shape E $B$ | 12 | 15 | 15 | 27 | 29 | 33 | 33 | |
| $L_c$ | 38 | 45 | 50 | 80 | 90 | 105 | 115 | |
| $L_t$ | 115 | 135 | 140 | 210 | 230 | 260 | 270 | |

| | |
|---|---|
| Shape C | Machined round test specimens with shouldered ends |
| Shape D | Machined round test specimens with conical ends |
| Shape F | Unmachined sections of round bars |
| Shape G | Unmachined sections of flat bar steel and profiles |
| Shape H | Flat specimens for testing sheets with thicknesses between 0.1 and 3 mm |
| ⇒ | **Tensile test specimen DIN 50125 – A10x50:** Shape A, $d_0$ = 10 mm, $L_0$ = 50 mm |

# Shear test, Notched bar impact bending test, Cupping test

## Shear test

cf. DIN 50141 (2008-07), withdrawn




$F_m$ maximum shear force
$d_0$ initial diameter of the test specimen
$l$ specimen length
$S_0$ initial cross section of the test specimen
$\tau_{sB}$ shear strength

**Shear strength**

$$\tau_{aB} = \frac{F_m}{2 \cdot S_0}$$

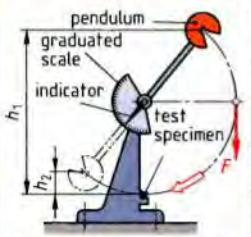
The test is carried out on tensile test machines with standardized shear devices.

**Shear test specimens**

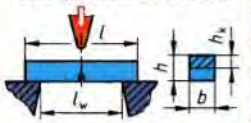
| $d_0$ | 3 | 4 | 5 | 6 | 8 | 10 | 12 | 16 |
|---|---|---|---|---|---|---|---|---|
| Limit deviations | −0.020<br>−0.370 | −0.020<br>−0.370 | −0.030<br>−0.390 | −0.030<br>−0.345 | −0.040<br>−0.370 | −0.013<br>−0.186 | −0.016<br>−0.193 | −0.016<br>−0.193 |
| $l$ | 50 | 50 | 50 | 50 | 50 | 110 | 110 | 110 |

## Charpy impact test

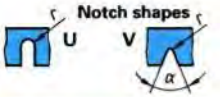
cf. DIN EN 10045 (1991-04)




**Test specimen cross section**




**Notch shapes**




KU Notch impact energy in J, measured on a test specimen with U-notch
KV Notch impact energy in J, measured on a test specimen with V-notch

**Test specimen**

The test specimen must be completely machined. Fabrication of the test material should alter the material's microstructure as little as possible. No notch should be visible with the naked eye at the notch root which runs parallel to the notch axis.

**Notch impact test specimens**

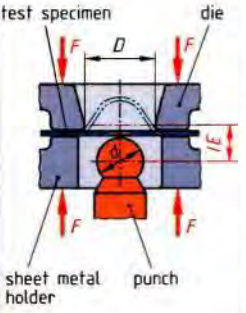
| Designation | Notch shape | Test dimension in mm or degree (°) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | $l$ | $l_w$ | $h$ | $b$ | $h_k$ | $r$ | $\alpha$ |
| Normal test specimen | U | 55 | 40 | 10 | 10 | 5 | 1.0 | – |
| Normal test specimen | V | 55 | 40 | 10 | 10 | 8 | 0.25 | 45° |
| DVM test specimen[1)] | U | 55 | 40 | 10 | 10 | 7 | 1.0 | – |
| Explanation | [1)] Deutscher Verband für Materialprüfung (German Association for Material Testing) | | | | | | | |

⇒ **KU = 115 J:** Normal test specimen with U-notch, Notch impact energy 115 J, work capacity of the pendulum impact tester 300 J

**KV150 = 85 J:** Normal test specimen with V-notch, Notch impact energy 85 J, work capacity of the pendulum impact tester 150 J

## Erichsen cupping test

cf. DIN EN ISO 20482 (2003-12), replacement for DIN 50101 and 50102




*IE* Erichsen cupping depth value in mm
*F* sheet metal holding force in kN
*l* length of the test sheet
*D* hole diameter of the die
*d* ball diameter of the punch
*t* thickness of the test sheet
*w* width of the test sheet

**Test specimens**

The test specimens must be flat and not have any burrs. Before clamping, the sheets are to be lightly greased over with a graphite lubricant.

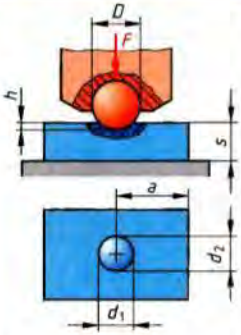
**Tools and test specimen dimensions**

| Abbreviation | Tool dimensions | | | Test specimen dimensions | | | Application |
|---|---|---|---|---|---|---|---|
| | $D$ mm | $d$ mm | $F$ kN | $l$ mm | $w$ mm | $t$ mm | |
| IE | 27 | 20 | 10 | ≥ 90 | ≥ 90 | 0.2–2 | Standard test |
| $IE_{40}$ | 40 | 20 | 10 | ≥ 90 | ≥ 90 | 2–3 | Tests on thicker or narrower strips |
| $IE_{21}$ | 21 | 15 | 10 | ≥ $w$ | 55–90 | 0.2–2 | |
| $IE_{11}$ | 11 | 8 | 10 | ≥ $b$ | 30–55 | 0.1–1 | |
| ⇒ | **IE = 12 mm:** Erichsen cupping depth = 12 mm, standard test | | | | | | |

# Hardness test by Brinell

## Hardness test by Brinell

cf. DIN EN ISO 6506-1 (2006-03)




$F$ test load in N
$D$ ball diameter in mm
$d$ diameter of the impression in mm
$d_1$, $d_2$ individual measurement values of the impression diameter in mm
$h$ depth of impression in mm
$s$ minimum thickness of the test specimen in mm
$a$ distance from edge in mm

**Test conditions**

Impression diameter
$0.24 \cdot D \le d \le 0.6 \cdot D$

Minimum test specimen thickness $s \ge 8 \cdot h$

Distance from edge $a \ge 3 \cdot d$

Test specimen surface: metallic bright

**Impression diameter**

$$d = \frac{d_1 + d_2}{2}$$

**Brinell hardness**

$$HBW = \frac{0.204 \cdot F}{\pi \cdot D \cdot (D - \sqrt{D^2 - d^2})}$$

**Designation examples:**

**180 HBW 2.5 / 62.5**
**600 HBW 1 / 30 / 25**

| Hardness value | Indenter | Ball diameter | Test force $F$ | Impact time |
|---|---|---|---|---|
| Brinell hardness 180<br>Brinell hardness 600 | W carbide ball | 2.5 mm<br>1 mm | 62.5 · 9.80665 N = 612.9 N<br>30 · 9.80665 N = 294.2 N | Unspecified: 10 to 15 s<br>Value entry: 25 s |

## Degree of loading, ball diameter, test loads and test materials

| Degree of loading $0.102 \cdot F/D^2$ | Test load $F$ in N with ball diameter $D$[1] in mm | | | | Test range | Brinell hardness HBW |
|---|---|---|---|---|---|---|
| | 1 | 2.5 | 5 | 10 | Materials | |
| 30 | 294.2 | 1839 | 7355 | 29420 | Steel, nickel and titanium alloys<br>Cast iron<br>Copper, copper alloys | ≤ 650<br>≥ 140<br>> 200 |
| 15 | – | – | – | 14710 | Light metal, light metal alloys | > 35 |
| 10 | 98.07 | 612.9 | 2452 | 9807 | Cast iron<br>Light metal, light metal alloys<br>Copper, copper alloys | < 140<br>> 35<br>35 – 200 |
| 5 | 49.03 | 306.5 | 1226 | 4903 | Copper, copper alloys<br>Light metals, light metal alloys | < 35<br>35 – 80 |
| 2.5 | 24.52 | 153.2 | 612.9 | 2452 | Light metals, light metal alloys | < 35 |
| 1 | 9.807 | 61.29 | 245.2 | 980.7 | Lead, tin | – |

[1] Small ball diameters for fine-grained materials, thin specimens or hardness tests in the outer layer. For hardness tests on cast iron, the ball diameter $D$ must be ≥ 2.5 mm. Hardness values are only comparable if the tests were carried out with the same degree of loading.

## Minimum thickness $s$ of the specimens

| Ball diameter $D$ in mm | Minimum thickness $s$ in mm for impression diameter $d$[1] in mm | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0.25 | 0.35 | 0.5 | 0.6 | 0.8 | 1.0 | 1.2 | 1.3 | 1.5 | 2.0 | 2.4 | 3.0 | 3.5 | 4.0 | 4.5 | 5.0 | 5.5 | 6.0 |
| 1 | 0.13 | 0.25 | 0.54 | 0.8 | | | | | | | | | | | | | | |
| 2 | | | 0.23 | 0.37 | 0.67 | 1.07 | 1.6 | | | | | | | | | | | |
| 2.5 | | | | 0.29 | 0.53 | 0.83 | 1.23 | 1.46 | 2.0 | | | | | | | | | |
| 5 | | | | | | | 0.58 | 0.69 | 0.92 | 1.67 | 2.45 | 4.0 | | | | | | |
| 10 | | | | | | | | | | | 1.17 | 1.84 | 2.53 | 3.34 | 4.28 | 5.36 | 6.59 | 8.0 |

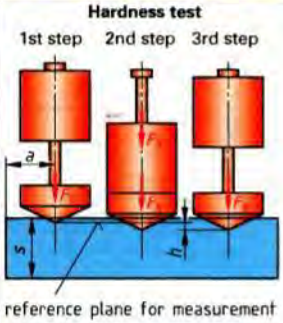
**Example:** $D = 2.5$ mm, $d = 1.2$ mm → minimum specimen thickness $s = 1.23$ mm

[1] Table fields without thickness indicated lie outside of the test range $0.24 \cdot D \le d \le 0.6 \cdot D$

# Hardness test by Rockwell, Hardness test by Vickers

## Hardness test by Rockwell

cf. DIN EN ISO 6508-1 (2006-03)




$F_0$ minor load in N
$F_1$ major load in N
$h$ permanent indentation depth in mm
$s$ test specimen thickness
$a$ distance from edge

**Test conditions**

Surface of specimen is ground to $Ra = 0.8–1.6$ µm. The machining of the specimen must not result in any changes to the microstructure.
Distance from edge $a \geq 1$ mm

**Rockwell hardness HRA, HRC**

$$\text{HRA, HRC} = 100 - \frac{h}{0.002\ \text{mm}}$$

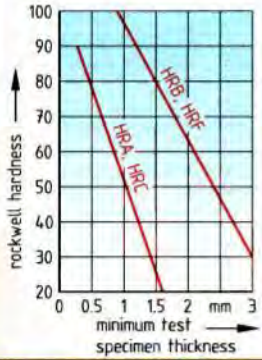
**Rockwell hardness HRB, HRF**

$$\text{HRB, HRF} = 130 - \frac{h}{0.002\ \text{mm}}$$

**Designation examples:**

**65 HRC**
**70 HRBW**

| Hardness value | Test method |
|---|---|
| 65 | HRC Rockwell hardness – C, test with diamond cone |
| 70 | HRBW Rockwell hardness – B, test with carbide ball |

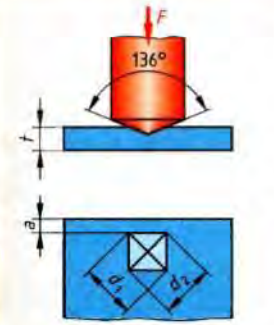



**Test method, applications** (selection)

| Method | Indenter | $F_0$ in N | $F_1$ in N | Measurement range from – to | Application |
|---|---|---|---|---|---|
| HRA | Diamond cone, cone angle 120° | 98 | 490.3 | 20–88 HRA | Hardened steel, high-strength metals |
| HRC | | 98 | 1373 | 20–70 HRC | |
| HRB | Carbide ball (W) 1.5785 mm | 98 | 882.6 | 20–100 HRB | Soft steel, non-ferrous metals |
| HRF | | 98 | 490.3 | 60–100 HRF | |

## Hardness test by Vickers

cf. DIN EN ISO 6507-1 (2006-03)




$F$ test load in N
$d$ diagonal of the indentation in mm
$s$ test specimen thickness
$a$ distance from edge

**Test conditions**

Surface of specimen is ground to $Ra = 0.4–0.8$ µm. The machining of the specimen must not result in any changes to the microstructure.
Distance from edge $a \geq 2.5 \cdot d$

**Diagonal of the impression**

$$d = \frac{d_1 + d_2}{2}$$

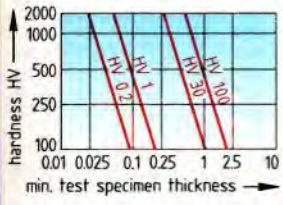
**Vickers hardness**

$$\text{HV} = 0.1891 \cdot \frac{F}{d^2}$$

**Designation examples:**

**540 HV 1 / 20**
**650 HV 5**

| Hardness value | Test load $F$ | Working time |
|---|---|---|
| Vickers hardn. 540 | 1 · 9.80665 N = 9.807 N | Value entry 20 s |
| Vickers hardn. 650 | 5 · 9.80665 N = 49.03 N | Unspecified: 10 to 15 s |



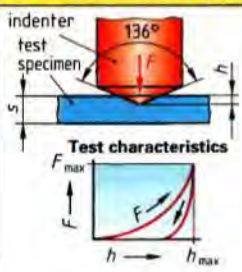

**Test conditions and applied loads for the Vickers hardness test**

| Test condition | HV100 | HV50 | HV30 | HV20 | HV10 | HV5 |
|---|---|---|---|---|---|---|
| Test load in N | 980.7 | 490.3 | 294.2 | 196.1 | 98.07 | 49.03 |
| Test condition | HV3 | HV2 | HV1 | HV0.5 | HV0.3 | HV0.2 |
| Test load in N | 29.42 | 19.61 | 9.807 | 4.903 | 2.942 | 1.961 |

# Martens hardness, Conversion of hardness values

## Martens hardness by penetrant testing

cf. DIN EN ISO 14577 (2003-05)




$F$ test load in N
$h$ depth of penetration in mm
$s$ specimen thickness in mm

| Test specimen surface | | | |
|---|---|---|---|
| Material | Average roughness $Ra$ at $F$ | | |
| | 0.1 N | 2 N | 100 N |
| Aluminum | 0.13 | 0.55 | 4.00 |
| Steel | 0.08 | 0.30 | 2.20 |
| Carbide | 0.03 | 0.10 | 0.80 |

**Martens hardness**

$$HM = \frac{F}{26.43 \cdot h^2}$$

**Designation:** HM 0.5 / 20 / 20 = 5700 N/mm²

| Test method | Test load $F$ | Test duration | Application of load | Martens hardn. value |
|---|---|---|---|---|
| Martens hardness | 0.5 N | 20 s | within 20 s | 5700 N/mm² |

| Test range | Conditions | Applications |
|---|---|---|
| Macro range | $2\ N \le F \le 30\ kN$ | Universal hardness test, e. g. for all metals, plastics, carbides, ceramic materials; micro and nano ranges: thin layer measurement, microstructure components |
| Micro range | $F < 2$ N or H > 0.2 µm | |
| Nano range | $h \le 0.2$ µm | |

## Conversion tables for hardness values and tensile strength [1]

cf. DIN EN ISO 18265 (2004-02)

| Tensile strength $R_m$ N/mm² | Vickers hardness HV ($F \ge 98$ N) | Brinell hardness HB30 | Rockwell hardness HRC | HRA | HRB [2] | HRF [2] | Tensile strength $R_m$ N/mm² | Vickers hardness HV ($F \ge 98$ N) | Brinell hardness HB30 | Rockwell hardness HRC | HRA |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 255 | 80 | 76 | – | – | – | – | 1155 | 360 | 342 | 37 | 69 |
| 285 | 90 | 86 | – | – | 48 | 83 | 1220 | 380 | 361 | 39 | 70 |
| 320 | 100 | 95 | – | – | 56 | 87 | 1290 | 400 | 380 | 41 | 71 |
| 350 | 110 | 105 | – | – | 62 | 91 | 1350 | 420 | 399 | 43 | 72 |
| 385 | 120 | 114 | – | – | 67 | 94 | 1420 | 440 | 418 | 45 | 73 |
| 415 | 130 | 124 | – | – | 71 | 96 | 1485 | 460 | 437 | 46 | 74 |
| 450 | 140 | 133 | – | – | 75 | 99 | 1555 | 480 | 456 | 48 | 75 |
| 480 | 150 | 143 | – | – | 79 | (101) | 1595 | 490 | 466 | 48 | 75 |
| 510 | 160 | 152 | – | – | 82 | (104) | 1665 | 510 | 485 | 50 | 76 |
| 545 | 170 | 162 | – | – | 85 | (106) | 1740 | 530 | 504 | 51 | 76 |
| 575 | 180 | 171 | – | – | 87 | (107) | 1810 | 550 | 523 | 52 | 77 |
| 610 | 190 | 181 | – | – | 90 | (109) | 1880 | 570 | 542 | 54 | 78 |
| 640 | 200 | 190 | – | – | 92 | (110) | 1955 | 590 | 561 | 55 | 78 |
| 675 | 210 | 199 | – | – | 94 | (111) | 2030 | 610 | 580 | 56 | 79 |
| 705 | 220 | 209 | – | – | 95 | (112) | 2105 | 630 | 599 | 57 | 80 |
| 740 | 230 | 219 | – | – | 97 | (113) | 2180 | 650 | 618 | 58 | 80 |
| 770 | 240 | 228 | 20 | 61 | 98 | (114) | – | 670 | – | 59 | 81 |
| 800 | 250 | 238 | 22 | 62 | 100 | (115) | – | 690 | – | 60 | 81 |
| 835 | 260 | 247 | 24 | 62 | (101) | – | – | 720 | – | 61 | 82 |
| 865 | 270 | 257 | 26 | 63 | (102) | – | – | 760 | – | 63 | 83 |
| 900 | 280 | 266 | 27 | 64 | (104) | – | – | 800 | – | 64 | 83 |
| 930 | 290 | 276 | 29 | 65 | (105) | – | – | 840 | – | 65 | 84 |
| 965 | 300 | 285 | 30 | 65 | – | – | – | 880 | – | 66 | 85 |
| 1030 | 320 | 304 | 32 | 66 | – | – | – | 920 | – | 68 | 85 |
| 1095 | 340 | 323 | 34 | 68 | – | – | – | 940 | – | 68 | 86 |

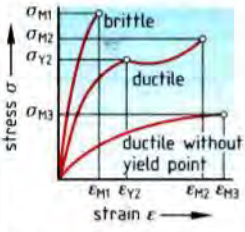
[1] Applies to unalloyed and low alloy steels and cast steel. Special tables of this standard are to be used for quenched and tempered, cold worked and high-speed steels, as well as for various carbide types. Considerable deviations are to be expected for high-alloyed and/or work-hardened steels.
[2] The values in parentheses lie outside of the measurement range.

# Testing of plastics: Tensile properties, Hardness testing

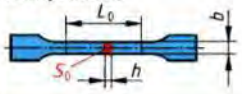
## Determination of the tensile properties on plastics

cf. DIN EN ISO 527-1 (1996-04)

**Typical stress-strain curves**




**Test specimens**




$F_M$ maximum force
$F_Y$ yield stress
$\Delta L_{FM}$ change in length with maximum load
$\Delta L_{FY}$ change in length with yield strength
$L_0$ gage length
$S_0$ initial cross section
$\sigma_M$ tensile strength
$\sigma_Y$ yield strength
$\varepsilon_M$ maximum elongation
$\varepsilon_Y$ yield strain

**Test Specimens**

For each property, e.g. tensile strength, yield strength, yield strain, at least five test specimens must be tested.

Application
- thermoplastic injection molded and extrusion molding materials
- thermoplastic slabs and films
- thermoset molding materials
- thermoset slabs
- fiber reinforced composite materials, thermoplastic and thermoset plastic

**Tensile strength**

$$\sigma_M = \frac{F_M}{S_0}$$

**Yield strength**

$$\sigma_Y = \frac{F_Y}{S_0}$$

**Maximum elongation**

$$\varepsilon_M = \frac{\Delta L_{FM}}{L_0} \cdot 100\%$$

**Yield strain**

$$\varepsilon_Y = \frac{\Delta L_{FY}}{L_0} \cdot 100\%$$

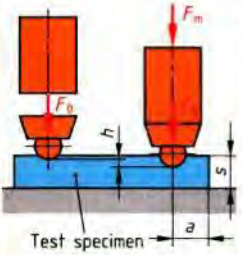
| Test speed | | | | | Test specimen according to | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | DIN EN ISO 527-2 for molding materials | | | | | DIN EN ISO 527-3 for films | | |
| Test speed in mm/min | | | | Tolerance | Type | | 1A | 1B | 5A | 5B | 2 | 4 | 5 |
| | | | | | $L_0$ | mm | 50 ± 0.5 | 50 ± 0.5 | 20 ± 0.5 | 10 ± 0.2 | 50 ± 0.5 | 50 ± 0.5 | 25 ± 0.25 |
| 1 | 2 | 5 | 10 | ±20% | $h$ | mm | 4 ± 0.2 | 4 ± 0.2 | ≥ 2 | ≥ 1 | ≤ 1 | ≤ 1 | ≤ 1 |
| 20 | 50 | 100 | 200 | ±10% | $b$ | mm | 10 ± 0.2 | 10 ± 0.2 | 4 ± 0.1 | 2 ± 0.1 | 10–25 | 25.4 ± 0.1 | 6 ± 0.4 |

⇒ **Tensile test ISO 527-2/1A/50:** Tensile test according to ISO 527-2; specimen type 1A; test speed 50 mm/min

## Hardness test on plastics

cf. DIN EN ISO 2039-1 (2003-06)

**Ball indentation test**




$F_0$ preload 9.8 N
$F_m$ test load
$h$ depth of penetration
$a$ distance from edge
$s$ specimen thickness

**Test Specimens**

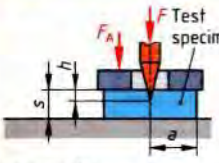
distance from edge $a \geq 10$ mm, minimum specimen thickness $s \geq 4$ mm

| Test load $F_m$ in N | Ball indentation hardness $H$ in N/mm² for indentation depth $h$ in mm | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0.16 | 0.18 | 0.20 | 0.22 | 0.24 | 0.26 | 0.28 | 0.30 | 0.32 | 0.34 |
| 49 | 22 | 19 | 16 | 15 | 13 | 12 | 11 | 10 | 9 | 9 |
| 132 | 59 | 51 | 44 | 39 | 35 | 32 | 30 | 27 | 25 | 24 |
| 358 | 160 | 137 | 120 | 106 | 96 | 87 | 80 | 74 | 68 | 64 |
| 961 | 430 | 370 | 320 | 290 | 260 | 234 | 214 | 198 | 184 | 171 |

⇒ **Ball indentation hardness ISO 2039-1 H 132:** $H = 31$ N/mm² at $F_m = 132$ N

## Hardness test by Shore on plastics

cf. DIN EN ISO 868 (2003-06)

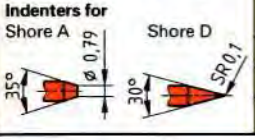



$F_A$ contact pressure in N
$F$ test load
$h$ depth of penetration
$a$ distance from edge
$s$ specimen thickness

**Test Specimens**

Distance from edge $a \geq 9$ mm, minimum specimen thickness $s \geq 4$ mm

**Indenters for**




**Test conditions for the Shore A and Shore D methods**

| Test method | $F_{max}$ in N | $F_A$ in N | Application |
|---|---|---|---|
| A | 7.30 | 10 | if Shore hardness with Type D is < 20 |
| D | 40.05 | 50 | if Shore hardness with Type A is > 90 |

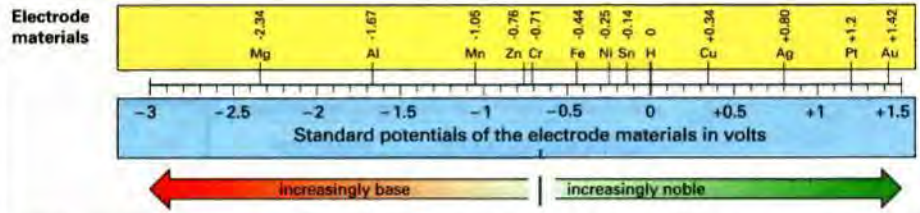
⇒ **85 Shore A:** Hardness value 85; test method Shore A

# Corrosion

## Electrochemical series of metals

In galvanic corrosion the same processes occur as in electrical elements where the base metals are corroded. The voltage produced between two dissimilar metals under influence of a conducting liquid (electrolyte) can be taken from the standard potentials of the electrochemical series. Standard potential refers to the voltage produced between the electrode material and a platinum electrode immersed in hydrogen.

Passivation (formation of protective layers) alters the voltage between the elements.




**Example:** The standard potentials of Cu = +0.34 V and Al = −1.7 V yield a voltage of U = +0.34 V − (−1.67 V) = 2.01 V between Cu and Al.

## Corrosion behavior of metallic materials

| Materials | Corrosion behavior | Resistance in following environment | | | | |
|---|---|---|---|---|---|---|
| | | Dry ambient air | Country air | Industrial air | Sea air | Salt water |
| Unalloyed and alloy steels | Only resist corrosion in dry areas | ● | ◴ | ◴ | ○ | ○ |
| Stainless steels | Resistant, but not against aggressive chemicals | ● | ● | ◐ | ◐ | ◐ |
| Aluminum and Al alloys | Resistant, except the Al alloys containing Cu | ● | ◐ | ◐ | ◐ | ● to ◴ |
| Copper and Cu alloys | Resistant, especially Cu alloys containing Ni | ● | ● | ◐ | ◐ | ● to ◴ |

● resistant ◐ fairly resistant ◴ non-resistant ○ unusable

## Corrosion protection

### Preparation of metal surfaces before coating

| Processing step | Purpose | Process |
|---|---|---|
| Mechanical cleaning and creating a good surface for adherence | Removal of mill scale, rust and dirt | Grinding, brushing, blasting with water jet mixed with silica sand |
| Chemical cleaning and creating an optimal surface finish | Removal of mill scale, rust and grease residues<br>Roughing or smoothing the surface | Etching with acid or lye; degreasing with solvents; chemical or electrochemical polishing |

## Preventative actions for corrosion protection

| Actions | Examples |
|---|---|
| Select suitable materials | Stainless steel for parts for preparation in the paper production |
| Observe corrosion protection principles in design | Same material on contact points, insulation layers between the parts, avoiding gaps |
| Protective layers: • protective oil or lubricant<br>• chemical surface treatment<br>• protective paint | Oiling sliding tracks and measuring tools<br>Phosphatizing, burnishing<br>Lacquer coat, possible after previous phosphatizing |
| Metallic coatings | Hot-dip galvanizing, galvanic metal plating, e.g. chrome plating |
| Cathodic corrosion protection | Part to be protected, e.g. a ship propeller, is connected to a sacrificial anode |
| Anodic oxidation of Al materials | A corrosion-resistant permanent oxide layer is produced on the part, e.g. a rim |

# Disposal of substances*

## Waste management laws

cf. Closed Substance Cycle and Waste Management Act (2001-10)

**Important principles of recycling management**

- Avoid waste, e.g. by in-house recycling management or a low-waste product design.
- Utilize material waste, e.g. by recovery of raw materials from waste (secondary raw materials).
- Use waste for recovery of energy (energy use), e.g. use as substitute fuel.
- Waste must be recycled properly without adverse effect on the well being of the general public.

The disposal of waste is subject to monitoring by the responsible authorities (usually the administrative district). In particular, wastes hazardous to health, air or water, explosive, and flammable especially need to be monitored.

**The waste producer is responsible for proper disposal and documentation of disposal.**

**Examples of waste requiring special monitoring (hazardous waste) in metal processing industry[1)]**

| Disposal code | Description of the type of waste | Appearance, description, source | Special instructions, actions |
|---|---|---|---|
| 150199D1 | Packaging containing hazardous impurities | Barrels, canisters, buckets and cans contain residues of paints, lacquers, solvents, cleaning agents, rust preventatives, rust and silicone removers, spackle, etc. | Emptied, drip free, brush or spatula clean conditions are not wastes requiring special monitoring. They are considered retail packaging. Disposal using the dual system or in metal bins using a waste management company. Bins with dried paint are similar to house-hold commercial waste. |
| | | Spray cans with residual contents | Spray cans should be avoided if possible; they must be disposed as hazardous waste. |
| 160602 | Nickel cadmium batteries | Rechargeable batteries, e.g. from drills and screwdrivers, etc. | All batteries containing contaminants are labeled. The dealer must accept their return at no charge. Consumers are required to return them to the dealer or to a public recycling center. |
| 160603 | Mercury dry cells | Coin cell batteries, mercury containing monocell batteries | |
| 160604 | Alkaline batteries | Non-rechargeable batteries | |
| 060404 | Mercury containing waste | Fluorescent lamps (so-called "neon tubes") | Can be recycled. Return to dealer or to waste disposer. Do not put in glass recycling! |
| 120106 | Used machining oils, containing halogens, no emulsion | Water free drilling, turning, grinding and cutting oils, so-called cooling lubricants | Avoid cooling lubricants as much as possible, e.g. by<br>• dry machining<br>• minimum quantity cooling lubrication<br>Separated collection of different cooling lubricants, emulsions, solvents. Inquire with supplier for reprocessing or combustion (energy recycling) options. |
| 120107 | Used machining oils, halogen free, no emulsion | Old, water free honing oil | |
| 110 | Synthetic machining oils | Cooling lubricants from synthetic oils, e.g. on ester-based | |
| 130202 | Non- chlorinated machine, gear and lubricating oils | Used oil and gear oil, hydraulic oil, compressor oil from piston air compressors | Recycling through supplier or a licensed waste disposal service. Used oils of known origin may be recycled by secondary refining or energy recovery. Do not mix with other materials! |
| 150299D1 | Vacuumed and filter materials, wipe cloths and protective clothing with hazardous contaminants | For example, used rags, cleaning cloths; brushes contaminated with oil or wax, oil binders, oil and lubricant cans | Option of using a rental service for cleaning cloths. |
| 130505 | Other emulsions | Condensation water from compressors | Use compressor oils with de-emulsifying properties; inquire about the option of oil free compressors. |
| 140102 | Other halogenated solvents and solvent mixtures | Per (-chloroethane)<br>Tri (-chloroethene)<br>Mixed solvents | Recycling by suppliers and test replacement with aqueous cleaning solution. |

[1)] Regulation governing wastes requiring special monitoring – BestbüAbfV (1999-01), Appendix 1: Wastes listed in the European Waste Catalog (EAK waste) are considered to be especially hazardous. Appendix 2: EAK waste requiring special monitoring as well as waste types not on the EAK list ( Letter "D" in Disposal code).

*) According to European Standards

# Hazardous materials and material characteristics of hazardous gases

## Identification and handling of hazardous materials

cf. EC Directive R 67/548/EEC[1]

| Substance | Identification[2] | | | Substance | Identification[2] | | |
|---|---|---|---|---|---|---|---|
| | Symbol | R-phrases | S-phrases | | Symbol | R-phrases | S-phrases |
| Acetone | F, Xi | 11; 36; 66; 67 | 9; 16; 26 | Tetrachlor-ethane ("Per") | Xn; N | 40; 51/53 | 23; 36/37; 61 |
| Acetylene | F+ | 5; 6; 12 | (2); 9; 16; 33 | Kerosine | T | 45 | 53; 45 |
| Acrylonitrile | F, T, N | 45; 11; 23/24; 25; 37/38; 41; 43; 51/53 | 9; 16; 45; 53; 61 | Phenol | T; C | 23/24/25; 34; 48/20/21/22; 68 | 24/25; 26; 28; 36/37; 39; 45 |
| Ammonia | C; N | 34; 50 | 26; 36/37/39; 61 | Phosphoric acid | C | 34 | 23; 45 |
| Arsenic | T; N | 23/25; 50/53 | 20/21; 28; 45; 60; 61 | Propane | F+ | 12 | 9; 16 |
| Asbestos | T | 45; 48/23 | 53; 45 | Mercury | T; N | 23; 33; 50/53 | 7; 45; 60; 61 |
| Gasoline | T | 45; 65 | 53; 45 | Hydrochloric acid | C | 34; 37 | 26; 45 |
| Benzene | F; T | 45; 46; 11; 36/38; 48/23/ 24/25; 65 | 53; 45 | Oxygen | O | 8 | 17 |
| Lead compounds | T; N | 61; 20/22; 33; 62; 50/53 | 53; 45; 60; 61 | Lubricating grease | T | 45 | 53; 45 |
| Chromium compounds | T; N | 49; 43; 50/53 | 53; 45; 60; 61 | Lubricating oil | T | 45 | 53; 45 |
| Hydrofluoric acid (HF) | T+; C | 26/27/28; 35 | 7/9; 26; 36/37; 45 | Sulphoric acid | C | 35 | 26; 30; 45 |
| Ceramic mineral fibers | T | 49; 38 | 53; 45 | Styrene | Xn | 10; 20; 36/38 | 23 |
| Carbon monoxide | F+; T | 61; 12; 23; 48/23 | 53; 45 | Turpentine, oil | Xn; N | 10; 20/21; 36/38; 43; 51/53; 65 | 36/37; 46; 61; 62 |
| Fiber glass | Xn | 38; 40 | 35/37 | Trichlorethylene (Tri) | T | 45; 36/38; 52/53; 67 | 53; 45; 61 |
| Nicotine | T+; N | 25; 27; 51/53 | 36/37; 45; 61 | Hydrogen | F+ | 12 | 9; 16; 33 |

[1] As per Art. 1a of the Regulation on Hazardous Materials applicable in Germany since 31 October 2005

[2] Cf. R-phrases on page 199, S-phrases on page 200, Safety signs on page 342; the slash (/) between the number indicates a combination of R-phrases or S-phrases.

## Material characteristics of hazardous gases

| Gas | Density ratio to air | Ignition temperature | Lower ignition limit vol.-% gas in air | Upper ignition limit vol.-% gas in air | Additional information |
|---|---|---|---|---|---|
| Acetylene | 0.91 | 305°C | 1.5 | 82 | With a pressure $p_e > 2$ bar self-disintegration and explosion |
| Argon | 1.38 | incombustible | – | – | Loss of breath; danger of suffocation |
| Butane | 2.11 | 365°C | 1.5 | 8.5 | Narcotic effect; suffocating effect |
| Carbon dioxide | 1.53 | incombustible | – | – | Liquid $CO_2$ and dry ice lead to serious frostbyte |
| Carbon monoxide | 0.97 | 605°C | 12.5 | 74 | Potent blood poison; damage to vision, lungs, liver, kidneys and hearing |
| Hydrogen | 0.07 | 570°C | 4 | 75.6 | Spontaneous combustion with high escaping speeds; forms explosive mixtures with air, $O_2$ and Cl |
| Nitrogen | 0.97 | incombustible | – | – | Lose of breath in enclosed spaces; danger of suffocation |
| Oxygen | 1.1 | incombustible | – | – | Greases and oils react with oxygen explosively; fire-promoting gas |
| Propane | 1.55 | 470°C | 2.1 | 9.5 | Loss of breath; liquid propane causes damage to skin and eyes |

# Hazardous substances, R-phrases*

Hazardous substances adversely affect the safety and health of humans and endanger the environment. They must be specially labeled (see page 342). The following R Phrases[1] are standard phrases and point out the special risks when handling a hazardous substance. Special safety data sheets for each hazardous substance contain further extensive information.

## R-Phrases: Notes on special risks

cf. RL 67/548/EWG[2] (2004-04)

| R-Phrases[3] | Meaning |
|---|---|
| R 1 | Explosive when dry |
| R 2 | Risk of explosion by shock, friction, fire, or other sources of ignition |
| R 3 | Extreme risk of explosion by shock, friction, fire, or other sources of ignition |
| R 4 | Forms very sensitive explosive metallic compounds |
| R 5 | Heating may cause an explosion |
| R 6 | Explosive with or without contact with air |
| R 7 | May cause fire |
| R 8 | Contact with combustible material may cause fire |
| R 10 | Flammable |
| R 11 | Highly flammable |
| R 12 | Extremely flammable |
| R 13 | Extremely flammable liquid gas |
| R 14 | Reacts violently with water |
| R 15 | Contact with water liberates extremely flammable gases |
| R 16 | Explosive when mixed with oxidizing substances |
| R 17 | Spontaneously flammable in air |
| R 18 | In use, may form flammable/explosive vapor-air mixture |
| R 19 | May form explosive peroxides |
| R 20 | Harmful by inhalation |
| R 21 | Harmful in contact with skin |
| R 22 | Harmful if swallowed |
| R 23 | Toxic by inhalation |
| R 24 | Toxic in contact with skin |
| R 25 | Toxic if swallowed |
| R 26 | Very toxic by inhalation |
| R 27 | Very toxic in contact with skin |
| R 28 | Very toxic if swallowed |
| R 29 | Contact with water liberates toxic gases |
| R 30 | Can become highly flammable in use |
| R 31 | Contact with acids liberates toxic gases |
| R 32 | Contact with acids liberates very toxic gases |
| R 33 | Danger of cumulative effects |
| R 34 | Causes burns |
| R 35 | Causes severe burns |
| R 36 | Irritating to the eyes |
| R 37 | Irritating to respiratory system |
| R 38 | Irritating to the skin |
| R 39 | Danger of very serious irreversible effects |
| R 40 | Limited evidence of a carcinogenic effect |
| R 41 | Risk of serious damage to eyes |
| R 42 | May cause sensitization by inhalation |
| R 43 | May cause sensitization by skin contact |
| R 44 | Risk of explosion if heated under confinement |
| R 45 | May cause cancer |
| R 46 | May cause heritable genetic damage |
| R 48 | Danger of serious damage to health by prolonged exposure |
| R 49 | May cause cancer by inhalation |
| R 50 | Very toxic to aquatic organisms |
| R 51 | Toxic to aquatic organisms |
| R 52 | Harmful to aquatic organisms |
| R 53 | May cause long-term adverse effects in the aquatic environment |
| R 54 | Toxic to flora (plants) |
| R 55 | Toxic to fauna (animals) |
| R 56 | Toxic to soil organisms |
| R 57 | Toxic to bees |
| R 58 | May cause long-term adverse effects in the environment |
| R 59 | Dangerous to the ozone layer |
| R 60 | May impair fertility |
| R 61 | May cause harm to the unborn child |
| R 62 | Possible risk of impaired fertility |
| R 63 | Possible risk of harm to the unborn child |
| R 64 | May cause harm to breastfed babies |
| R 65 | Harmful: May cause lung damage if swallowed |
| R 66 | Repeated exposure may cause skin dryness or cracking |
| R 67 | Vapors may cause drowsiness and dizziness |
| R 68 | Possible irreversible damage |

[1] R = Risk [2] EU-Directive, Appendix III

[3] Combinations of the risk phrases are possible; e.g. R 23/24: Toxic by inhalation and in contact with skin

*) According to European Standards

# Hazardous substances, S-Phrases*

The following standardized recommended safety measures (S phrases)[1] are to be followed while handling hazardous substances and preparations. By complying with them dangers can be avoided or reduced.

## S (safety) phrases: Recommended Safety Measures

cf. RL 67/548/EWG[2] (2004-04)

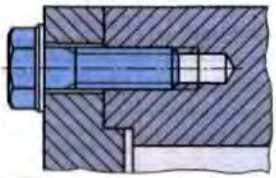
| S phrase[3] | Meaning |
|---|---|
| S 1 | Keep locked up |
| S 2 | Keep out of the reach of children |
| S 3 | Keep in a cool place |
| S 4 | Keep away from living quarters |
| S 5 | Keep contents under ... (appropriate liquid to be specified by the manufacturer) |
| S 6 | Keep contents under ... (appropriate linert gas to be specified by the manufacturer) |
| S 7 | Keep container tightly closed |
| S 8 | Keep container dry |
| S 9 | Keep container in a well-ventilated place |
| S 12 | Do not keep the container sealed |
| S 13 | Keep away from food, drink and animal feeding stuffs |
| S 14 | Keep away from ... (incompatible materials to be indicated by the manufacturer) |
| S 15 | Keep away from heat |
| S 16 | Keep away from sources of ignition – no smoking |
| S 17 | Keep away from combustible materials |
| S 18 | Handle and open container with care |
| S 20 | When using do not eat or drink |
| S 21 | When using do not smoke |
| S 22 | Do not breathe dust |
| S 23 | Do not breathe gas/fumes/vapor/spray (appropriate wording to be specified by the manufacturer ) |
| S 24 | Avoid contact with skin |
| S 25 | Avoid contact with eyes |
| S 26 | In case of contact with eyes, rinse immediately with plenty of water and seek medical advice |
| S 27 | Take off immediately all contaminated clothing |
| S 28 | After contact with skin, wash immediately with plenty of ... (to be specified by the manufacturer) |
| S 29 | Do not empty into drains |
| S 30 | Never add water to this product |
| S 33 | Take precautionary measures against static discharges |
| S 35 | This material and its container must be disposed of in a safe way |
| S 36 | Wear suitable protective clothing |
| S 37 | Wear suitable gloves |
| S 38 | In case of insufficient ventilation, wear suitable respiratory equipment |
| S 39 | Wear eye/face protection |
| S 40 | To clean the floor and all objects contam. by this material, use ... (to be specif. by the manufacturer) |
| S 41 | In case of fire and/or explosions do not breathe fumes |
| S 42 | During fumigation/spraying wear suitable respiratory equipment (appropriate wording to be specified by the manufacturer) |
| S 43 | In case of fire, use ... (indicate in the space the precise type of fire-fighting equipment if water increases risk, add: 'Never use water') |
| S 45 | In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible) |
| S 46 | If swallowed, seek medical advice immediately and show this container or label |
| S 47 | Keep at temperature not exceeding ... °C (To be specified by the manufacturer) |
| S 48 | Keep wet with ... (appropriate material to be specified by the manufacturer) |
| S 49 | Keep only in the original container |
| S 50 | Do not mix with ... (to be specified by the manufacturer) |
| S 51 | Use only in well-ventilated areas |
| S 52 | Not recommended for interior use on large surface areas |
| S 53 | Avoid exposures[4], obtain special instructions before use |
| S 56 | Dispose of this material and its container at hazardous or special waste collection point |
| S 57 | Use appropriate container to avoid[5] environmental contamination |
| S 59 | Refer to manufacturer/supplier for information on recovery/recycling |
| S 60 | This material and its container must be disposed of as hazardous waste |
| S 61 | Avoid release to the environment. Refer to special instructions/safety data sheets |
| S 62 | If swallowed, do not induce vomiting: seek medical advice immediately and show this container or label |
| S 63 | In case of accident by inhalation: move victim to fresh air and keep at rest |
| S 64 | If swallowed, rinse mouth with water (only if the person is conscious) |

[1] S = safety [2] EU- Directive, Appendix IV
[3] Combinations of the S phrases are possible; e.g. S 20/21: when using do not eat, drink or smoke.
[4] i.e. do not expose yourself to this hazard [5] Contamination, infestation
*) According to European Standards

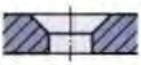
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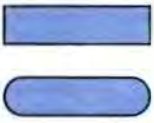


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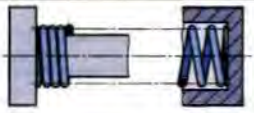




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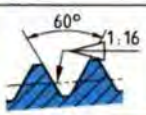


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# Types of threads, Overview

cf. DIN 202 (1999-11)

## Right-hand threads, single-start

| Thread name | Thread profile | Code letter | Designation example | Nominal sizes | Application |
|---|---|---|---|---|---|
| Metric threads ISO threads |   | M | DIN 14 – M 08 | 0.3 to 0.9 mm | Clocks, precision mechanisms |
| | | | DIN 13 – M 30 | 1 to 68 mm | General purpose (coarse thread) |
| | | | DIN 13 – M 20 × 1 | 1 to 1000 mm | General purpose (fine thread) |
| Metric threads with large clearance | | | DIN 2510 – M 36 | 12 to 180 mm | Bolts/screws with anti-fatigue shank |
| Metric straight internal threads | | | DIN 158 – M 30 × 2 | 6 to 60 mm | Drain plugs and grease nipples |
| Metric taper external threads |   | M | DIN 158 – M 30 × 2 keg | 6 to 60 mm | Drain plugs and grease nipples |
| Pipe threads, straight |   | G | DIN ISO 228 – G 1 1/2 (internal)<br>DIN ISO 228 – G 1 1/2 A (external) | 1/8 to 6 inches | Does not seal on thread |
| Parallel pipe threads (internal threads) |   | Rp | DIN 2999 – Rp 1/2 | 1/16 to 6 inch | Pipe threads, seals on thread; for threaded pipe, fittings, screwed pipe joints |
| | | | DIN 3858 – Rp 1/8 | 1/8 to 1 1/2 inch | |
| Taper pipe threads (external threads) |   | R | DIN 2999 – R 1/2 | 1/16 to 6 inches | |
| | | | DIN 3858 – R 1/8 – 1 | 1/8 to 1 1/2 inches | |
| Metric ISO trapezoidal threads |   | Tr | DIN 103 – Tr 40 × 7 | 8 to 300 mm | General purpose as motion screw threads |
| Buttress threads |   | S | DIN 513 – S 48 × 8 | 10 to 640 mm | General purpose as motion screw threads |
| Knuckle threads |   | Rd | DIN 405 – Rd 40 × 1/6 | 8 to 200 mm | General purpose |
| | | | DIN 20400 – Rd 40 × 5 | 10 to 300 mm | Knuckle threads with large thread overlap |
| Tapping screw threads |   | ST | ISO 1478 – ST 3,5 | 1.5 to 9.5 mm | For tapping screws |

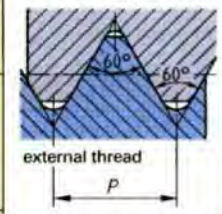
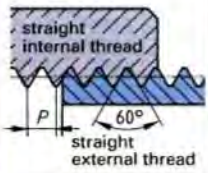
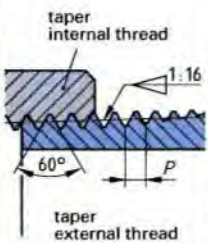
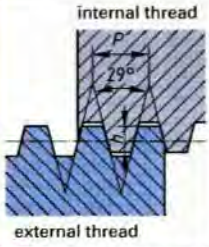
## Designation of left-hand and multiple start threads

cf. DIN ISO 965-1 (1999-11)

| Type of thread | Explanation | Code designation (examples) |
|---|---|---|
| Left-hand threads | The code designation "LH" is placed after the complete thread designation (LH = Left-Hand). | M 30 – LH<br>Tr 40 × 7 – LH |
| Multiple start right-hand thread | The lead $P_h$ and the pitch $P$ follow the code designation and the thread diameter. | M 16 x $P_h$ 3 P 1,5 or<br>M 16 x $P_h$ 3 P 1,5 (double-start) |
| Multiple start left-hand thread | "LH" is placed after the thread designation of the multiple start.[1] | M 14 x $P_h$ 6 P 2-LH or<br>M 14 x $P_h$ 6 P 2 (triple-start)-LH |

[1] For parts which have right-hand and left-hand threads, "RH" (Right-Hand) is placed after the thread designation of the right-hand thread and "LH" (Left-Hand) after the left-hand thread. The number of starts for multiple-starts is found by: **no. of starts = lead $P_h$/ pitch $P$.**

## Thread standards of various countries (selection)[1]

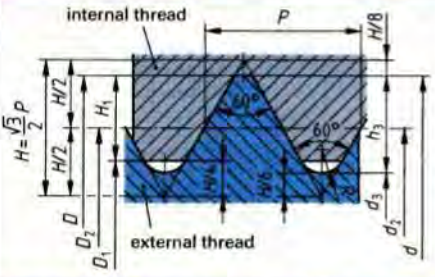
| Thread name | Thread profile | Code | Thread designation | | Country[2] |
|---|---|---|---|---|---|
| | | | Example | Meaning | |
| Unified National Coarse Thread |   | UNC | 1/4 – 20 UNC – 2A | ISO-UNC-thread with 1/4 inch nominal diameter, 20 threads/inch, Class 2A | ARG, AUS, CAN, GBR, IND, JPN, NOR, PAK, SWE and others |
| Unified National Fine Thread | | UNF | 1/4 – 28 UNC – 3A | ISO-UNF threads with 1/4 inch nominal diameter, 28 threads/inch, Class 3A | ARG, AUS, CAN, GBR, IND, JPN, NOR, PAK, SWE and others |
| Unified National Extra Fine Thread | | UNEF | 1/4 – 32 UNEF – 3A | ISO-UNEF thread with 1/4 inch nominal diameter, 32 threads/inch, Class 3A | ARG, AUS, CAN, IND, NOR, PAK, SWE and others |
| Unified National Special Thread, special diameter/lead combinations | | UNS | 1/4 – 27 UNS | UNS threads with 1/4 inch nominal diameter, 27 threads/inch | ARG, AUS, CAN, NZL, USA |
| Straight Pipe Threads for Mechanical Joints |   | NPSM | 1/2 – 14 NPSM | NPSM threads with 1/2 inch nominal diameter, 14 threads/inch | USA, CAN |
| American Standard Taper Pipe Thread |   | NPT | 3/8 – 18 NPT | NPT thread with 3/8 inch nominal diameter, 18 threads/inch | BRA, CAN, FRA, USA and others |
| American Taper Pipe Thread, Fuel | | NPTF | 1/2 – 14 NPTF (dryseal) | NPTF threads with 1/2 inch nominal diameter, 14 threads/inch, (dry sealing) | BRA, CAN, USA |
| American trapezoidal threads $h = 0.5 \cdot P$ |   | Acme | 1 3/4 – 4 Acme – 2G | Acme threads with 1 3/4 inch nominal diameter 4 threads/inch, Class 2G | AUS, CAN, GBR, NZL, USA |
| American truncated trapezoidal threads $h = 0.3 \cdot P$ | | Stub Acme | 1/2 – 20 Stub Acme | Stub Acme threads with 1/2 inch nominal diameter, 20 threads/inch | CAN, USA |

[1] cf. Kaufmann, Manfred: "Wegweiser zu den Gewindenormen verschiedener Länder" DIN, Beuth-Verlag

[2] Three-letter codes for countries, cf. DIN EN ISO 3166-1 (2008-06)

# Imperial Threads

## Imperial Threads for general purposes




| | |
|---|---|
| Major diameter | $d = D$ |
| Pitch | $P$ |
| Depth of external thread | $h_3 = 0.6134 \cdot P$ |
| Depth of internal thread | $H_1 = 0.5413 \cdot P$ |
| Radius at root | $R = 0.1443 \cdot P$ |
| Basic pitch Ø | $d_2 = D_2 = d - 0.6495 \cdot P$ |
| Minor Ø of external thread | $d_3 = d - 1.1904 \cdot P$ |
| Minor Ø of internal thread | $D_1 = d - 1.0825 \cdot P$ |
| Tap hole drill Ø | $= d - P$ |
| Thread angle | 60° |
| Stress area | $S = \frac{\pi}{4} \cdot \left(\frac{d_2 + d_3}{2}\right)^2$ |

## Basic sizes for Unified National Coarse Threads (UNC)

ANSI/ASME B1.1 (1989)

| No. size or inches | Threads per inch | Major diameter $D$ inches | Pitch $P$ inches | Pitch diameter $d_2 = D_2$ inches | Minor: External threads $d_3$ inches | Minor: Internal threads $D_1$ inches | Thread depth: External threads $h_3$ inches | Thread depth: Internal threads $H_1$ inches | Radius $R$ inches | Stress area $S$ inch² | Drill bit for tap hole: Drill size | Drill bit for tap hole: Decimal equival. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6 | 32 | 0.1380 | 0.0313 | 0.1177 | 0.1008 | 0.1042 | 0.01920 | 0.01691 | 0.0045 | 0.0093 | #36 | 0.1065 |
| 8 | 32 | 0.1640 | 0.0313 | 0.1437 | 0.1268 | 0.1302 | 0.01920 | 0.01691 | 0.0045 | 0.0142 | #29 | 0.1360 |
| 10 | 24 | 0.1900 | 0.0417 | 0.1629 | 0.1404 | 0.1449 | 0.02558 | 0.02255 | 0.0060 | 0.0179 | #25 | 0.1495 |
| 12 | 24 | 0.2160 | 0.0417 | 0.1889 | 0.1664 | 0.1709 | 0.02558 | 0.02255 | 0.0060 | 0.0246 | #16 | 0.1770 |
| 1/4 | 20 | 0.2500 | 0.0500 | 0.2175 | 0.1905 | 0.1959 | 0.03067 | 0.02706 | 0.0072 | 0.0324 | #7 | 0.2010 |
| 5/16 | 18 | 0.3125 | 0.0556 | 0.2764 | 0.2464 | 0.2524 | 0.03411 | 0.03007 | 0.0080 | 0.0532 | F | 0.2579 |
| 3/8 | 16 | 0.3750 | 0.0625 | 0.3344 | 0.3006 | 0.3073 | 0.03834 | 0.03383 | 0.0090 | 0.0786 | 5/16 | 0.3125 |
| 7/16 | 14 | 0.4375 | 0.0714 | 0.3911 | 0.3525 | 0.3602 | 0.04380 | 0.03866 | 0.0103 | 0.1078 | U | 0.3680 |
| 1/2 | 13 | 0.5000 | 0.0769 | 0.4500 | 0.4084 | 0.4167 | 0.04717 | 0.04164 | 0.0111 | 0.1438 | 27/64 | 0.4219 |
| 9/16 | 12 | 0.5625 | 0.0833 | 0.5084 | 0.4633 | 0.4723 | 0.05110 | 0.04511 | 0.0120 | 0.1842 | 31/64 | 0.4843 |
| 5/8 | 11 | 0.6250 | 0.0909 | 0.5660 | 0.5168 | 0.5266 | 0.05576 | 0.04921 | 0.0131 | 0.2288 | 17/32 | 0.5313 |
| 3/4 | 10 | 0.7500 | 0.1000 | 0.6851 | 0.6310 | 0.6418 | 0.06134 | 0.05413 | 0.0144 | 0.3382 | 21/32 | 0.6562 |
| 7/8 | 9 | 0.8750 | 0.1111 | 0.8028 | 0.7427 | 0.7547 | 0.06815 | 0.06014 | 0.0160 | 0.4666 | 49/64 | 0.7656 |
| 1 | 8 | 1.0000 | 0.1250 | 0.9188 | 0.8512 | 0.8647 | 0.07668 | 0.06766 | 0.0180 | 0.6120 | 7/8 | 0.8750 |
| 1 1/8 | 7 | 1.1250 | 0.1429 | 1.0322 | 0.9549 | 0.9704 | 0.08765 | 0.07732 | 0.0206 | 0.7713 | 63/64 | 0.9844 |
| 1 1/4 | 7 | 1.2500 | 0.1429 | 1.1572 | 1.0799 | 1.0954 | 0.08765 | 0.07732 | 0.0206 | 0.9781 | 1 7/64 | 1.1093 |
| 1 3/8 | 6 | 1.3750 | 0.1667 | 1.2668 | 1.1766 | 1.1946 | 0.10225 | 0.09021 | 0.0241 | 1.1664 | 1 7/32 | 1.2187 |
| 1 1/2 | 6 | 1.5000 | 0.1667 | 1.3918 | 1.3016 | 1.3196 | 0.10225 | 0.09021 | 0.0241 | 1.4179 | 1 11/32 | 1.3437 |
| 1 3/4 | 5 | 1.7500 | 0.2000 | 1.6201 | 1.5119 | 1.5335 | 0.12268 | 0.10825 | 0.0289 | 1.9171 | 1 9/16 | 1.5625 |
| 2 | 4.5 | 2.0000 | 0.2222 | 1.8557 | 1.7355 | 1.7594 | 0.13630 | 0.12028 | 0.0321 | 2.5207 | 1 25/32 | 1.7812 |

## Basic sizes for Unified National Fine Threads (UNF)

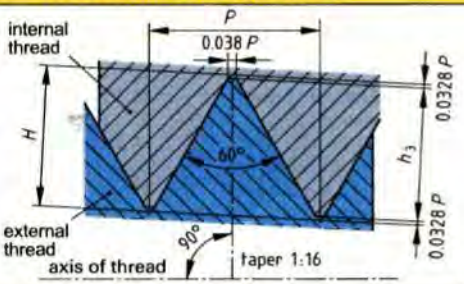
ANSI/ASME B1.1 (1989)

| No. size or inches | Threads per inch | Major diameter $D$ inches | Pitch $P$ inches | Pitch diameter $d_2 = D_2$ inches | Minor: External threads $d_3$ inches | Minor: Internal threads $D_1$ inches | Thread depth: External threads $h_3$ inches | Thread depth: Internal threads $H_1$ inches | Radius $R$ inches | Stress area $S$ inch² | Drill bit for tap hole: Drill size | Drill bit for tap hole: Decimal equival. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6 | 40 | 0.1380 | 0.0250 | 0.1218 | 0.1082 | 0.1109 | 0.0153 | 0.01353 | 0.0036 | 0.0103 | #33 | 0.1130 |
| 8 | 36 | 0.1640 | 0.0278 | 0.1460 | 0.1309 | 0.1339 | 0.0170 | 0.01504 | 0.0040 | 0.0149 | #29 | 0.1360 |
| 10 | 32 | 0.1900 | 0.0313 | 0.1697 | 0.1528 | 0.1562 | 0.0192 | 0.01691 | 0.0045 | 0.0203 | #21 | 0.1590 |
| 12 | 28 | 0.2160 | 0.0357 | 0.1928 | 0.1735 | 0.1773 | 0.0219 | 0.01933 | 0.0052 | 0.0262 | #14 | 0.1820 |
| 1/4 | 28 | 0.2500 | 0.0357 | 0.2268 | 0.2075 | 0.2113 | 0.0219 | 0.01933 | 0.0052 | 0.0368 | I | 0.2720 |
| 5/16 | 24 | 0.3125 | 0.0417 | 0.2854 | 0.2629 | 0.2674 | 0.0256 | 0.02255 | 0.0060 | 0.0587 | I | 0.2720 |
| 3/8 | 24 | 0.3750 | 0.0417 | 0.3479 | 0.3254 | 0.3299 | 0.0256 | 0.02255 | 0.0060 | 0.0886 | Q | 0.3320 |
| 7/16 | 20 | 0.4375 | 0.0500 | 0.4050 | 0.3780 | 0.3834 | 0.0307 | 0.02706 | 0.0072 | 0.1198 | 25/64 | 0.3906 |
| 1/2 | 20 | 0.5000 | 0.0500 | 0.4675 | 0.4405 | 0.4459 | 0.0307 | 0.02706 | 0.0072 | 0.1612 | 29/64 | 0.4531 |
| 9/16 | 18 | 0.5625 | 0.0556 | 0.5264 | 0.4964 | 0.5024 | 0.0341 | 0.03007 | 0.0080 | 0.2046 | 33/64 | 0.5156 |
| 5/8 | 18 | 0.6250 | 0.0556 | 0.5889 | 0.5589 | 0.5649 | 0.0341 | 0.03007 | 0.0080 | 0.2578 | 37/64 | 0.5781 |
| 3/4 | 16 | 0.7500 | 0.0625 | 0.7094 | 0.6756 | 0.6823 | 0.0383 | 0.03383 | 0.0090 | 0.3754 | 11/16 | 0.6875 |
| 7/8 | 14 | 0.8750 | 0.0714 | 0.8286 | 0.7900 | 0.7977 | 0.0438 | 0.03866 | 0.0103 | 0.5127 | 13/16 | 0.8125 |
| 1 | 12 | 1.0000 | 0.0833 | 0.9459 | 0.9008 | 0.9098 | 0.0511 | 0.04511 | 0.0120 | 0.6674 | 59/64 | 0.9219 |
| 1 1/8 | 12 | 1.1250 | 0.0833 | 1.0709 | 1.0258 | 1.0348 | 0.0511 | 0.04511 | 0.0120 | 0.8607 | 1 3/64 | 1.0469 |
| 1 1/4 | 12 | 1.2500 | 0.0833 | 1.1959 | 1.1508 | 1.1598 | 0.0511 | 0.04511 | 0.0120 | 1.0785 | 1 11/64 | 1.1719 |
| 1 3/8 | 12 | 1.3750 | 0.0833 | 1.3209 | 1.2758 | 1.2848 | 0.0511 | 0.04511 | 0.0120 | 1.3208 | 1 19/64 | 1.2968 |
| 1 1/2 | 12 | 1.5000 | 0.0833 | 1.4459 | 1.4008 | 1.4098 | 0.0511 | 0.04511 | 0.0120 | 1.5877 | 1 27/64 | 1.4219 |

# Imperial Threads

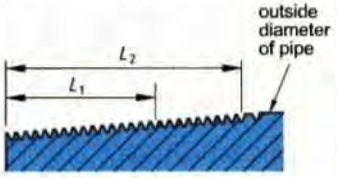
## Basic sizes National Pipe Taper (NPT)

ANSI/ASME B1.20.1 – 1983 (R 1992)




Thread depth $h_3 = 0.8 \cdot P$

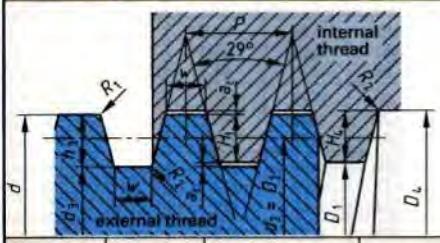
Hight $H = 0.865 \cdot P$




| No. size | Threads | Outside diam. of pipe $D$ | Pitch $P$ | Pitch diameter $d_2 = D_2$ | Gauge length $L_1$ | Usuable length of ext. thread $L_2$ | Depth of external thread $h_3 = 8P$ | Drill bit for tap hole Drill size | Decimal equival. |
|---|---|---|---|---|---|---|---|---|---|
| | all dimensions in inches | | | | | | | | |
| 1/16 | 27 | 0.3125 | 0.03704 | 0.28120 | 0.1598 | 0.2611 | 0.02963 | C | 0.2420 |
| 1/8 | 27 | 0.4050 | 0.03704 | 0.37360 | 0.1613 | 0.2639 | 0.02963 | Q | 0.3320 |
| 1/4 | 18 | 0.5400 | 0.05556 | 0.49163 | 0.2275 | 0.4018 | 0.04444 | 7/16 | 0.4380 |
| 3/8 | 18 | 0.6750 | 0.05556 | 0.62701 | 0.2398 | 0.0478 | 0.04444 | 9/16 | 0.5620 |
| 1/2 | 14 | 0.0625 | 0.07143 | 0.77843 | 0.3199 | 0.5337 | 0.05714 | 45/64 | 0.7030 |
| 3/4 | 14 | 1.0500 | 0.07143 | 0.98887 | 0.3391 | 0.5457 | 0.05714 | 29/32 | 0.9060 |
| 1 | 11 1/2 | 1.3150 | 0.08696 | 1.23863 | 0.3997 | 0.6828 | 0.06957 | 1 9/64 | 1.1410 |
| 1 1/4 | 11 1/2 | 1.6600 | 0.08696 | 1.58338 | 0.4197 | 0.7068 | 0.06957 | 1 31/64 | 1.484 |
| 1 1/2 | 11 1/2 | 1.9000 | 0.08696 | 1.82234 | 0.4197 | 0.7235 | 0.06957 | 1 23/32 | 1.7190 |
| 2 | 11 1/2 | 2.3750 | 0.08696 | 2.29627 | 0.4354 | 0.7565 | 0.06957 | 2 3/16 | 2.1880 |
| 2 1/2 | 8 | 2.8750 | 0.12500 | 2.76215 | 0.6825 | 1.1375 | 0.10000 | 2 39/64 | 2.6090 |

## Basic sizes American National Standard General Purp. Acme Screw Thread

ANSI/ASME B1.5 – 1988 (R 1994)



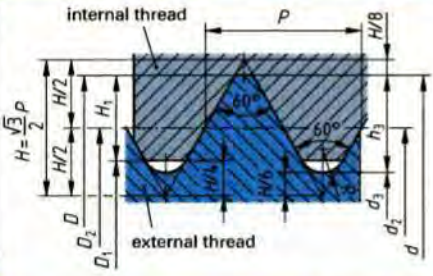

| | |
|---|---|
| $a_c$ | up to 10 tpi = 0.020 |
| $a_c$ | over 10 tpi = 0.010 |
| $R_1$ | $0.06 \cdot P$ |
| $R_2$ | $0.12 \cdot P$ |
| Minor ∅ external threads | $d_3 = d - (P + 2 \cdot a_c)$ |
| Major ∅ internal threads | $D_4 = d + 2 \cdot a_c$ |
| Minor ∅ internal threads | $D_1 = d - P$ |
| Pitch ∅ | $d_2 = D_2 = d - 0.5 \cdot P$ |
| Thread depth | $h_3 = H_4 = 0.5 \cdot P + a_c$ |
| Width of flat | $w = 0.370 \cdot P - 0.259 \cdot a_c$ |

| No. size | Threads per inch | Nominal diameter $d$ | Pitch $P$ | Pitch diameter $d_2 = D_2$ | Minor diameter External thread $d_3$ | Minor diameter Internal thread $D_1$ | Thread depth $h_3 = H4$ |
|---|---|---|---|---|---|---|---|
| | all dimensions in inches | | | | | | |
| 3/8 | 12 | 0.3750 | 0.0833 | 0.3333 | 0.2717 | 0.2917 | 0.0517 |
| 7/16 | 12 | 0.4375 | 0.0833 | 0.3958 | 0.3342 | 0.3542 | 0.0517 |
| 1/2 | 10 | 0.5000 | 0.1000 | 0.4500 | 0.3600 | 0.4000 | 0.0700 |
| 5/8 | 8 | 0.6250 | 0.1250 | 0.5625 | 0.4600 | 0.5000 | 0.0825 |
| 3/4 | 6 | 0.7500 | 0.1667 | 0.6667 | 0.5433 | 0.5833 | 0.1033 |
| 7/8 | 6 | 0.8750 | 0.1667 | 0.7917 | 0.6683 | 0.7083 | 0.1033 |
| 1 | 5 | 1.0000 | 0.2000 | 0.9000 | 0.7600 | 0.8000 | 0.1200 |
| 1 1/8 | 5 | 1.1250 | 0.2000 | 1.0250 | 0.8850 | 0.9250 | 0.1200 |
| 1 1/4 | 5 | 1.2500 | 0.2000 | 1.1500 | 1.0100 | 1.0500 | 0.1200 |
| 1 3/8 | 4 | 1.3750 | 0.2500 | 1.2500 | 1.0850 | 1.1250 | 0.1450 |
| 1 1/2 | 4 | 1.5000 | 0.2500 | 1.3750 | 1.2100 | 1.2500 | 0.1450 |
| 1 3/4 | 4 | 1.7500 | 0.2500 | 1.6250 | 1.4600 | 1.5000 | 0.1450 |
| 2 | 4 | 2.0000 | 0.2500 | 1.8750 | 1.7100 | 1.7500 | 0.1450 |
| 2 1/4 | 3 | 2.2500 | 0.3333 | 2.0833 | 1.8767 | 1.9167 | 0.1867 |
| 2 1/2 | 3 | 2.5000 | 0.3333 | 2.3333 | 2.1267 | 2.1667 | 0.1867 |
| 2 3/4 | 3 | 2.7500 | 0.3333 | 2.5833 | 2.3767 | 2.4167 | 0.1867 |
| 3 | 2 | 3.0000 | 0.5000 | 2.7500 | 2.4600 | 2.5000 | 0.2700 |
| 3 1/2 | 2 | 3.5000 | 0.5000 | 3.2500 | 2.9600 | 3.0000 | 0.2700 |
| 4 | 2 | 4.0000 | 0.5000 | 3.7500 | 3.4600 | 3.5000 | 0.2700 |
| 4 1/2 | 2 | 4.5000 | 0.5000 | 4.2500 | 3.9600 | 4.0000 | 0.2700 |
| 5 | 2 | 5.0000 | 0.5000 | 4.7500 | 4.4600 | 4.5000 | 0.2700 |

# Metric threads and fine threads

## Metric ISO threads for general purpose application, basic profiles

cf. DIN 13-19 (1999-11)




| | |
|---|---|
| Major diameter | $d = D$ |
| Pitch | $P$ |
| Depth of external thread | $h_3 = 0.6134 \cdot P$ |
| Depth of internal thread | $H_1 = 0.5413 \cdot P$ |
| Radius at root | $R = 0.1443 \cdot P$ |
| Basic pitch Ø | $d_2 = D_2 = d - 0.6495 \cdot P$ |
| Minor Ø of external thread | $d_3 = d - 1.2269 \cdot P$ |
| Minor Ø of internal thread | $D_1 = d - 1.0825 \cdot P$ |
| Tap hole drill Ø | $= d - P$ |
| Thread angle | 60° |
| Stress area | $S = \frac{\pi}{4} \cdot \left(\frac{d_2 + d_3}{2}\right)^2$ |

## Basic sizes for coarse threads Series 1[1] (dimensions in mm)

cf. DIN 13-1 (1999-11)

| Thread-designation $d = D$ | Pitch $P$ | Pitch Ø $d_2 = D_2$ | Minor Ø external threads $d_3$ | Minor Ø internal threads $D_1$ | Thread depth external threads $h_3$ | Thread depth internal threads $H_1$ | Rounded root $R$ | Stress area $S$ mm² | Drill bit Ø for tap hole [2] | Hexagonal width across flats[3] |
|---|---|---|---|---|---|---|---|---|---|---|
| M 1 | 0.25 | 0.84 | 0.69 | 0.73 | 0.15 | 0.14 | 0.04 | 0.46 | 0.75 | – |
| M 1.2 | 0.25 | 1.04 | 0.89 | 0.93 | 0.15 | 0.14 | 0.04 | 0.73 | 0.95 | – |
| M 1.6 | 0.35 | 1.38 | 1.17 | 1.22 | 0.22 | 0.19 | 0.05 | 1.27 | 1.25 | 3.2 |
| M 2 | 0.4 | 1.74 | 1.51 | 1.57 | 0.25 | 0.22 | 0.06 | 2.07 | 1.6 | 4 |
| M 2.5 | 0.45 | 2.21 | 1.95 | 2.01 | 0.28 | 0.24 | 0.07 | 3.39 | 2.05 | 5 |
| M 3 | 0.5 | 2.68 | 2.39 | 2.46 | 0.31 | 0.27 | 0.07 | 5.03 | 2.5 | 5.5 |
| M 4 | 0.7 | 3.55 | 3.14 | 3.24 | 0.43 | 0.38 | 0.10 | 8.78 | 3.3 | 7 |
| M 5 | 0.8 | 4.48 | 4.02 | 4.13 | 0.49 | 0.43 | 0.12 | 14.2 | 4.2 | 8 |
| M 6 | 1 | 5.35 | 4.77 | 4.92 | 0.61 | 0.54 | 0.14 | 20.1 | 5.0 | 10 |
| M 8 | 1.25 | 7.19 | 6.47 | 6.65 | 0.77 | 0.68 | 0.18 | 36.6 | 6.8 | 13 |
| M 10 | 1.5 | 9.03 | 8.16 | 8.38 | 0.92 | 0.81 | 0.22 | 58.0 | 8.5 | 16 |
| M 12 | 1.75 | 10.86 | 9.85 | 10.11 | 1.07 | 0.95 | 0.25 | 84.3 | 10.2 | 18 |
| M 16 | 2 | 14.70 | 13.55 | 13.84 | 1.23 | 1.08 | 0.29 | 157 | 14 | 24 |
| M 20 | 2.5 | 18.38 | 16.93 | 17.29 | 1.53 | 1.35 | 0.36 | 245 | 17.5 | 30 |
| M 24 | 3 | 22.05 | 20.32 | 20.75 | 1.84 | 1.62 | 0.43 | 353 | 21 | 36 |
| M 30 | 3.5 | 27.73 | 25.71 | 26.21 | 2.15 | 1.89 | 0.51 | 561 | 26.5 | 46 |
| M 36 | 4 | 33.40 | 31.09 | 31.67 | 2.45 | 2.17 | 0.58 | 817 | 32 | 55 |
| M 42 | 4.5 | 39.08 | 36.48 | 37.13 | 2.76 | 2.44 | 0.65 | 1121 | 37.5 | 65 |
| M 48 | 5 | 44.75 | 41.87 | 42.59 | 3.07 | 2.71 | 0.72 | 1473 | 43 | 75 |
| M 56 | 5.5 | 52.43 | 49.25 | 50.05 | 3.37 | 2.98 | 0.79 | 2030 | 50.5 | 85 |
| M 64 | 6 | 60.10 | 56.64 | 57.51 | 3.68 | 3.25 | 0.87 | 2676 | 58 | 95 |

## Basic sizes for fine threads (dimensions in mm)

cf. DIN 13-2 – 10 (1999-11)

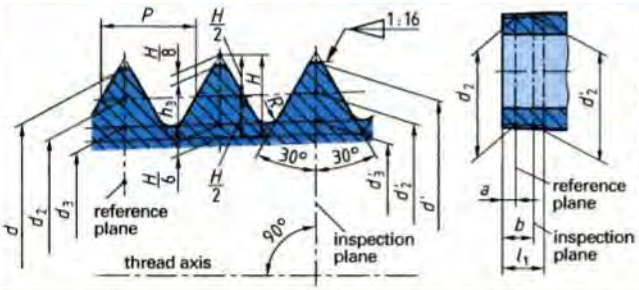
| Thread designation $d \times P$ | Pitch Ø $d_2 = D_2$ | Minor Ø ext. th. $d_3$ | Minor Ø int. th. $D_1$ | Thread designation $d \times P$ | Pitch Ø $d_2 = D_2$ | Minor Ø ext. th. $d_3$ | Minor Ø int. th. $D_1$ | Thread designation $d \times P$ | Pitch Ø $d_2 = D_2$ | Minor Ø ext. th. $d_3$ | Minor Ø int. th. $D_1$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| M 2 × 0.25 | 1.84 | 1.69 | 1.73 | M 10 × 0.25 | 9.84 | 9.69 | 9.73 | M 24 × 2 | 22.70 | 21.55 | 21.84 |
| M 3 × 0.25 | 2.84 | 2.69 | 2.73 | M 10 × 0.5 | 9.68 | 9.39 | 9.46 | M 30 × 1.5 | 29.03 | 28.16 | 28.38 |
| M 4 × 0.2 | 3.87 | 3.76 | 3.78 | M 10 × 1 | 9.35 | 8.77 | 8.92 | M 30 × 2 | 28.70 | 27.55 | 27.84 |
| M 4 × 0.35 | 3.77 | 3.57 | 3.62 | M 12 × 0.35 | 11.77 | 11.57 | 11.62 | M 36 × 1.5 | 35.03 | 34.16 | 34.38 |
| M 5 × 0.25 | 4.84 | 4.69 | 4.73 | M 12 × 0.5 | 11.68 | 11.39 | 11.46 | M 36 × 2 | 34.70 | 33.55 | 33.84 |
| M 5 × 0.5 | 4.68 | 4.39 | 4.46 | M 12 × 1 | 11.35 | 10.77 | 10.92 | M 42 × 1.5 | 41.03 | 40.16 | 40.38 |
| M 6 × 0.25 | 5.84 | 5.69 | 5.73 | M 16 × 0.5 | 15.68 | 15.39 | 15.46 | M 42 × 2 | 40.70 | 39.55 | 39.84 |
| M 6 × 0.5 | 5.68 | 5.39 | 5.46 | M 16 × 1 | 15.35 | 14.77 | 14.92 | M 48 × 1.5 | 47.03 | 46.16 | 46.38 |
| M 6 × 0.75 | 5.51 | 5.08 | 5.19 | M 16 × 1.5 | 15.03 | 14.16 | 14.38 | M 48 × 2 | 46.70 | 45.55 | 45.84 |
| M 8 × 0.25 | 7.84 | 7.69 | 7.73 | M 20 × 1 | 19.35 | 18.77 | 18.92 | M 56 × 1.5 | 55.03 | 54.16 | 54.38 |
| M 8 × 0.5 | 7.68 | 7.39 | 7.46 | M 20 × 1.5 | 19.03 | 18.16 | 18.38 | M 56 × 2 | 54.70 | 53.55 | 53.84 |
| M 8 × 1 | 7.35 | 6.77 | 6.92 | M 24 × 1.5 | 23.03 | 22.16 | 22.38 | M 64 × 2 | 62.70 | 61.55 | 61.84 |

[1] Series 2 and Series 3 also have intermediate sizes (e. g. M 7, M 9, M 14).
[2] cf. DIN 336 (2003-07) 3) cf. DIN ISO 272 (1979-10)

# Metric taper threads

## Metric taper external and mating internal straight screw threads (standard design)[1]

cf. DIN 158-1 (1997-06)




**Thread dimensions of external threads**

| | |
|---|---|
| Pitch Ø | $d_2 = d - 0.650 \cdot P$ |
| Minor Ø | $d_3 = d - 1.23 \cdot P$ |
| Height | $H_1 = 0.866 \cdot P$ |
| Thread depth | $h_3 = 0.613 \cdot P$ |
| Root radius | $R = 0.144 \cdot P$ |

| Thread designation $d \times P$ | Thread length $l_1$ | Thread depth $h_3$ max. | Distance $a$ | Dimensions in reference plane: Thread dimensions $d = D^{2)}$ | $d_2 = D_2^{3)}$ | $d_3$ | Distance $b$ | Dimensions in inspection plane: Thread dimensions $d'$ | $d'_2$ | $d'_3$ |
|---|---|---|---|---|---|---|---|---|---|---|
| M 5 keg | 5 | 0.52 | 2 | 5 | 4.48 | 4.02 | 2.8 | 5.05 | 4.5 | 4.07 |
| M 6 keg | 5.5 | 0.66 | 2.5 | 6 | 5.35 | 4.77 | 3.5 | 6.06 | 5.4 | 4.84 |
| M 8 × 1 keg | | | | 8 | 7.35 | 6.77 | | 8.06 | 7.4 | 6.84 |
| M 10 × 1 keg | | | | 10 | 9.35 | 8.77 | | 10.06 | 9.4 | 8.84 |
| M 12 × 1 keg | | | | 12 | 11.35 | 10.77 | | 12.06 | 11.4 | 10.84 |
| M 10 × 1.25 keg | 7 | 0.82 | 3 | 10 | 9.19 | 8.47 | 5 | 10.13 | 9.3 | 8.59 |
| M 12 × 1.25 keg | | | | 12 | 11.19 | 10.47 | | 12.13 | 11.3 | 10.59 |
| M 12 × 1.5 keg | 8.5 | 0.98 | 3.5 | 12 | 11.03 | 10.16 | 6.5 | 12.19 | 11.2 | 10.35 |
| M 14 × 1.5 keg | | | | 14 | 13.03 | 12.16 | | 14.19 | 13.2 | 12.35 |
| M 16 × 1.5 keg | | | | 16 | 15.03 | 14.16 | | 16.19 | 15.2 | 14.35 |
| M 18 × 1.5 keg | | | | 18 | 17.03 | 16.16 | | 18.19 | 17.2 | 16.35 |
| M 20 × 1.5 keg | | | | 20 | 19.03 | 18.16 | | 20.19 | 19.2 | 18.35 |
| M 22 × 1.5 keg | | | | 22 | 21.03 | 20.16 | | 22.19 | 21.2 | 20.35 |
| M 24 × 1.5 keg | | | | 24 | 23.03 | 22.16 | | 24.19 | 23.2 | 22.35 |
| M 26 × 1.5 keg | | | | 26 | 25.03 | 24.16 | | 26.19 | 25.2 | 24.35 |
| M 30 × 1.5 keg | 10.5 | 1.01 | 4.5 | 30 | 29.03 | 28.16 | 8 | 30.19 | 29.2 | 28.35 |
| M 36 × 1.5 keg | | | | 36 | 35.03 | 34.16 | | 36.22 | 35.2 | 34.38 |
| M 38 × 1.5 keg | | | | 38 | 37.03 | 36.16 | | 38.22 | 37.2 | 36.38 |
| M 42 × 1.5 keg | | | | 42 | 41.03 | 40.16 | | 42.22 | 41.2 | 40.38 |
| M 45 × 1.5 keg | | | | 45 | 44.03 | 43.16 | | 45.22 | 44.2 | 43.38 |
| M 48 × 1.5 keg | | | | 48 | 47.03 | 46.16 | | 48.22 | 47.2 | 46.38 |
| M 52 × 1.5 keg | | | | 52 | 51.03 | 50.16 | | 52.22 | 51.2 | 50.38 |
| M 27 × 2 keg | 12 | 1.32 | 5 | 27 | 25.70 | 24.55 | 9 | 27.25 | 25.9 | 24.80 |
| M 30 × 2 keg | | | | 30 | 28.70 | 27.55 | | 30.25 | 28.9 | 27.80 |
| M 33 × 2 keg | | | | 33 | 31.70 | 30.55 | | 33.25 | 31.9 | 30.80 |
| M 36 × 2 keg | 13 | 1.34 | 6 | 36 | 34.70 | 33.55 | 10 | 36.25 | 34.9 | 33.80 |
| M 39 × 2 keg | | | | 39 | 37.70 | 36.55 | | 39.25 | 37.9 | 36.80 |
| M 42 × 2 keg | | | | 42 | 40.70 | 39.55 | | 42.25 | 40.9 | 39.80 |
| M 45 × 2 keg | | | | 45 | 43.70 | 42.55 | | 45.25 | 43.9 | 42.80 |
| M 48 × 2 keg | | | | 48 | 46.70 | 45.55 | | 48.25 | 46.9 | 45.80 |
| M 52 × 2 keg | | | | 52 | 50.70 | 49.55 | | 52.25 | 50.9 | 49.80 |
| M 56 × 2 keg | | | | 56 | 54.70 | 53.55 | | 56.25 | 54.9 | 53.80 |
| M 60 × 2 keg | | | | 60 | 58.70 | 57.55 | | 60.25 | 58.9 | 57.80 |

⇒ **Threads DIN 158 – M 30 x 2 keg**: Metric taper external threads, $d = 30$ mm, $P = 2$ mm, standard design

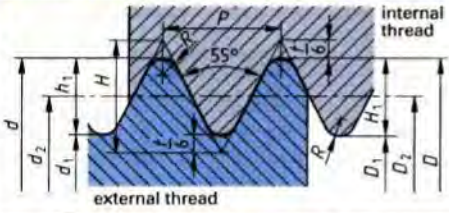
[1] For self-sealing joints (e.g. Drain plugs, grease nipples). For larger nominal diameters it is recommended to use a joint compound to seal in the threads.

[2] $D$ Basic major diameter of internal thread [3] $D_2$ Basic pitch diameter of internal thread

# Whitworth threads, Pipe threads

## Whitworth threads

(not standardized)




| | |
|---|---|
| Major diameter | $d = D$ |
| Minor diameter | $d_1 = D_1 = d - 1.28 \cdot P$ <br> $= d - 2 \cdot t_1$ |
| Pitch diameter | $d_2 = D_2 = d - 0.640 \cdot P$ |
| Threads/inch | $N$ |
| Pitch | $P = \frac{25.4\ \text{mm}}{N}$ |
| Thread depth | $h_1 = H_1 = 0.640 \cdot P$ |
| Radius | $R = 0.137 \cdot P$ |
| Thread angle | 55° |

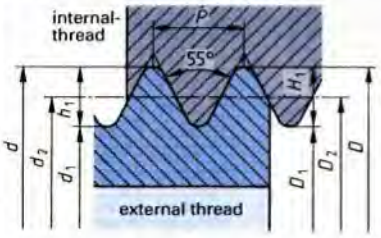
| Thread designation $d$ | Dimensions in mm for external and internal threads: Major Ø $d = D$ | Minor Ø $d_1 = D_1$ | Pitch Ø $d_2 = D_2$ | Threads per inch $N$ | Thread depth $h_1 = H_1$ | Core cross section mm² |
|---|---|---|---|---|---|---|
| 1/4" | 6.35 | 4.72 | 5.54 | 20 | 0.81 | 17.5 |
| 5/16" | 7.94 | 6.13 | 7.03 | 18 | 0.90 | 29.5 |
| 3/8" | 9.53 | 7.49 | 8.51 | 16 | 1.02 | 44.1 |
| 1/2" | 12.70 | 9.99 | 11.35 | 12 | 1.36 | 78.4 |
| 5/8" | 15.88 | 12.92 | 14.40 | 11 | 1.48 | 131 |
| 3/4" | 19.05 | 15.80 | 17.42 | 10 | 1.63 | 196 |
| 7/8" | 22.23 | 18.61 | 20.42 | 9 | 1.81 | 272 |
| 1" | 25.40 | 21.34 | 23.37 | 8 | 2.03 | 358 |
| 1 1/4" | 31.75 | 27.10 | 29.43 | 7 | 2.32 | 577 |
| 1 1/2" | 38.10 | 32.68 | 35.39 | 6 | 2.71 | 839 |
| 1 3/4" | 44.45 | 37.95 | 41.20 | 5 | 3.25 | 1131 |
| 2" | 50.80 | 43.57 | 47.19 | 4.5 | 3.61 | 1491 |
| 2 1/4" | 57.15 | 49.02 | 53.09 | 4 | 4.07 | 1886 |
| 2 1/2" | 63.50 | 55.37 | 59.44 | 4 | 4.07 | 2408 |
| 3" | 76.20 | 66.91 | 72.56 | 3.5 | 4.65 | 3516 |
| 3 1/2" | 88.90 | 78.89 | 83.89 | 3.25 | 5.00 | 4888 |

## Pipe threads

cf. DIN ISO 228-1 (2003-05), DIN EN 10226-1 (2004-10)

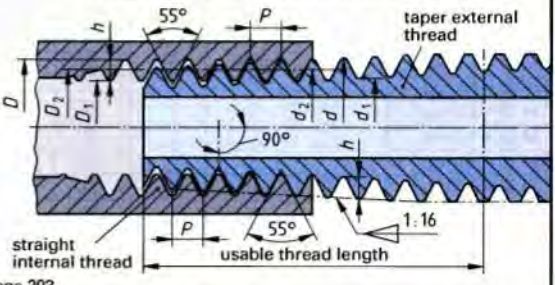
**Pipe threads DIN ISO 228-1**

for joints not sealed by threads;
straight internal and external threads




**Pipe threads DIN EN 10226-1**

sealed by threads;
straight internal threads, taper external threads



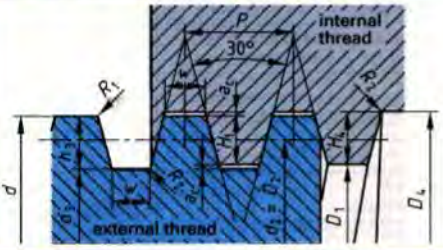

cf. American Taper Standard-Pipe Threads NPT: page 203

| Thread designation DIN ISO 228-1 External and internal threads | DIN EN10226-1 External threads | DIN EN10226-1 Internal threads | Major diameter $d = D$ | Pitch diameter $d_2 = D_2$ | Minor diameter $d_1 = D_1$ | Pitch $P$ | Threads per inch $N$ | Profile height $h = h_1 = H_1$ | Usable length of external threads ≥ |
|---|---|---|---|---|---|---|---|---|---|
| G 1/16 | R 1/16 | Rp 1/16 | 7.723 | 7.142 | 6.561 | 0.907 | 28 | 0.581 | 6.5 |
| G 1/8 | R 1/8 | Rp 1/8 | 9.728 | 9.147 | 8.566 | 0.907 | 28 | 0.581 | 6.5 |
| G 1/4 | R 1/4 | Rp 1/4 | 13.157 | 12.301 | 11.445 | 1.337 | 19 | 0.856 | 9.7 |
| G 3/8 | R 3/8 | Rp 3/8 | 16.662 | 15.806 | 14.950 | 1.337 | 19 | 0.856 | 10.1 |
| G 1/2 | R 1/2 | Rp 1/2 | 20.995 | 19.793 | 18.631 | 1.814 | 14 | 1.162 | 13.2 |
| G 3/4 | R 3/4 | Rp 3/4 | 26.441 | 25.279 | 24.117 | 1.814 | 14 | 1.162 | 14.5 |
| G 1 | R 1 | Rp 1 | 33.249 | 31.770 | 30.291 | 2.309 | 11 | 1.479 | 16.8 |
| G 1 1/4 | R 1 1/4 | Rp 1 1/4 | 41.910 | 40.431 | 38.952 | 2.309 | 11 | 1.479 | 19.1 |
| G 1 1/2 | R 1 1/2 | Rp 1 1/2 | 47.803 | 46.324 | 44.845 | 2.309 | 11 | 1.479 | 19.1 |
| G 2 | R 2 | Rp 2 | 59.614 | 58.135 | 56.656 | 2.309 | 11 | 1.479 | 23.4 |
| G 2 1/2 | R 2 1/2 | Rp 2 1/2 | 75.184 | 73.705 | 72.226 | 2.309 | 11 | 1.479 | 26.7 |
| G 3 | R 3 | Rp 3 | 87.884 | 86.405 | 84.926 | 2.309 | 11 | 1.479 | 29.8 |
| G 4 | R 4 | Rp 4 | 113.030 | 111.551 | 110.072 | 2.309 | 11 | 1.479 | 35.8 |
| G 5 | R 5 | Rp 5 | 138.430 | 136.951 | 135.472 | 2.309 | 11 | 1.479 | 40.1 |
| G 6 | R 6 | Rp 6 | 163.830 | 162.351 | 160.872 | 2.309 | 11 | 1.479 | 40.1 |

# Trapezoidal and buttress threads

## Metric ISO trapezoidal screw threads

cf. DIN 103-1 (1977-04)



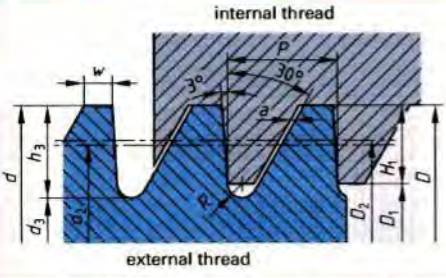

| Dimension | For pitch $P$ in mm 1.5 | 2–5 | 6–12 | 14–44 |
|---|---|---|---|---|
| $a_c$ | 0.15 | 0.25 | 0.5 | 1 |
| $R_1$ | 0.075 | 0.125 | 0.25 | 0.5 |
| $R_2$ | 0.15 | 0.25 | 0.5 | 1 |

| | |
|---|---|
| Nominal diameter | $d$ |
| Single start pitch and multiple start lead | $P$ |
| Multiple start pitch | $P_h$ |
| No. of threads | $n = P_h : P$ |
| Minor Ø external threads | $d_3 = d - (P + 2 \cdot a_c)$ |
| Major Ø internal threads | $D_4 = d + 2 \cdot a_c$ |
| Minor Ø internal threads | $D_1 = d - P$ |
| Pitch Ø | $d_2 = D_2 = d - 0.5 \cdot P$ |
| Thread depth | $h_3 = H_4 = 0.5 \cdot P + a_c$ |
| Thread overlap | $H_1 = 0.5 \cdot P$ |
| Crest clearance | $a_c$ |
| Radius | $R_1$ and $R_2$ |
| Width of flat | $w = 0.366 \cdot P - 0.54 \cdot a_c$ |
| Thread angle | 30° |

| Thread designation $d \times P$ | Thread dimensions in mm: Pitch Ø $d_2 = D_2$ | Minor Ø ext. th. $d_3$ | Minor Ø int. th. $D_1$ | Major Ø $D_4$ | Thread depth $h_3 = H_4$ | Width of flat $w$ |
|---|---|---|---|---|---|---|
| Tr 10 × 2 | 9 | 7.5 | 8 | 10.5 | 1.25 | 0.60 |
| Tr 12 × 3 | 10.5 | 8.5 | 9 | 12.5 | 1.75 | 0.96 |
| Tr 16 × 4 | 14 | 11.5 | 12 | 16.5 | 2.25 | 1.33 |
| Tr 20 × 4 | 18 | 15.5 | 16 | 20.5 | 2.25 | 1.33 |
| Tr 24 × 5 | 21.5 | 18.5 | 19 | 24.5 | 2.75 | 1.70 |
| Tr 28 × 5 | 25.5 | 22.5 | 23 | 28.5 | 2.75 | 1.70 |
| Tr 32 × 6 | 29 | 25 | 26 | 33 | 3.5 | 1.93 |
| Tr 36 × 3 | 34.5 | 32.5 | 33 | 36.5 | 2.0 | 0.83 |
| Tr 36 × 6 | 33 | 29 | 30 | 37 | 3.5 | 1.93 |
| Tr 36 × 10 | 31 | 25 | 26 | 37 | 5.5 | 3.39 |
| Tr 40 × 7 | 36.5 | 32 | 33 | 41 | 4 | 2.29 |
| Tr 44 × 7 | 40.5 | 36 | 37 | 45 | 4 | 2.29 |
| Tr 48 × 8 | 44 | 39 | 40 | 49 | 4.5 | 2.66 |
| Tr 52 × 8 | 48 | 43 | 44 | 53 | 4.5 | 2.66 |
| Tr 60 × 9 | 55.5 | 50 | 51 | 61 | 5 | 3.02 |
| Tr 70 × 10 | 65 | 59 | 60 | 71 | 5.5 | 3.39 |
| Tr 80 × 10 | 75 | 69 | 70 | 81 | 5.5 | 3.39 |
| Tr 90 × 12 | 84 | 77 | 78 | 91 | 6.5 | 4.12 |
| Tr 100 × 12 | 94 | 87 | 88 | 101 | 6.5 | 4.12 |
| Tr 140 × 14 | 133 | 124 | 126 | 142 | 8 | 4.58 |

## Metric buttress threads

cf. DIN 513 (1985-04)




| | |
|---|---|
| Nominal thread size | $d = D$ |
| Pitch | $P$ |
| Minor Ø external threads | $d_3 = d - 1.736 \cdot P$ |
| Minor Ø internal threads | $D_1 = d - 1.5 \cdot P$ |
| Pitch Ø external threads | $d_2 = d - 0.75 \cdot P$ |
| Pitch Ø internal threads | $D_2 = d - 0.75 \cdot P + 3.176 \cdot a$ |
| Axial clearance | $a = 0.1 \cdot \sqrt{P}$ |
| External thread depth | $h_3 = 0.8678 \cdot P$ |
| Internal thread depth | $H_1 = 0.75 \cdot P$ |
| Radius | $R = 0.124 \cdot P$ |
| Crest width on major Ø | $w = 0.264 \cdot P$ |
| Thread angle | 33° |

| Thread designation $d \times P$ | External threads: Minor Ø $d_3$ | Thread depth $h_3$ | Internal threads: Minor Ø $D_1$ | Thread depth $H_1$ | Pitch Ø $d_2$ |
|---|---|---|---|---|---|
| S 12 x 3 | 6.79 | 2.60 | 7.5 | 2.25 | 9.75 |
| S 16 x 4 | 9.06 | 3.47 | 10.0 | 3.00 | 13.00 |
| S 20 x 4 | 13.06 | 3.47 | 14.0 | 3.00 | 17.00 |
| S 24 x 5 | 15.32 | 4.34 | 16.5 | 3.75 | 20.25 |
| S 28 x 5 | 19.32 | 4.34 | 20.5 | 3.75 | 24.25 |
| S 32 x 6 | 21.58 | 5.21 | 23.0 | 4.50 | 27.50 |
| S 36 x 6 | 25.59 | 5.21 | 27.0 | 4.50 | 31.50 |
| S 40 x 7 | 27.85 | 6.07 | 29.5 | 5.25 | 34.75 |
| S 44 x 7 | 31.85 | 6.07 | 33.5 | 5.25 | 38.75 |
| S 48 x 8 | 34.12 | 6.94 | 36 | 6.00 | 42.00 |
| S 52 x 8 | 38.11 | 6.94 | 40 | 6.00 | 46.00 |
| S 60 x 9 | 44.38 | 7.81 | 46.5 | 6.75 | 53.25 |
| S 70 x 10 | 52.64 | 8.68 | 55 | 7.50 | 62.50 |
| S 80 x 10 | 62.64 | 8.68 | 65 | 7.50 | 72.50 |
| S 90 x 12 | 69.17 | 10.41 | 72 | 9.00 | 81.00 |
| S 100 x 12 | 79.17 | 10.41 | 82 | 9.00 | 91.00 |

# Thread tolerances

## Tolerance classes for metric ISO threads

cf. DIN ISO 965-1 (1999-11)

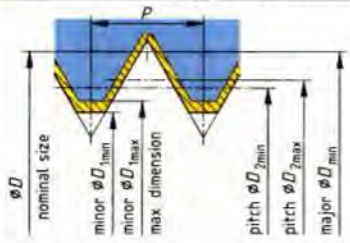
Screw thread tolerances are to ensure the function and interchangeability of internal and external threads. They are dependent on the diameter tolerances set in this standard and on the precision of the pitch and the thread angle.

The tolerance class (fine, medium and coarse) is also dependent on the **surface finish** of the threads. Thick electroplated protective coatings require more clearance (e.g. Tolerance Class 6G) than bright or phosphatized surfaces (Tolerance Class 5H).

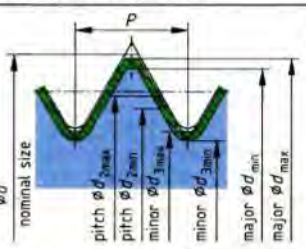
| Thread tolerance | Internal threads | External threads |
|---|---|---|
| Applies to | pitch and minor diameters | pitch and major diameters |
| Labeled by | upper case letters | lower case letters |
| Tolerance class (example) | **5H** | **6g** |
| Tolerance grade (size of tolerance) | 5 | 6 |
| Tolerance zone (position of zero line) | H | g |

| Designation examples | Explanations |
|---|---|
| M12 x 1 – 5g 6g | External fine threads, nominal ∅ 12 mm, pitch 1 mm; 5g → Tolerance class for pitch ∅; 6g → Tolerance class for major ∅ |
| M12 – 6g | External coarse threads, nominal ∅ 12 mm; 6g → Tolerance class for pitch and major ∅ |
| M24 – 6G/6e | Thread fit for coarse threads, nominal ∅ 24 mm, 6G → Tolerance class of the internal threads, 6e → Tolerance class of the external threads |
| M16 | Tolerance class medium 6H/6g applies to threads without tolerance indication |

Tolerance Class 6H/6g is assigned to the "medium" (general purpose) tolerance class and "normal" engagement length in DIN ISO 965-1 (see table below).




Internal threads, tolerance zone location H




External threads, tolerance zone location g

## Limits for external and internal threads (selection)

cf. DIN ISO 965-2 (1999-11)

| Threads | Internal threads – Tolerance class 6H | | | | | External threads – Tolerance class 6g | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Major Ø $D$ | Pitch Ø $D_2$ | | Minor Ø $D_1$ | | Major Ø $d$ | | Pitch Ø $d_2$ | | Minor Ø [1] $d_3$ | |
| | min. | min. | max. | min. | max. | max. | min. | max. | min. | max. | min. |
| M3 | 3.0 | 2.675 | 2.775 | 2.459 | 2.599 | 2.980 | 2.874 | 2.655 | 2.580 | 2.367 | 2.273 |
| M4 | 4.0 | 3.545 | 3.663 | 3.242 | 3.422 | 3.978 | 3.838 | 3.523 | 3.433 | 3.119 | 3.002 |
| M5 | 5.0 | 4.480 | 4.605 | 4.134 | 4.334 | 4.976 | 4.826 | 4.456 | 4.361 | 3.995 | 3.869 |
| M6 | 6.0 | 5.350 | 5.500 | 4.917 | 5.135 | 5.974 | 5.794 | 5.324 | 5.212 | 4.747 | 4.596 |
| M8 | 8.0 | 7.188 | 7.348 | 6.647 | 6.912 | 7.972 | 7.760 | 7.160 | 7.042 | 6.438 | 6.272 |
| M8 × 1 | 8.0 | 7.350 | 7.500 | 6.917 | 7.153 | 7.974 | 7.794 | 7.324 | 7.212 | 6.747 | 6.596 |
| M10 | 10.0 | 9.026 | 9.206 | 8.376 | 8.676 | 9.968 | 9.732 | 8.994 | 8.862 | 8.128 | 7.938 |
| M10 ×1 | 10.0 | 9.350 | 9.500 | 8.917 | 9.153 | 9.974 | 9.794 | 9.324 | 9.212 | 8.747 | 8.596 |
| M12 | 12.0 | 10.863 | 11.063 | 10.106 | 10.441 | 11.966 | 11.701 | 10.829 | 10.679 | 9.819 | 9.602 |
| M12 × 1.5 | 12.0 | 11.026 | 11.216 | 10.376 | 10.676 | 11.968 | 11.732 | 10.994 | 10.854 | 10.128 | 9.930 |
| M16 | 16.0 | 14.701 | 14.913 | 13.385 | 14.210 | 15.962 | 15.682 | 14.663 | 14.503 | 13.508 | 13.271 |
| M16 × 1.5 | 16.0 | 15.026 | 15.216 | 14.376 | 14.676 | 15.968 | 15.732 | 14.994 | 14.854 | 14.128 | 13.930 |
| M20 | 20.0 | 18.376 | 18.600 | 17.294 | 17.744 | 19.958 | 19.623 | 18.334 | 18.164 | 16.891 | 16.625 |
| M20 × 1.5 | 20.0 | 19.026 | 19.216 | 18.376 | 18.676 | 19.968 | 19.732 | 18.994 | 18.854 | 18.128 | 18.930 |
| M24 | 24.0 | 22.051 | 22.316 | 20.752 | 21.252 | 23.952 | 23.577 | 22.003 | 21.803 | 20.271 | 19.955 |
| M24 × 2 | 24.0 | 22.701 | 22.925 | 21.835 | 22.210 | 23.962 | 23.682 | 22.663 | 22.493 | 21.508 | 21.261 |
| M30 | 30.0 | 27.727 | 28.007 | 26.211 | 26.771 | 29.947 | 29.522 | 27.674 | 27.462 | 25.653 | 25.306 |
| M30 × 2 | 30.0 | 28.701 | 28.925 | 27.835 | 28.210 | 29.962 | 29.682 | 28.663 | 28.493 | 27.508 | 27.261 |
| M36 | 36.0 | 33.402 | 33.702 | 31.670 | 32.270 | 35.940 | 35.465 | 33.342 | 33.118 | 31.033 | 30.655 |
| M36 × 3 | 36.0 | 34.051 | 34.316 | 32.752 | 33.252 | 35.952 | 35.577 | 34.003 | 33.803 | 32.271 | 31.955 |

[1] cf. DIN 13-20 (2000-08) and DIN 13-21 (2005-08)

# Bolts and screws – Overview

| Illustration | Design | Standard range from–to | Standard | Application, properties |
|---|---|---|---|---|
| **Hexagon head bolts and screws** | | | | pages 212–214 |
|  | Partly threaded and with coarse threads | M1.6–M64 | DIN EN ISO 4014 | The most commonly used bolts/screws in machine, equipment and automotive industry<br>**Fully threaded type:** higher fatigue strength |
| | Fully threaded with fine threads | M1.6–M64 | DIN EN ISO 4017 | |
|  | Partly threaded and with fine threads | M8x1–M64x4 | DIN EN ISO 8765 | **Compared to coarse threads:** smaller thread depth, smaller pitch, higher load capacity, larger minimum engagement depth $l_e$ |
| | Fully threaded with fine threads | M8x1–M64x4 | DIN EN ISO 8676 | |
|  | With reduced shank | M3–M20 | DIN EN ISO 24015 | Waisted bolts; for dynamic loads, no nut retention necessary when properly installed |
|  | Fit bolt | M8–M48 | DIN 609 | Fixing position of parts against movement, fit shank transmits transverse loads |
| **Hexagon bolts and screws for steel structures** | | | | page 214 |
|  | With larger width across flats | M12–M36 | DIN EN 14399-4 | High-strength structural bolting assemblies (HV), with nuts as per DIN EN 14399-4 (page 230) |
|  | Fit bolt with large widths across flats | M12–M30 | DIN 7999 | Friction grip (FG) joints, shear/bearing stress connection |
| **Cap screws** | | | | pages 215, 216 |
|  | With hexagon socket, with coarse threads | M1.6–M64 | DIN EN ISO 4762 | Machine, equipment and automotive industry; low space requirements, head sinkable<br>**With low-profile head:** small height, low stress<br>**Slotted bolts/screws:** small screws, low stresses<br>**Fine threads:** smaller thread depth, capable of higher loads, larger minimum engagement depth $l_e$ |
| | With hexagon socket, fine threads | M8x1–M64x4 | DIN EN ISO 21269 | |
| | With hexagon socket and low head | M3–M24 | DIN 7984 | |
|  | Slotted | M1.6–M10 | DIN EN ISO 1207 | |
| **Countersunk head screws** | | | | pages 216, 217 |
|  | Slotted | M1.6–M10 | DIN EN ISO 2009 | Variety of applications in machine, equipment and automotive industry<br>**For screws with hexagon socket:** greater load capacity<br>**For screws with cross recess:** Secure tightening and loosening compared to slotted screws |
| | With hexagon socket | M3–M20 | DIN EN ISO 10642 | |
|  | Slotted raised head countersunk | M1.6–M10 | DIN EN ISO 2010 | |
| | Recessed raised head countersunk cross | M1.6–M10 | DIN EN ISO 7047 | |
| **Sheet metal screws with tapping threads** | | | | pages 217, 218 |
|  | Round head screw | ST2.2–ST9.5 | DIN ISO 7049 | Vehicle body and sheet metal manufacturing.<br>The sheets to be joined have tap holes. The threads are formed by the screw. Locking fasteners are only needed for thin sheets. |
| | Countersunk head screw | ST2.2–ST6.3 | DIN ISO 7050 | |
| | Round head countersunk screws | ST2.2–ST9.9 | DIN ISO 7051 | |

# Bolts and screws – Overview, Designation of bolts and screws

| Illustration | Design | Standard range from–to | Standard | Application, properties |
|---|---|---|---|---|
| **Drilling screws with tapping threads** | | | | |
|  | Flat head with cross recess | ST2.2–ST6.3 | DIN EN ISO 15481 | Vehicle body and sheet metal manufacturing drilling screws bore the tap hole while being screwed in and form the threads. |
| | Round head countersunk with cross/recess | ST2.2–ST6.3 | DIN EN ISO 15483 | |
| **Studs** | | | | page 219 |
|  | $l_e \approx 2 \cdot d$<br>$l_e \approx 1.25 \cdot d$<br>$l_e \approx 1 \cdot d$ | M4–M24<br>M4–M48<br>M4–M48 | DIN 835<br>DIN 939<br>DIN 938 | For aluminum alloys<br>For cast iron materials<br>For steel |
| **Set screws** | | | | page 220 |
|  | With dog point and slotted | M1.6–M12 | DIN EN 27435 | Compression loadable screws for securing position of parts, e.g. levers, bearing bushings, hubs<br>Set screws are not suitable for power transmission of torques, e.g. for joining shafts to hubs. |
| | With dog point and hex socket | M1.6–M24 | DIN EN ISO 4028 | |
|  | With cone point and slotted | M1.6–M12 | DIN EN 27434 | |
| | With cone point and hex socket | M1.6–M24 | DIN EN ISO 4027 | |
|  | With flat point and slotted | M1.6–M12 | DIN EN 24766 | |
| | With flat point and hex socket | M1.6–M24 | DIN EN ISO 4026 | |
| **Drain plugs** | | | | page 219 |
|  | Heavy type with hexagon socket or hexagon head | M10x1–M52x1.5 | DIN 908<br>DIN 910 | Gearbox manufacturing; Fill, overflow and drain screws for gear oil; milling of seating surface necessary |
| **Thread forming screws** | | | | page 218 |
|  | Various head forms e.g. hexagon, cheese head | M2–M10 | DIN 7500-1 | For low loading in malleable materials, e.g. S235, DC01–DC04, non-ferrous metals; use without locking fastener |
| **Eye bolts** | | | | page 219 |
|  | With coarse threads | M8–M100x6 | DIN 580 | Transport eyes on machines and equipment; stress depends on the angle of the applied load, milling of seating surface necessary |

## Designation of bolts and screws

cf. DIN 962 (2001-11)

**Examples:**

| | | |
|---|---|---|
| **Hex screw** | **ISO 4017** | **– M12 x 80 – A2-70** |
| **Drain plug** | **DIN 910** | **– M24 x 1.5 – St** |
| **Cap screws** | **ISO 4762** | **– M10 x 55 – 8.8** |

| Type | Reference standard, e.g. ISO, DIN, EN; Sheet number of the standard[1)] | Nominal data, e.g.<br>M → metric screw thread<br>12 → nominal diameter *d*<br>80 → shank length *l* | Property class, e.g. 8.8, 10.9, A2-70, A4-70<br>Material, e.g. St steel, CuZn copper-zinc-alloy |
|---|---|---|---|

[1)] Bolts and screws standardized according to ISO, DIN EN or DIN EN ISO have the abbreviation **ISO** in their designation. Bolts and screws standardized according to DIN have the abbreviation **DIN** in their designation.

# Property classes, Product grades, Clearance holes, Minimum engagement depth

## Property classes of screws and bolts

cf. DIN EN ISO 898-1 (1999-11), DIN EN ISO 3506-1 (1998-03)

**Examples:** Unalloyed and alloy steels DIN EN ISO 898-1

**9 . 8**

| Tensile strength $R_m$ | Yield strength $R_e$ |
|---|---|
| $R_m$ = **9** · 100 N/mm² = 900 N/mm² | $R_e$ = **9** · **8** · 10 N/mm² = 720 N/mm² |

Stainless steels DIN EN ISO 3506-1

**A 2 – 70**

| Steel microstr. | Steel group | Tensile strength $R_m$ |
|---|---|---|
| A austenitic<br>F ferritic | 2 alloyed with Cr, Ni<br>4 alloyed with Cr, Ni, Mo | $R_m$ = **70** · 10 N/mm² = 700 N/mm² |

### Property classes and material properties

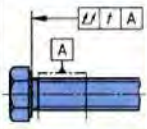



| Material property | Property classes for bolts and screws made of unalloyed and alloyed steels | | | | | | stainless steels[1] | | |
|---|---|---|---|---|---|---|---|---|---|
| | 5.8 | 6.8 | 8.8 | 9.8 | 10.9 | 12.9 | A2-50 | A4-50 | A2-70 |
| Tens. strength $R_m$ in N/mm² | 500 | 600 | 800 | 900 | 1000 | 1200 | 500 | 500 | 700 |
| Yield strength $R_e$ in N/mm² | 400 | 480 | 640 | 720 | 900 | 1080 | 210 | 210 | 450 |
| Elong. at fracture *EL* in % | 10 | 8 | 12 | 10 | 9 | 8 | 20 | 20 | 13 |

[1] Material properties apply to threads ≤ M20.

## Product grades for bolts and nuts

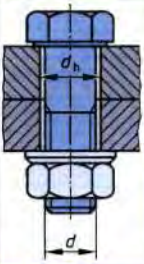
cf. DIN EN ISO 4759-1 (2001-04)




| Product grade | Tolerances | Explanation, application |
|---|---|---|
| A | fine | Dimensional, form and positional tolerances for bolts and nuts with ISO threads are specified in tolerance grades A, B, C. |
| B | medium | |
| C | coarse | |

## Clearance holes for bolts

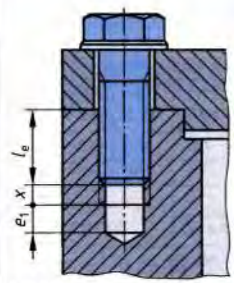
cf. DIN EN 20273 (1992-02)




| Thread | Clearance hole $d_h$[1] Series | | | Thread | Clearance hole $d_h$[1] Series | | | Thread | Clearance hole $d_h$[1] Series | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $d$ | fine | med. | coarse | $d$ | fine | med. | coarse | $d$ | fine | med. | coarse |
| M1 | 1.1 | 1.2 | 1.3 | M5 | 5.3 | 5.5 | 5.8 | M24 | 25 | 26 | 28 |
| M1.2 | 1.3 | 1.4 | 1.5 | M6 | 6.4 | 6.6 | 7 | M30 | 31 | 33 | 35 |
| M1.6 | 1.7 | 1.8 | 2 | M8 | 8.4 | 9 | 10 | M36 | 37 | 39 | 42 |
| M2 | 2.2 | 2.4 | 2.6 | M10 | 10.5 | 11 | 12 | M42 | 43 | 45 | 48 |
| M2.5 | 2.7 | 2.9 | 3.1 | M12 | 13 | 13.5 | 14.5 | M48 | 50 | 52 | 56 |
| M3 | 3.2 | 3.4 | 3.6 | M16 | 17 | 17.5 | 18.5 | M56 | 58 | 62 | 66 |
| M4 | 4.3 | 4.5 | 4.8 | M20 | 21 | 22 | 24 | M64 | 66 | 70 | 74 |

[1] Tolerance grades for $d_h$: fine series: H12, medium series: H13, coarse series: H14

## Minimum engagement depth in blind hole




$x \approx 3 \cdot P$ (thread pitch)
$e_1$ according to DIN 76, see page 89

| Area of application | | Minimum engagement depth $l_e$[1] for coarse threads and property class | | | |
|---|---|---|---|---|---|
| | | 3.6, 4.6 | 4.8–6.8 | 8.8 | 10.9 |
| Struc. steel | $R_m \le 400$ N/mm² | 0.8 · $d$ | 1.2 · $d$ | – | – |
| | $R_m$ = 400–600 N/mm² | 0.8 · $d$ | 1.2 · $d$ | 1.2 · $d$ | – |
| | $R_m$ > 600–800 N/mm² | 0.8 · $d$ | 1.2 · $d$ | 1.2 · $d$ | 1.2 · $d$ |
| | $R_m$ > 800 N/mm² | 0.8 · $d$ | 1.2 · $d$ | 1.0 · $d$ | 1.0 · $d$ |
| Cast iron materials | | 1.3 · $d$ | 1.5 · $d$ | 1.5 · $d$ | – |
| Copper alloys | | 1.3 · $d$ | 1.3 · $d$ | – | – |
| Aluminum casting alloys | | 1.6 · $d$ | 2.2 · $d$ | – | – |
| Al alloys, age-hardened | | 0.8 · $d$ | 1.2 · $d$ | 1.6 · $d$ | – |
| Al alloys, not age-hardened | | 1.2 · $d$ | 1.6 · $d$ | – | – |
| Plastics | | 2.5 · $d$ | – | – | |

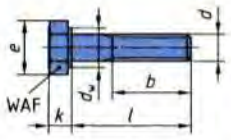
[1] Engagement depth for fine threads $l_e$ = 1.25 · Engagement depth for coarse threads

# Hexagon head bolts

## Hexagon head bolt with shank and coarse threads

cf. DIN EN ISO 4014 (2001-03)

| Valid standard DIN EN ISO | Replaces DIN EN | Replaces DIN |
|---|---|---|
| 4014 | 24014 | 931 |




| Thread $d$ | M1.6 | M2 | M2.5 | M3 | M4 | M5 | M6 | M8 | M10 |
|---|---|---|---|---|---|---|---|---|---|
| WAF | 3.2 | 4 | 5 | 5.5 | 7 | 8 | 10 | 13 | 16 |
| $k$ | 1.1 | 1.4 | 1.7 | 2 | 2.8 | 3.5 | 4 | 5.3 | 6.4 |
| $d_w$ | 2.3 | 3.1 | 4.1 | 4.6 | 5.9 | 6.9 | 8.9 | 11.6 | 14.6 |
| $e$ | 3.4 | 4.3 | 5.5 | 6 | 7.7 | 8.8 | 11.1 | 14.4 | 17.8 |
| $b$ | 9 | 10 | 11 | 12 | 14 | 16 | 18 | 22 | 26 |
| $l$ from | 12 | 16 | 16 | 20 | 25 | 25 | 30 | 40 | 45 |
| $l$ to | 16 | 20 | 25 | 30 | 40 | 50 | 60 | 80 | 100 |
| Property classes | 5.6, 8.8, 9.8, 10.9, A2-70, A4-70 | | | | | | | | |

| Thread $d$ | M12 | M16 | M20 | M24 | M30 | M36 | M42 | M48 | M56 |
|---|---|---|---|---|---|---|---|---|---|
| WAF | 18 | 24 | 30 | 36 | 46 | 55 | 65 | 75 | 85 |
| $k$ | 7.5 | 10 | 12.5 | 15 | 18.7 | 22.5 | 26 | 30 | 35 |
| $d_w$ | 16.6 | 22 | 27.7 | 33.3 | 42.8 | 51.1 | 60 | 69.5 | 78.7 |
| $e$ | 20 | 26.2 | 33 | 39.6 | 50.9 | 60.8 | 71.3 | 82.6 | 93.6 |
| $b^{1)}$ | 30 | 38 | 46 | 54 | 66 | – | – | – | – |
| $b^{2)}$ | – | 44 | 52 | 60 | 72 | 84 | 96 | 108 | – |
| $b^{3)}$ | – | – | – | 73 | 85 | 97 | 109 | 121 | 137 |
| $l$ from | 50 | 65 | 80 | 90 | 110 | 140 | 160 | 180 | 220 |
| $l$ to | 120 | 160 | 200 | 240 | 300 | 360 | 440 | 500 | 500 |
| Property classes | 5.6, 8.8, 9.8, 10.9 | | | | | | as per agreement | | |
| | A2-70, A4-70 | | | | A2-50, A4-50 | | | | |
| Nominal lengths $l$ | 12, 16, 20, 25, 30, 35–60, 65, 70, 80, 90–140, 150, 160, 180, 200–460, 480, 500 mm | | | | | | | | |

[1)] for $l$ < 125 mm
[2)] for $l$ = 125–200 mm
[3)] for $l$ > 200 mm

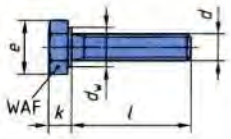
| Product grades (page 211) | | |
|---|---|---|
| Threads $d$ | $l$ in mm | Grade |
| ≤ M12 | all | A |
| M16–M24 | $l \le 150$ | A |
| | $l \ge 160$ | B |
| ≥ M30 | all | B |

⇒ **Hexagon head bolt ISO 4014 – M10 x 60 – 8.8:**
$d$ = M10, $l$ = 60 mm, property class 8.8

## Hexagon head bolts with coarse threads, fully threaded

cf. DIN EN ISO 4017 (2001-03)

| Valid standard DIN EN ISO | Replaces DIN EN | Replaces DIN |
|---|---|---|
| 4017 | 24017 | 933 |




| Thread $d$ | M1.6 | M2 | M2.5 | M3 | M4 | M5 | M6 | M8 | M10 |
|---|---|---|---|---|---|---|---|---|---|
| WAF | 3.2 | 4 | 5 | 5.5 | 7 | 8 | 10 | 13 | 16 |
| $k$ | 1.1 | 1.4 | 1.7 | 2 | 2.8 | 3.5 | 4 | 5.3 | 6.4 |
| $d_w$ | 2.3 | 3.1 | 4.1 | 4.6 | 5.9 | 6.9 | 8.9 | 11.6 | 14.6 |
| $e$ | 3.4 | 4.3 | 5.5 | 6 | 7.7 | 8.8 | 11.1 | 14.4 | 17.8 |
| $l$ from | 2 | 4 | 5 | 6 | 8 | 10 | 12 | 16 | 20 |
| $l$ to | 16 | 20 | 25 | 30 | 40 | 50 | 60 | 80 | 100 |
| Property classes | 5.6, 8.8, 9.8, 10.9, A2-70, A4-70 | | | | | | | | |

| Thread $d$ | M12 | M16 | M20 | M24 | M30 | M36 | M42 | M48 | M56 |
|---|---|---|---|---|---|---|---|---|---|
| WAF | 18 | 24 | 30 | 36 | 46 | 55 | 65 | 75 | 85 |
| $k$ | 7.5 | 10 | 12.5 | 15 | 18.7 | 22.5 | 26 | 30 | 35 |
| $d_w$ | 16.6 | 22 | 27.7 | 33.3 | 42.8 | 51.1 | 60 | 69.5 | 78.7 |
| $e$ | 20 | 26.2 | 33 | 39.6 | 50.9 | 60.8 | 71.3 | 82.6 | 93.6 |
| $l$ from | 25 | 30 | 40 | 50 | 60 | 70 | 80 | 100 | 110 |
| $l$ to | 120 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 |
| Property classes | 5.6, 8.8, 9.8, 10.9 | | | | | | as per agreement | | |
| | A2-70, A4-70 | | | | A2-50, A4-50 | | | | |
| Nominal lengths $l$ | 2, 3, 4, 5, 6, 8, 10, 12, 16, 20, 25, 30, 35–60, 65, 70, 80, 90–140, 150, 160, 180, 200 mm | | | | | | | | |

| Product grades (page 211) | | |
|---|---|---|
| Threads $d$ | $l$ in mm | Grade |
| ≤ M12 | all | A |
| M16–M24 | $l \le 150$ | A |
| | $l \ge 160$ | B |
| ≥ M30 | all | B |

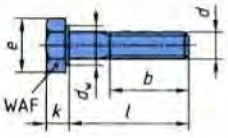
⇒ **Hexagon head bolt ISO 4017 – M8 x 40 – A4-50:**
$d$ = M8, $l$ = 40 mm, property class A4-50

# Hexagon head bolts

## Hexagon head bolt with shank and fine threads

cf. DIN EN ISO 8765 (2001-03)

| Valid standard DIN EN ISO | Replaces DIN EN | Replaces DIN |
|---|---|---|
| 8765 | 28765 | 960 |




Product grades (page 211)

| Threads $d$ | $l$ in mm | Grade |
|---|---|---|
| ≤ M12x1.5 | all | A |
| M16x1.5–M24x2 | ≤ 150 | A |
| | > 150 | B |
| ≥ M30x2 | all | B |

| Thread $d$ | M8 x1 | M10 x1 | M12 x1.5 | M16 x1.5 | M20 x1.5 | M24 x2 | M30 x2 | M36 x3 | M42 x3 | M48 x3 | M56 x4 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| WAF | 13 | 16 | 18 | 24 | 30 | 36 | 46 | 55 | 65 | 75 | 85 |
| $k$ | 5.3 | 6.4 | 7.5 | 10 | 12.5 | 15 | 18.7 | 22.5 | 26 | 30 | 35 |
| $d_w$ | 11.6 | 14.6 | 16.6 | 22.5 | 28.2 | 33.6 | 42.8 | 51.1 | 60 | 69.5 | 78.7 |
| $e$ | 14.4 | 17.8 | 20 | 26.2 | 33 | 39.6 | 50.9 | 60.8 | 71.3 | 82.6 | 93.6 |
| $b^{1)}$ | 22 | 26 | 30 | 38 | 46 | 54 | 66 | – | – | – | – |
| $b^{2)}$ | – | – | – | 44 | 52 | 60 | 72 | 84 | 96 | 108 | – |
| $b^{3)}$ | – | – | – | – | – | 73 | 85 | 97 | 109 | 121 | 137 |
| $l$ from | 40 | 45 | 50 | 65 | 80 | 100 | 120 | 140 | 160 | 200 | 220 |
| $l$ to | 80 | 100 | 120 | 160 | 200 | 240 | 300 | 360 | 440 | 480 | 500 |

Nominal lengths $l$: 40, 45, 50, 55, 60, 65, 70, 80, 90–140, 150, 160, 180, 200, 220–460, 480, 500 mm

Property classes: $d$ ≤ M24x2: 5.6, 8.8, 10.9, A2-70, A4-70; $d$ = M30x2–M36x2: 5.6, 8.8, 10.9, A2-50, A4-50; $d$ ≥ M42x3: as per agreement

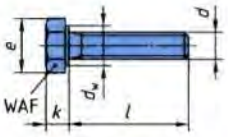
Explanations: 1) for $l$ < 125 mm 2) for $l$ = 125–200 mm 3) for $l$ > 200 mm

⇒ **Hexagon head bolt ISO 8765–M20 x 1.5 x 120 – 5.6:** $d$ = M20 x 1.5, $l$ = 120 mm, property class 5.6

## Hexagon head bolts with fine threads, fully threaded

cf. DIN EN ISO 8676 (2001-03)

| Valid standard DIN EN ISO | Replaces DIN EN | Replaces DIN |
|---|---|---|
| 8676 | 28676 | 961 |




Product grades according to DIN EN ISO 8765

| Thread $d$ | M8 x1 | M10 x1 | M12 x1.5 | M16 x1.5 | M20 x1.5 | M24 x2 | M30 x2 | M36 x3 | M42 x3 | M48 x3 | M56 x4 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| WAF | 13 | 16 | 18 | 24 | 30 | 36 | 46 | 55 | 65 | 75 | 85 |
| $k$ | 5.3 | 6.4 | 7.5 | 10 | 12.5 | 15 | 18.7 | 22.5 | 26 | 30 | 35 |
| $d_w$ | 11.6 | 14.6 | 16.6 | 22.5 | 28.2 | 33.6 | 42.8 | 51.1 | 60 | 69.5 | 78.7 |
| $e$ | 14.4 | 17.8 | 20 | 26.2 | 33 | 39.6 | 50.9 | 60.8 | 71.3 | 82.6 | 93.6 |
| $l$ from | 16 | 20 | 25 | 35 | 40 | 40 | 40 | 40 | 90 | 100 | 120 |
| $l$ to | 80 | 100 | 120 | 160 | 200 | 200 | 200 | 200 | 420 | 480 | 500 |

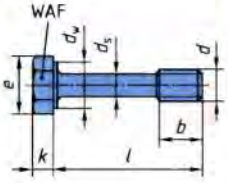
Nominal lengths $l$: 16, 20, 25, 30, 35–60, 65, 70, 80, 90–140, 150, 160, 180, 200, 220–460, 480, 500 mm

Property classes: d ≤ M24x2: 5.6, 8.8, 10.9, A2-70, A4-70; $d$ = M30x2–M36x2: 5.6, 8.8, 10.9, A2-50, A4-50; d ≥ M42x3: as per agreement

⇒ **Hexagon head bolt ISO 8676 – M8 x 1,5 x 55 – 8.8:** $d$ = M8 x 1.5, $l$ = 55 mm, property class 8.8

## Hex head bolt with reduced shank

cf. DIN EN 24015 (1991-12)




Product grades (page 211)

| Threads $d$ | $l$ in mm | Grade |
|---|---|---|
| ≤ M20 | all | B |

| Thread $d$ | M3 | M4 | M5 | M6 | M8 | M10 | M12 | M16 | M20 |
|---|---|---|---|---|---|---|---|---|---|
| WAF | 5.5 | 7 | 8 | 10 | 13 | 16 | 18 | 24 | 30 |
| $k$ | 2 | 2.8 | 3.5 | 4 | 5.3 | 6.4 | 7.5 | 10 | 12.5 |
| $d_w$ | 4.4 | 5.7 | 6.7 | 8.7 | 11.4 | 14.4 | 16.4 | 22 | 27.7 |
| $d_s$ | 2.6 | 3.5 | 4.4 | 5.3 | 7.1 | 8.9 | 10.7 | 14.5 | 18.2 |
| $e$ | 6 | 7.5 | 8.7 | 10.9 | 14.2 | 17.6 | 19.9 | 26.2 | 33 |
| $b^{1)}$ | 12 | 14 | 16 | 18 | 22 | 26 | 30 | 38 | 46 |
| $b^{2)}$ | – | – | – | – | 28 | 32 | 36 | 44 | 52 |
| $l$ from | 20 | 20 | 25 | 25 | 30 | 40 | 45 | 55 | 65 |
| $l$ to | 30 | 40 | 50 | 60 | 80 | 100 | 120 | 150 | 150 |

Nominal lengths $l$: 20, 25, 30–65, 70, 75, 80, 90, 100–130, 140, 150 mm

Property classes: 5.8, 6.8, 8.8, A2-70

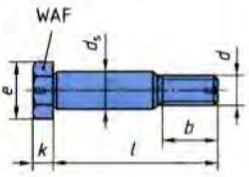
Explanations: 1) for $l$ ≤ 120 mm 2) for $l$ > 125 mm

⇒ **Hexagon head bolt ISO 4015 – M8 x 45 – 8.8:** $d$ = M8, $l$ = 45 mm, property class 8.8

# Hexagon head bolts

## Hexagon head fit bolts with long thread

cf. DIN 609 (1995-02)



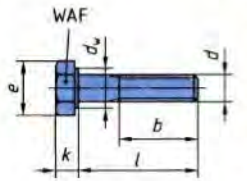

| Thread $d$ | M8<br>M8<br>x1 | M10<br>M10<br>x1 | M12<br>M12<br>x1.5 | M16<br>M16<br>x1.5 | M20<br>M20<br>x1.5 | M24<br>M24<br>x2 | M30<br>M30<br>x2 | M36<br>M36<br>x3 | M42<br>M42<br>x3 | M48<br>M48<br>x3 |
|---|---|---|---|---|---|---|---|---|---|---|
| WAF<br>$k$ | 13<br>5.3 | 16<br>6.4 | 18<br>7.5 | 24<br>10 | 30<br>12.5 | 36<br>15 | 46<br>19 | 55<br>22 | 65<br>26 | 75<br>30 |
| $d_s$ k6<br>$e$ | 9<br>14.4 | 11<br>17.8 | 13<br>19.9 | 17<br>26.2 | 21<br>33 | 25<br>39.6 | 32<br>50.9 | 38<br>60.8 | 44<br>71.3 | 50<br>82.6 |
| $b^{1)}$<br>$b^{2)}$<br>$b^{3)}$ | 14.5<br>16.5<br>– | 17.5<br>19.5<br>– | 20.5<br>22.5<br>– | 25<br>27<br>32 | 28.5<br>30.5<br>35.5 | –<br>36.5<br>41.5 | –<br>43<br>48 | –<br>49<br>54 | –<br>56<br>61 | –<br>63<br>68 |
| $l$ from<br>to | 25<br>80 | 30<br>100 | 32<br>120 | 38<br>150 | 45<br>150 | 55<br>150 | 65<br>200 | 70<br>200 | 80<br>200 | 85<br>200 |
| Nominal lengths $l$ | 25, 28, 30, 32, 35, 38, 40, 42, 45, 48, 50, 55, 60–150, 160–200 mm | | | | | | | | | |
| Property classes | 8.8 | | | | | | | | | as per agreement |
| | A2-70 | | | | | A2-50 | | | | |
| Explanations | $^{1)}$ for $l \leq 150$ mm $^{2)}$ for $l = 50$–150 mm $^{3)}$ for $l > 150$ mm | | | | | | | | | |
| ⇒ | **Fit bolt DIN 609 – M16 x 1.5 x 125 – A2-70:**<br>$d$ = M16 x 1.5, $l$ = 125 mm, property class A2-70 | | | | | | | | | |

Product grades (page 211)

| $d$ in mm | $l$ in mm | Grade |
|---|---|---|
| ≤ 10 | all | A |
| ≥ 12 | all | B |

## Hexagon head bolts with large width across flats for high-strength structural bolting assemblies (HV)

cf. DIN EN 14399-4 (2006-06), replaces DIN 6914

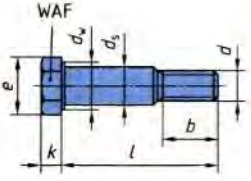



| Thread $d$ | M12 | M16 | M20 | M22 | M24 | M27 | M30 | M36 |
|---|---|---|---|---|---|---|---|---|
| WAF<br>$k$<br>$d_w$ | 22<br>8<br>20.1 | 27<br>10<br>24.9 | 32<br>13<br>29.5 | 36<br>14<br>33.3 | 41<br>15<br>38 | 46<br>17<br>42.8 | 50<br>19<br>46.6 | 60<br>23<br>55.9 |
| $e$<br>$b_{min}$ | 23.9<br>23 | 29.6<br>28 | 35<br>33 | 39.6<br>34 | 45.2<br>39 | 50.9<br>41 | 55.4<br>44 | 66.4<br>52 |
| $l$ from<br>to | 35<br>95 | 40<br>130 | 45<br>155 | 50<br>165 | 60<br>195 | 70<br>200 | 75<br>200 | 85<br>200 |
| Nominal lengths $l$ | 35, 40, 45, 50, 55, 60, 65, 70–175, 180, 185, 190, 195, 200 mm | | | | | | | |
| Property class, surface | 10.9<br>normal –> with thin oil film, hot-galvanized –> code: tZn | | | | | | | |
| ⇒ | **Hexagon head bolt EN 14399-4 – M12 x 65 – 10.9 – HV – tZn:**<br>$d$ = M12, $l$ = 65 mm, property class 10.9, for high-strength bolting assemblies, with hot-galvanized surface | | | | | | | |

Product grade C

## Hexagon fit bolts with large width across flats

cf. DIN 7999 (1983-12)




| Thread $d$ | M12 | M16 | M20 | M22 | M24 | M27 | M30 |
|---|---|---|---|---|---|---|---|
| WAF<br>$k$<br>$d_w$ | 21<br>8<br>19 | 27<br>10<br>25 | 34<br>13<br>32 | 36<br>14<br>34 | 41<br>15<br>39 | 46<br>17<br>43.5 | 50<br>19<br>47.5 |
| $d_s$ b11<br>$e$<br>$b$ | 13<br>22.8<br>18.5 | 17<br>29.6<br>22 | 21<br>37.3<br>26 | 23<br>39.6<br>28 | 25<br>45.2<br>29.5 | 28<br>50.9<br>32.5 | 31<br>55.4<br>35 |
| $l$ from<br>to | 40<br>120 | 45<br>160 | 50<br>180 | 55<br>200 | 55<br>200 | 60<br>200 | 65<br>200 |
| Nominal lengths $l$ | 40, 45, 50, 55, 60, 65–180, 185, 190, 195, 200 mm | | | | | | |
| Property classes | All bolts: property class 10.9 | | | | | | |
| ⇒ | **Hexagon head bolt DIN 7999 – M24 x 165:**<br>$d$ = M24, $l$ = 165 mm, property class 10.9 | | | | | | |

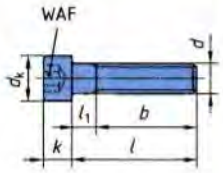
Product grade C

# Hexagon socket head cap screws

## Hexagon socket head cap screws with coarse threads

cf. DIN EN ISO 4762 (2004-06)

| Valid standard DIN EN ISO | Replaces DIN |
|---|---|
| 4762 | 912 |




| Thread $d$ | M1.6 | M2 | M2.5 | M3 | M4 | M5 | M6 | M8 | M10 |
|---|---|---|---|---|---|---|---|---|---|
| WAF | 1.5 | 1.5 | 2 | 2.5 | 3 | 4 | 5 | 6 | 8 |
| $k$ | 1.6 | 2 | 2.5 | 3 | 4 | 5 | 6 | 8 | 10 |
| $d_k$ | 3 | 3.8 | 4.5 | 5.5 | 7 | 8.5 | 10 | 13 | 16 |
| $b$ for $l$ | – – | 16 20 | 17 25 | 18 ≥ 25 | 20 ≥ 30 | 22 ≥ 30 | 24 ≥ 35 | 28 ≥ 40 | 32 ≥ 45 |
| $l_1$ for $l$ | 1.1 ≤ 16 | 1.2 ≤ 16 | 1.4 ≤ 20 | 1.5 ≤ 20 | 2.1 ≤ 25 | 2.4 ≤ 25 | 3 ≤ 30 | 3.8 ≤ 35 | 4.5 ≤ 40 |
| $l$ from to | 2.5 16 | 3 20 | 4 25 | 5 30 | 6 40 | 8 50 | 10 60 | 12 80 | 16 100 |
| Property classes | by agreement | | | 8.8, 10.9, 12.9 | | | | | |
| | Stainless steels A2-70, A4-70 | | | | | | | | |

| Thread $d$ | M12 | M16 | M20 | M24 | M30 | M36 | M42 | M48 | M56 |
|---|---|---|---|---|---|---|---|---|---|
| WAF | 10 | 14 | 17 | 19 | 22 | 27 | 32 | 36 | 41 |
| $k$ | 12 | 16 | 20 | 24 | 30 | 36 | 42 | 48 | 56 |
| $d_k$ | 18 | 24 | 30 | 36 | 45 | 54 | 63 | 72 | 84 |
| $b$ for $l$ | 36 ≥ 55 | 44 ≥ 65 | 52 ≥ 80 | 60 ≥ 90 | 72 ≥ 110 | 84 ≥ 120 | 96 ≥ 140 | 108 ≥ 160 | 124 ≥ 180 |
| $l_1$ for $l$ | 5.3 ≤ 50 | 6 ≤ 60 | 7.5 ≤ 70 | 9 ≤ 80 | 10.5 ≤ 100 | 12 ≤ 110 | 13.5 ≤ 130 | 15 ≤ 150 | 16.5 ≤ 160 |
| $l$ from to | 20 120 | 25 160 | 30 200 | 40 200 | 45 200 | 45 200 | 60 300 | 70 300 | 80 300 |
| Property classes | 8.8, 10.9, 12.9 | | | | | | as per agreement | | |
| | A2-70, A4-70 | | | | A2-50, A4-50 | | | | |
| Nominal lengths $l$ | 2.5, 3, 4, 5, 6, 8, 10, 12, 16, 20, 25, 30–65, 70, 80–150, 160, 180, 200, 220, 240, 260, 280, 300 mm | | | | | | | | |

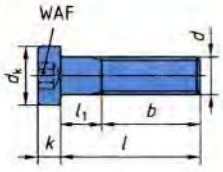
Product grades (page 211)

| Thread $d$ | Grade |
|---|---|
| M1.6–M56 | A |

⇒ **Cap screw ISO 4762 – M10 x 55 – 10.9:**
$d$ = M10, $l$ = 55 mm, property class 10.9

## Hexagon socket head cap screws, low head

cf. DIN 7984 (2002-12)




| Thread $d$ | M3 | M4 | M5 | M6 | M8 | M10 | M12 | M16 | M20 | M24 |
|---|---|---|---|---|---|---|---|---|---|---|
| WAF | 2 | 2.5 | 3 | 4 | 5 | 7 | 8 | 12 | 14 | 17 |
| $k$ | 2 | 2.8 | 3.5 | 4 | 5 | 6 | 7 | 9 | 11 | 13 |
| $d_k$ | 5.5 | 7 | 8.5 | 10 | 13 | 16 | 18 | 24 | 30 | 36 |
| $b$ for $l$ | 12 ≥ 20 | 14 ≥ 25 | 16 ≥ 30 | 18 ≥ 30 | 22 ≥ 35 | 26 ≥ 40 | 30 ≥ 50 | 38 ≥ 60 | 44 ≥ 70 | 46 ≥ 90 |
| $l_1$ for $l$ | 1.5 ≤ 16 | 2.1 ≤ 20 | 2.4 ≤ 25 | 3 ≤ 25 | 3.8 ≤ 30 | 4.5 ≤ 35 | 5.3 ≤ 45 | 6 ≤ 50 | 7.5 ≤ 60 | 9 ≤ 80 |
| $l$ from to | 5 20 | 6 25 | 8 30 | 10 40 | 12 80 | 16 100 | 20 80 | 30 80 | 40 100 | 50 100 |
| Nominal lengths $l$ | 5, 6, 8, 10, 12, 16, 20, 25, 30, 35, 40, 45, 50, 60, 70, 80, 90, 100 mm | | | | | | | | | |
| Property classes | 8.8, A2-70, A4-70 | | | | | | | | | |

Product grades (page 211)

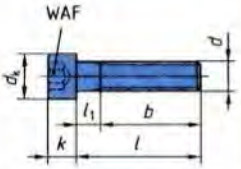
| Thread $d$ | Grade |
|---|---|
| M3–M24 | A |

⇒ **Cap screw DIN 7984 – M12 x 50 – A2-70:**
$d$ = M12, $l$ = 50 mm, property class A2-70

# Cap screws, Countersunk head screws

## Hexagon socket head cap screws with fine threads

cf. DIN EN ISO 21269 (2004-06)

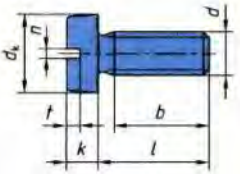



| Thread $d$ | M8 x1 | M10 x1 | M12 x1.5 | M16 x1.5 | M20 x1.5 | M24 x2 | M30 x2 | M36 x3 | M42 x3 | M48 3x | M56 x4 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| WAF | 6 | 8 | 10 | 14 | 17 | 19 | 22 | 27 | 32 | 36 | 41 |
| $k$ | 8 | 10 | 12 | 16 | 20 | 24 | 30 | 36 | 42 | 48 | 56 |
| $d_k$ | 13 | 16 | 18 | 24 | 30 | 36 | 45 | 54 | 63 | 72 | 84 |
| $b$ | 28 | 32 | 36 | 44 | 52 | 60 | 72 | 84 | 96 | 108 | 124 |
| for $l$ | ≥ 40 | ≥ 45 | ≥ 55 | ≥ 65 | ≥ 80 | ≥ 90 | ≥ 110 | ≥ 120 | ≥ 140 | ≥ 160 | ≥ 180 |
| $l_1$ | 3 | 3 | 4.5 | 4.5 | 4.5 | 6 | 6 | 9 | 9 | 9 | 9 |
| for $l$ | ≤ 35 | ≤ 40 | ≤ 50 | ≤ 60 | ≤ 70 | ≤ 70 | ≤ 100 | ≤ 110 | ≤ 130 | ≤ 150 | ≤ 160 |
| $l$ from | 12 | 20 | 20 | 25 | 30 | 40 | 45 | 55 | 60 | 70 | 80 |
| $l$ to | 80 | 100 | 120 | 160 | 200 | 200 | 200 | 200 | 300 | 300 | 300 |
| Nominal lengths $l$ | 12, 16, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 80, 90, 100, 110, 120, 130, 140, 150, 160, 180, 200, 220, 240, 260, 280, 300 mm | | | | | | | | | | |
| Property classes | 8.8, 10.9, 12.9 | | | | | | | | as per agreement | | |
| | A2-70, A4-70 | | | | | | 1) | | | | |
| Explanation | 1) Property classes A2-50, A4-50 (stainless steels) | | | | | | | | | | |
| ⇒ | **Cap screw ISO 21269 – M20 x 1,5 x 120 – 10.9:** $d$ = M20x1.5, $l$ = 120 mm, property class 10.9 | | | | | | | | | | |

Product grade A (page 211)

## Slotted cheese head screws

cf. DIN EN ISO 1207 (1994-10)

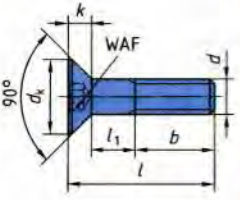



| Thread $d$ | M1.6 | M2 | M2.5 | M3 | M4 | M5 | M6 | M8 | M10 |
|---|---|---|---|---|---|---|---|---|---|
| $d_k$ | 3 | 3.8 | 4.5 | 5.5 | 7 | 8.5 | 10 | 13 | 16 |
| $k$ | 1.1 | 1.4 | 1.8 | 2 | 2.6 | 3.3 | 3.9 | 5 | 6 |
| $n$ | 0.4 | 0.5 | 0.6 | 0.8 | 1.2 | 1.2 | 1.6 | 2 | 2.5 |
| $t$ | 0.5 | 0.6 | 0.7 | 0.9 | 1.1 | 1.3 | 1.6 | 2 | 2.4 |
| $l$ from | 2 | 3 | 3 | 4 | 5 | 6 | 8 | 10 | 12 |
| $l$ to | 16 | 20 | 25 | 30 | 40 | 50 | 60 | 80 | 80 |
| $b$ | for $l$ < 45 mm → threads near to head<br>for $l$ ≥ 45 mm → $b$ = 38 mm | | | | | | | | |
| Nominal lengths $l$ | 2, 3, 4, 5, 6, 8, 10, 12, 16, 20, 25–45, 50, 60, 70, 80 mm | | | | | | | | |
| Property classes | 4.8, 5.8, A2-50, A4-50 | | | | | | | | |
| ⇒ | **Cheese head screw ISO 1207 – M6 x 25 – 5.8:** $d$ = M6, $l$ = 25 mm, property class 5.8 | | | | | | | | |

Product grade A (page 211)

## Hexagon socket head countersunk screws

cf. DIN EN ISO 10642 (2004-06), replaces DIN 7991



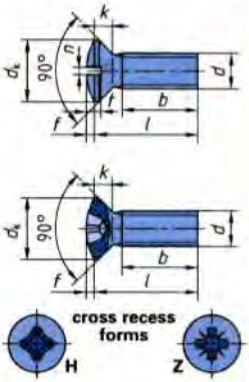

| Thread $d$ | M3 | M4 | M5 | M6 | M8 | M10 | M12 | M16 | M20 |
|---|---|---|---|---|---|---|---|---|---|
| WAF | 2 | 2.5 | 3 | 4 | 5 | 6 | 8 | 10 | 12 |
| $d_k$ | 5.5 | 7.5 | 9.4 | 11.3 | 15.2 | 19.2 | 23.1 | 29 | 36 |
| $k$ | 1.9 | 2.5 | 3.1 | 3.7 | 5 | 6.2 | 7.4 | 8.8 | 10.2 |
| $b$ | 18 | 20 | 22 | 24 | 28 | 32 | 36 | 44 | 52 |
| for $l$ | ≥ 30 | ≥ 30 | ≥ 35 | ≥ 40 | ≥ 50 | ≥ 55 | ≥ 65 | ≥ 80 | 100 |
| $l_1$ | 1.5 | 2.1 | 2.4 | 3 | 3.8 | 4.5 | 5.3 | 6 | 7.5 |
| for $l$ | ≤ 25 | ≤ 25 | ≤ 30 | ≤ 35 | ≤ 45 | ≤ 50 | ≤ 60 | ≤ 70 | ≤ 90 |
| $l$ from | 8 | 8 | 8 | 8 | 10 | 12 | 20 | 30 | 35 |
| $l$ to | 30 | 40 | 50 | 60 | 80 | 100 | 100 | 100 | 100 |
| Property classes | 8.8, 10.9, 12.9 | | | | | | | | |
| Nominal lengths $l$ | 8, 10, 12, 16, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 80, 90, 100 mm | | | | | | | | |
| ⇒ | **Countersunk head screw ISO 10642 – M5 x 30 – 8.8:** $d$ = M5, $l$ = 30 mm, property class 8.8 | | | | | | | | |

Product grade A (page 211)

# Countersunk head screws, Raised head countersunk screws, Tapping screws

## Slotted raised head countersunk screws
## Raised head countersunk screws with cross recess

cf. DIN EN ISO 2010 (1994-10)
cf. DIN EN ISO 7047 (1994-10)

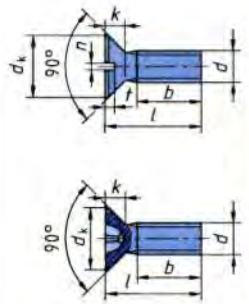



Product grade A (page 211)

| Thread $d$ | M1.6 | M2 | M2.5 | M3 | M4 | M5 | M6 | M8 | M10 |
|---|---|---|---|---|---|---|---|---|---|
| $d_k$ | 3 | 3.8 | 4.7 | 5.5 | 8.4 | 9.3 | 11.3 | 15.8 | 18.3 |
| $k$ | 1 | 1.2 | 1.5 | 1.7 | 2.7 | 2.7 | 3.3 | 4.7 | 5 |
| $n$ | 0.4 | 0.5 | 0.6 | 0.8 | 1.2 | 1.2 | 1.6 | 2 | 2.5 |
| $f$ | 0.4 | 0.5 | 0.6 | 0.7 | 1.0 | 1.2 | 1.4 | 2 | 2.3 |
| $t$ | 0.6 | 0.8 | 1.0 | 1.2 | 1.6 | 2.0 | 2.4 | 3.2 | 3.8 |
| C [1] | 0 | | 1 | | 2 | | 3 | 4 | |
| $l$ from | 2.5 | 3 | 4 | 5 | 6 | 8 | 8 | 10 | 12 |
| $l$ to | 16 | 20 | 25 | 30 | 40 | 50 | 60 | 80 | 80 |
| $b$ | for $l < 45$ mm → $b \approx l$; for $l \geq 45$ mm → $b = 38$ mm | | | | | | | | |
| Property classes | DIN EN ISO 2010: 4.8, 5.8, A2-50, A2-70<br>DIN EN ISO 7047: 4.8, A2-50, A2-70 | | | | | | | | |
| Nominal lengths $l$ | 2.5, 3, 4, 5, 6, 8, 10, 12, 16, 20, 25–45, 50, 60, 70, 80 mm | | | | | | | | |
| Explanation | [1] C cross recess size, forms H and Z | | | | | | | | |
| ⇒ | **Countersunk head screw ISO 7047 – M3 x 20 – 4.8 – H:**<br>$d$ = M3, $l$ = 20 mm, property class 5.8, cross recess form H | | | | | | | | |

## Slotted flat head countersunk screws
## Flat head countersunk screws with cross recess

cf. DIN EN ISO 2009 (1994-10)
cf. DIN EN ISO 7046-1 (1994-10)

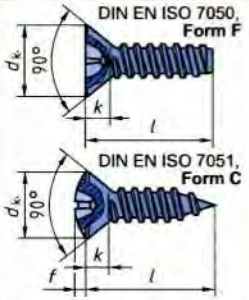



Product grade A (page 211)

| Thread $d$ | M1.6 | M2 | M2.5 | M3 | M4 | M5 | M6 | M8 | M10 |
|---|---|---|---|---|---|---|---|---|---|
| $d_k$ | 3 | 3.8 | 4.7 | 5.5 | 8.4 | 9.3 | 11.3 | 15.8 | 18.3 |
| $k$ | 1 | 1.2 | 1.5 | 1.7 | 2.7 | 2.7 | 3.3 | 4.7 | 5 |
| $n$ | 0.4 | 0.5 | 0.6 | 0.8 | 1.2 | 1.2 | 1.6 | 2 | 2.5 |
| $t$ | 0.5 | 0.6 | 0.8 | 0.9 | 1.3 | 1.4 | 1.6 | 2.3 | 2.6 |
| C [1] | 0 | | 1 | | 2 | | 3 | 4 | |
| $l$ from | 2.5 | 3 | 4 | 5 | 6 | 8 | 8 | 10 | 12 |
| $l$ to | 16 | 20 | 25 | 30 | 40 | 50 | 60 | 80 | 80 |
| $b$ | for $l < 45$ mm → $b \approx l$; for $l \geq 45$ mm → $b = 38$ mm | | | | | | | | |
| Property classes | DIN EN ISO 2009: 4.8, 5.8, A2-50, A2-70<br>DIN EN ISO 7046-1: 4.8, A2-50, A2-70 | | | | | | | | |
| Nominal lengths $l$ | 2.5, 3, 4, 5, 6, 8, 10, 12, 16, 20, 25–45, 50, 60, 70, 80 mm | | | | | | | | |
| Explanation | [1] C cross recess size, forms H and Z (DIN EN 2010) | | | | | | | | |
| ⇒ | **Countersunk head screw ISO 7046-1 – M5 x 40 – 4.8 – H:**<br>$d$ = M3, $l$ = 40 mm, property class 4.8, cross recess form H | | | | | | | | |

## Flat head countersunk tapping screws
## Raised head countersunk tapping screws

cf. DIN EN ISO 7050 (1990-08)
cf. DIN EN ISO 7051 (1990-08)



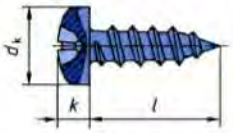

Product grade A (page 211)

| Thread $d$ | ST2.2 | ST2.9 | ST3.5 | ST4.2 | ST4.8 | ST5.5 | ST6.3 |
|---|---|---|---|---|---|---|---|
| $d_k$ | 3.8 | 5.5 | 7.3 | 8.4 | 9.3 | 10.3 | 11.3 |
| $k$ | 1.1 | 1.7 | 2.4 | 2.6 | 2.8 | 3 | 3.2 |
| $f$ | 0.5 | 0.7 | 0.8 | 1.0 | 1.2 | 1.3 | 1.4 |
| $l$ from | 4.5 | 6.5 | 9.5 | 9.5 | 9.5 | 13 | 13 |
| $l$ to | 16 | 19 | 25 | 32 | 32 | 38 | 38 |
| C [1] | 0 | 1 | 2 | | | 3 | |
| Nominal lengths $l$ | 4.5, 6.5, 9.5, 13, 16, 19, 22, 25, 32, 38 mm | | | | | | |
| Forms | Form C with cone point, form F with dog point | | | | | | |
| Explanation | [1] C cross recess size, forms H and Z (DIN EN 2010) | | | | | | |
| ⇒ | **Tapping screw ISO 7050 – ST4.8 x 32 – F – Z:**<br>$d$ = ST4.8, $l$ = 32 mm, form F, cross recess form Z | | | | | | |

# Tapping screws, Thread forming screws

## Pan head tapping screws

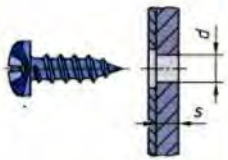
cf. DIN ISO 7049 (1990-08)




| Thread $d$ | ST2.2 | ST2.9 | ST3.5 | ST4.2 | ST4.8 | ST5.5 | ST6.3 |
|---|---|---|---|---|---|---|---|
| $d_k$ | 4 | 5.6 | 7 | 8 | 9.5 | 11 | 13 |
| $k$ | 1.6 | 2.4 | 2.6 | 3.1 | 3.7 | 4 | 4.6 |
| $l$ from | 4.5 | 6.5 | 9.5 | 9.5 | 9.5 | 13 | 13 |
| $l$ to | 16 | 19 | 25 | 32 | 32 | 38 | 38 |
| C[1] | 0 | 1 | 2 | | | 3 | |
| Nominal lengths $l$ | 4.5, 6.5, 9.5, 13, 16, 19, 22, 25, 32, 38 mm | | | | | | |
| Forms | Form C with cone point, form F with dog point | | | | | | |
| Explanation | [1] C cross recess size, forms H and Z (DIN EN 2010) | | | | | | |
| ⇒ | **Tapping screw ISO 7049 – ST2.9 x 13 – C – H:** $d$ = ST2.9, $l$ = 13 mm, form C, cross recess form H | | | | | | |

Product grade A (page 211)

## Tap hole diameter for tapping screws (selection)



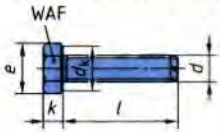

| Sheet metal thickness $s$ in mm from–to | Tap hole diameter $d$ for tapping screw threads[1] | | | | | | |
|---|---|---|---|---|---|---|---|
| | ST2.2 | ST2.9 | ST3.5 | ST4.2 | ST4.8 | ST5.5 | ST6.3 |
| 0–0.5 | 1.6 | 2.2 | 2.6 | – | – | – | – |
| 0.6–0.8 | 1.7 | 2.3 | 2.7 | 3.2 | 3.7 | – | – |
| 0.9–1.1 | 1.8 | 2.4 | 2.8 | 3.2 | 3.7 | 4.2 | 4.9 |
| 1.2–1.4 | 1.8 | 2.4 | 2.8 | 3.3 | 3.9 | 4.3 | 4.9 |
| 1.5–1.7 | – | 2.5 | 2.9 | 3.5 | 3.9 | 4.5 | 5.0 |
| 1.8–2.0 | – | 2.6 | 3.0 | 3.5 | 4.0 | 4.6 | 5.2 |
| 2.0–2.5 | – | – | 3.0 | 3.5 | 4.0 | 4.6 | 5.3 |
| 2.6–3.0 | – | – | 3.0 | 3.8 | 4.1 | 4.7 | 5.3 |
| 3.1–3.5 | – | – | – | 3.9 | 4.3 | 5.0 | 5.8 |

[1] Holes bored or punched in steel or copper alloy sheet

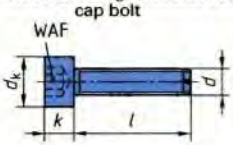
## Thread forming screws

cf. DIN 7500-1 (2007-03)

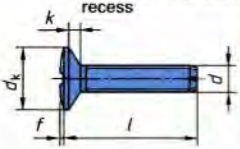
**Form DE:** hexagon head bolt




**Form EE:** hexagon socket head cap bolt




**Form NE:** raised countersunk head bolt with cross recess



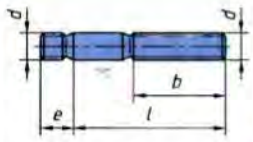

| Form | Thread $d$ | M2 | M2.5 | M3 | M4 | M5 | M6 | M8 | M10 |
|---|---|---|---|---|---|---|---|---|---|
| DE | WAF | 4 | 5 | 5,5 | 7 | 8 | 10 | 13 | 16 |
| | $k$ | 1.4 | 1.7 | 2 | 2.8 | 3.5 | 4 | 5.3 | 6.4 |
| | $d_k$ | 2.3 | 3.1 | 4.1 | 4.6 | 6 | 6.9 | 11.6 | 14.6 |
| | $e$ | 3.4 | 4.3 | 5.5 | 6 | 7.7 | 11.1 | 14.4 | 17.8 |
| | $l$ from | 3 | 4 | 4 | 6 | 8 | 8 | 10 | 12 |
| | $l$ to | 16 | 20 | 25 | 30 | 40 | 50 | 60 | 80 |
| EE | WAF | 1.5 | 2 | 2.5 | 3 | 4 | 5 | 6 | 8 |
| | $k$ | 2 | 2.5 | 3 | 4 | 5 | 6 | 8 | 10 |
| | $d_k$ | 3.8 | 4.5 | 5.5 | 7 | 8.5 | 10 | 13 | 16 |
| | $l$ from | 3 | 4 | 4 | 6 | 8 | 8 | 10 | 12 |
| | $l$ to | 16 | 20 | 25 | 30 | 40 | 50 | 60 | 80 |
| NE | $d_k$ | 3.8 | 4.7 | 5.5 | 8.4 | 9.3 | 11.3 | 15.8 | 18.3 |
| | $k$ | 1.2 | 1.5 | 1.7 | 2.7 | 2.7 | 3.3 | 4.7 | 5 |
| | $f$ | 0.4 | 0.5 | 1 | 1.2 | 1.4 | 1.4 | 2 | 2.3 |
| | $l$ from | 4 | 5 | 6 | 8 | 10 | 10 | 12 | 20 |
| | $l$ to | 16 | 20 | 25 | 30 | 40 | 50 | 60 | 80 |
| | C[1] | 0 | 1 | | 2 | | 3 | 4 | |
| Nominal lengths $l$ | 3, 4, 5, 6, 8, 10, 12, 16, 20, 25, 30–50, 55, 60, 70, 80 mm | | | | | | | | |
| Explanation | [1] C cross recess size, forms H and Z (DIN EN 2010) | | | | | | | | |
| ⇒ | **Screw DIN 7500 – DE – M8 x 25 – St:** DE Hex head, $d$ = M8, $l$ = 25 mm (material: case hardened and tempered steel) | | | | | | | | |

Product grade A (page 211)

# Studs, Eye bolts, Drain plugs

## Studs

cf. DIN 835, 938, 939 (1995-02)



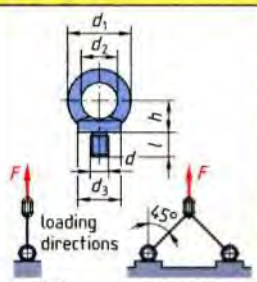

Product grade A (page 211)

| Application | |
|---|---|
| DIN | For screwing into |
| 835 | Aluminum alloys |
| 938 | Steel |
| 939 | Cast iron |

| Thread $d$ | M3 | M4 | M5 | M6 | M8<br>M8 x1 | M10<br>M10 x1.25 | M12<br>M12 x1.25 | M16<br>M16 x1.5 | M20<br>M20 x1.5 | M24<br>M24 x2 |
|---|---|---|---|---|---|---|---|---|---|---|
| $b$ for $l$ < 125 | 12 | 14 | 16 | 18 | 22 | 26 | 30 | 38 | 46 | 54 |
| $l$ < 125 | 18 | 20 | 22 | 24 | 28 | 32 | 36 | 44 | 52 | 60 |
| $e$ DIN 835 | – | 8 | 10 | 12 | 16 | 20 | 24 | 32 | 40 | 48 |
| $e$ DIN 938 | 3 | 4 | 5 | 6 | 8 | 10 | 12 | 16 | 20 | 24 |
| $e$ DIN 939 | – | 5 | 6.5 | 7.5 | 10 | 12 | 15 | 20 | 25 | 30 |
| $l$ from | 20 | 20 | 25 | 25 | 30 | 35 | 40 | 50 | 60 | 70 |
| $l$ to | 30 | 40 | 50 | 60 | 80 | 100 | 120 | 170 | 200 | 200 |
| Property classes | 5.6, 8.8, 10.9 | | | | | | | | | |
| Nominal lengths $l$ | 20, 25, 30–75, 80, 90–180, 190, 200 mm | | | | | | | | | |
| ⇒ | **Stud ISO 939 – M10 x 65 – 8.8:** $d$ = M10, $l$ = 65 mm, property class 8.8 | | | | | | | | | |

## Eye bolts

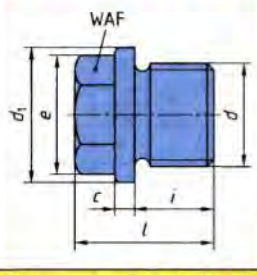
cf. DIN 580 (2003-08)




| Thread $d$ | M8 | M10 | M12 | M16 | M20 | M24 | M30 | M36 | M42 | M48 | M56 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $h$ | 18 | 22.5 | 26 | 30.5 | 35 | 45 | 55 | 65 | 75 | 85 | 95 |
| $d_1$ | 36 | 45 | 54 | 63 | 72 | 90 | 108 | 126 | 144 | 166 | 184 |
| $d_2$ | 20 | 25 | 30 | 35 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
| $d_3$ | 20 | 25 | 30 | 35 | 40 | 50 | 65 | 75 | 85 | 100 | 110 |
| $l$ | 13 | 17 | 20.5 | 27 | 30 | 36 | 45 | 54 | 63 | 68 | 78 |
| Materials | Case hardened steel C15E, A2, A3, A4, A5 | | | | | | | | | | |
| | Carrying capacity in t for loading direction | | | | | | | | | | |
| Vertical | 0.14 | 0.23 | 0.34 | 0.70 | 1.20 | 1.80 | 3.20 | 4.60 | 6.30 | 8.60 | 11.5 |
| under 45° | 0.10 | 0.17 | 0.24 | 0.50 | 0.86 | 1.29 | 2.30 | 3.30 | 4.50 | 6.10 | 8.20 |
| ⇒ | **Eye bolt DIN 580 – M20 – C15E:** $d$ = M20, material C15E | | | | | | | | | | |

## Hexagon head Drain plugs

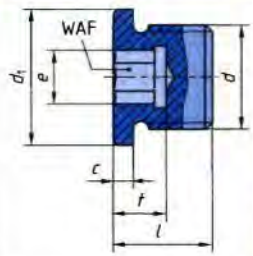
cf. DIN 910 (1992-01)




| Thread $d$ | M10<br>x1 | M12<br>x1.5 | M16<br>x1.5 | M20<br>x1.5 | M24<br>x1.5 | M30<br>x1.5 | M36<br>x1.5 | M42<br>x1.5 | M48<br>x1.5 | M52<br>x1.5 |
|---|---|---|---|---|---|---|---|---|---|---|
| $d_1$ | 14 | 17 | 21 | 25 | 29 | 36 | 42 | 49 | 55 | 60 |
| $l$ | 17 | 21 | 21 | 26 | 27 | 30 | 32 | 33 | 33 | 33 |
| $i$ | 8 | 12 | 12 | 14 | 14 | 16 | 16 | 16 | 16 | 16 |
| $c$ | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 5 | 5 | 5 |
| WAF | 10 | 13 | 17 | 19 | 22 | 24 | 27 | 30 | 30 | 30 |
| $e$ | 10.9 | 14.2 | 18.7 | 20.9 | 23.9 | 26.1 | 29.6 | 33 | 33 | 33 |
| Materials | St steel, Al Al-alloy, CuZn copper-zinc-alloy | | | | | | | | | |
| ⇒ | **Screw plug DIN 910 – M24 x 1.5 – St:** $d$ = M24 x 1.5, material: steel | | | | | | | | | |

## Hexagon socket Drain plugs

cf. DIN 908 (1992-01)



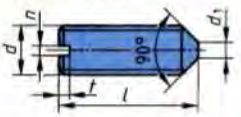

| Thread $d$ | M10<br>x1 | M12<br>x1.5 | M16<br>x1.5 | M20<br>x1.5 | M24<br>x1.5 | M30<br>x1.5 | M36<br>x1.5 | M42<br>x1.5 | M48<br>x1.5 | M52<br>x1.5 |
|---|---|---|---|---|---|---|---|---|---|---|
| $d_1$ | 14 | 17 | 21 | 25 | 29 | 36 | 42 | 49 | 55 | 60 |
| $l$ | 11 | 15 | 15 | 18 | 18 | 20 | 21 | 21 | 21 | 21 |
| $c$ | 3 | 3 | 3 | 4 | 4 | 4 | 5 | 5 | 5 | 5 |
| WAF | 5 | 6 | 8 | 10 | 12 | 17 | 19 | 22 | 24 | 24 |
| $t$ | 5 | 7 | 7.5 | 7.5 | 7.5 | 9 | 10.5 | 10.5 | 10.5 | 10.5 |
| $e$ | 5.7 | 6.9 | 9.2 | 11.4 | 13.7 | 19.4 | 21.7 | 25.2 | 27.4 | 27.4 |
| Materials | St steel, Al Al-alloy, CuZn copper-zinc-alloy | | | | | | | | | |
| ⇒ | **Screw plug DIN 908 – M20 x 1.5 – CuZn:** $d$ = M24 x 1.5, material: copper-zinc-alloy | | | | | | | | | |

# Set screws

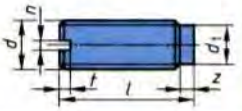
## Slotted set screws

cf. DIN EN 27434, 27435, 24766 (all 1992-10)

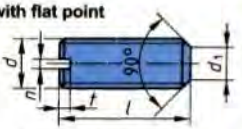
**with cone point**




**with dog point**




**with flat point**




Product grade A (page 211)

| Valid standard | Replaces |
|---|---|
| DIN EN 27434 | DIN 553 |
| DIN EN 27435 | DIN 417 |
| DIN EN 24766 | DIN 551 |

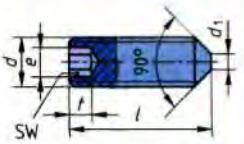
| Thread $d$ | | M1.2 | M1.6 | M2 | M2.5 | M3 | M4 | M5 | M6 | M8 | M10 | M12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DIN EN 27434 | $d_1$ | 0.1 | 0.2 | 0.2 | 0.3 | 0.3 | 0.4 | 0.5 | 1.5 | 2 | 2.5 | 3.6 |
| | $n$ | 0.2 | 0.3 | 0.3 | 0.4 | 0.4 | 0.6 | 0.8 | 1 | 1.2 | 1.6 | 2 |
| | $t$ | 0.5 | 0.7 | 0.8 | 1 | 1.1 | 1.4 | 1.6 | 2 | 2.5 | 3 | 3 |
| | $l$ from | 2 | 2 | 3 | 3 | 4 | 6 | 8 | 5 | 10 | 12 | 16 |
| | $l$ to | 6 | 8 | 10 | 12 | 16 | 25 | 30 | 35 | 40 | 55 | 60 |
| DIN EN 27435 | $d_1$ | – | 0.8 | 1 | 1.5 | 2 | 2.5 | 3.5 | 4.3 | 5.5 | 7 | 8.5 |
| | $z$ | – | 1.1 | 1.3 | 1.5 | 1.8 | 2.3 | 2.8 | 3.3 | 4.3 | 5.3 | 6.3 |
| | $n$ | – | 0.3 | 0.3 | 0.4 | 0.4 | 0.6 | 0.8 | 1 | 1.2 | 1.6 | 2 |
| | $t$ | – | 0.7 | 0.8 | 1 | 1.1 | 1.4 | 1.6 | 2 | 2.5 | 3 | 3 |
| | $l$ from | – | 2.5 | 3 | 4 | 5 | 6 | 8 | 8 | 10 | 12 | 16 |
| | $l$ to | – | 8 | 10 | 12 | 16 | 20 | 25 | 30 | 40 | 50 | 60 |
| DIN EN 24766 | $d_1$ | 0.6 | 0.8 | 1 | 1.5 | 2 | 2.5 | 3.5 | 4 | 5.5 | 7 | 8.5 |
| | $n$ | 0.2 | 0.3 | 0.3 | 0.4 | 0.4 | 0.6 | 0.8 | 1 | 1.2 | 1.6 | 2 |
| | $t$ | 0.5 | 0.7 | 0.8 | 1 | 1.1 | 1.4 | 1.6 | 2 | 2.5 | 3 | 3.6 |
| | $l$ from | 2 | 2 | 2 | 2.5 | 3 | 4 | 5 | 6 | 8 | 10 | 12 |
| | $l$ to | 6 | 8 | 10 | 12 | 16 | 20 | 25 | 30 | 40 | 50 | 60 |
| Property classes | | 45H, A1-12H, A2-21H, A3-21H, A4-21H, A5-21H | | | | | | | | | | |
| Nominal lengths $l$ | | 2, 2.5, 3, 4, 5, 6, 8, 10, 12, 16, 20, 25, 30–50, 55, 60 mm | | | | | | | | | | |

⇒ **Set screw ISO 7434 – M6 x 25 – 14H:**
$d$ = M6, $l$ = 25 mm, property class 14H

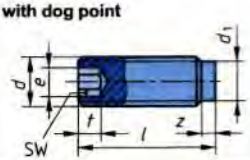
## Set screws with hexagon socket

cf. DIN EN ISO 4026, 4027, 4028 (2004-05)

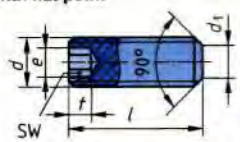
**with cone point**




**with dog point**




**with flat point**




Product grade A (page 211)

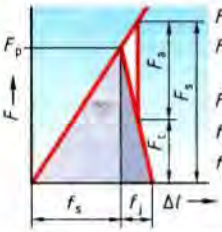
| Valid standard | Replaces |
|---|---|
| DIN EN ISO 4026 | DIN 913 |
| DIN EN ISO 4027 | DIN 914 |
| DIN EN ISO 4028 | DIN 915 |

| Thread $d$ | | M2 | M2.5 | M3 | M4 | M5 | M6 | M8 | M10 | M12 | M16 | M20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DIN EN ISO 4027 | $d_1$ | 0.5 | 0.7 | 0.8 | 1 | 1.3 | 1.5 | 2 | 2.5 | 3 | 4 | 5 |
| | WAF | 0.9 | 1.3 | 1.5 | 2 | 2.5 | 3 | 4 | 5 | 6 | 8 | 10 |
| | $e$ | 1 | 1.5 | 1.7 | 2.3 | 2.9 | 3.4 | 4.6 | 5.7 | 6.9 | 9.1 | 11.4 |
| | $t$ | 0.8 | 1.2 | 1.2 | 1.5 | 2 | 2 | 3 | 4 | 4.8 | 6.4 | 8 |
| | $l$ from | 2 | 2.5 | 3 | 4 | 5 | 6 | 8 | 10 | 12 | 16 | 20 |
| | $l$ to | 10 | 12 | 16 | 20 | 25 | 30 | 40 | 50 | 60 | 60 | 60 |
| DIN EN ISO 4028 | $d_1$ | 1 | 1.5 | 2 | 2.5 | 3.5 | 4 | 5.5 | 7 | 8.5 | 12 | 15 |
| | $z$ | 1.3 | 1.5 | 1.8 | 2.3 | 2.8 | 3.3 | 4.3 | 5.3 | 6.3 | 8.4 | 10.4 |
| | WAF | 0.9 | 1.3 | 1.5 | 2 | 2.5 | 3 | 4 | 5 | 6 | 8 | 10 |
| | $e$ | 1 | 1.5 | 1.7 | 2.3 | 2.9 | 3.4 | 4.6 | 5.7 | 6.9 | 9.1 | 11.4 |
| | $t$ | 0.8 | 1.2 | 1.2 | 1.5 | 2 | 2 | 3 | 4 | 4.8 | 6.4 | 8 |
| | $l$ from | 2.5 | 3 | 4 | 5 | 6 | 8 | 8 | 20 | 12 | 16 | 20 |
| | $l$ to | 10 | 12 | 16 | 20 | 25 | 30 | 40 | 50 | 60 | 60 | 60 |
| DIN EN ISO 4026 | $d_1$ | 1 | 1.5 | 2 | 2.5 | 3.5 | 4 | 5.5 | 7 | 8.5 | 12 | 15 |
| | WAF | 0.9 | 1.3 | 1.5 | 2 | 2.5 | 3 | 4 | 5 | 6 | 8 | 10 |
| | $e$ | 1 | 1.5 | 1.7 | 2.3 | 2.9 | 3.4 | 4.6 | 5.7 | 6.9 | 9.2 | 11.4 |
| | $t$ | 0.8 | 1.2 | 1.2 | 1.5 | 2 | 2 | 3 | 4 | 4.8 | 6.4 | 8 |
| | $l$ from | 2 | 2.5 | 3 | 4 | 5 | 6 | 8 | 10 | 12 | 16 | 20 |
| | $l$ to | 10 | 12 | 16 | 20 | 25 | 30 | 40 | 50 | 60 | 60 | 60 |
| Property classes | | 45H, A1-12H, A2-21H, A3-21H, A4-21H, A5-21H | | | | | | | | | | |
| Nominal lengths $l$ | | 2, 2.5, 3, 4, 5, 6, 8, 10, 12, 16, 20, 25, 30–50, 60 mm | | | | | | | | | | |

⇒ **Set screw ISO 4026 – M6 x 25 – A5-21H:**
$d$ = M6, $l$ = 25 mm, A5 stainless steel, property class 21H

# Screw joint calculations

**Joint diagram**




$F_p$ preload
$F_a$ applied force
$F_c$ joint clamp force
$F_s$ total bolt load
$f_s$ bolt extension
$f_j$ joint compression

**Preselection of shank bolts**[1]

| Load | | Applied force per bolt $F_a$[2] in kN | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| • static | | 2.5 | 4 | 6.3 | 10 | 16 | 25 | 40 | 63 |
| • dynamic | | 1.6 | 2.5 | 4 | 6.3 | 10 | 16 | 25 | 40 |
| Property class | 5.8, 6.8 | M5 | M6 | M8 | M10 | M12 | M16 | M20 | M24 |
| | 8.8 | M5 | M6 | M8 | M8 | M10 | M16 | M20 | M24 |
| | 10.9 | M4 | M5 | M6 | M8 | M10 | M12 | M16 | M20 |
| | 12.9 | M4 | M5 | M5 | M8 | M8 | M10 | M12 | M16 |

[1] It is necessary to check the values of the selected bolts in accordance with VDI Guideline 2230 for instance.
[2] For waisted bolts select next higher applied force level.

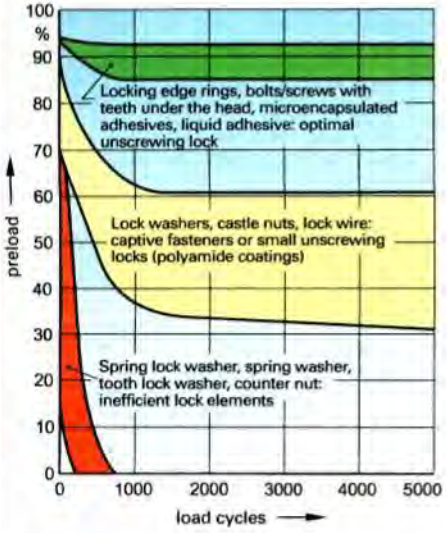
**Preload and tightening torques**

| Thread | $F$[3] | Shank bolts $A_s$[1] in mm² | Shank bolts: Preload $F_p$ in kN, Overall coefficient of friction $\mu$[4] | | | Shank bolts: Tightening torque $M_t$ in N · m, Overall coefficient of friction $\mu$[4] | | | Waisted bolts $A_w$[2] in mm² | Waisted bolts: Preload $F_p$ in kN, Total coefficient of friction $\mu$[4] | | | Waisted bolts: Tightening torque $M_t$ in N · m, Total coefficient of friction $\mu$[4] | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 0.08 | 0.12 | 0.14 | 0.08 | 0.12 | 0.14 | | 0.08 | 0.12 | 0.14 | 0.08 | 0.12 | 0.14 |
| M8 | 8.8 | 36.6 | 18.6 | 17.2 | 16.5 | 17.9 | 23.1 | 25.3 | 26.6 | 12.9 | 11.8 | 11.2 | 13.6 | 17.6 | 19.2 |
| | 10.9 | | 27.1 | 25.2 | 24.2 | 26.2 | 34 | 37.2 | | 19 | 17.3 | 16.4 | 20 | 25.8 | 28.2 |
| | 12.9 | | 31.9 | 29.5 | 28.3 | 30.7 | 39.6 | 43.6 | | 22.2 | 20.2 | 19.2 | 23.4 | 30.2 | 33 |
| M8 x 1 | 8.8 | 39.2 | 20.3 | 18.8 | 18.1 | 18.8 | 24.8 | 27.3 | 29.2 | 14.6 | 13.4 | 12.7 | 13.6 | 17.6 | 19.2 |
| | 10.9 | | 29.7 | 27.7 | 26.6 | 27.7 | 36.4 | 40.1 | | 21.5 | 19.6 | 18.7 | 20 | 25.8 | 28.2 |
| | 12.9 | | 34.8 | 32.4 | 31.1 | 32.4 | 42.6 | 47.1 | | 25.1 | 23 | 21.9 | 23.4 | 30.2 | 33 |
| M10 | 8.8 | 58.0 | 29.5 | 27.3 | 26.2 | 36 | 46 | 51 | 42.4 | 20.7 | 18.9 | 17.9 | 25 | 32 | 35 |
| | 10.9 | | 43.3 | 40.2 | 38.5 | 53 | 68 | 75 | | 30.4 | 27.7 | 26.4 | 37 | 47 | 51 |
| | 12.9 | | 50.7 | 47 | 45 | 61 | 80 | 88 | | 35.6 | 32.4 | 30.8 | 43 | 55 | 60 |
| M10x1.25 | 8.8 | 61.2 | 31.5 | 29.4 | 28.3 | 37 | 49 | 54 | 45.6 | 22.7 | 20.9 | 19.9 | 27 | 35 | 38 |
| | 10.9 | | 46.5 | 43.2 | 41.5 | 55 | 72 | 80 | | 33.5 | 30.6 | 29.2 | 40 | 51 | 56 |
| | 12.9 | | 54.4 | 50.6 | 48.6 | 64 | 84 | 93 | | 39.2 | 35.9 | 34.4 | 46 | 60 | 65 |
| M12 | 8.8 | 84.3 | 43 | 39.9 | 38.3 | 61 | 80 | 87 | 61.7 | 30.3 | 27.6 | 26.3 | 43 | 55 | 60 |
| | 10.9 | | 63 | 58.5 | 56.2 | 90 | 117 | 128 | | 44.6 | 40.6 | 38.6 | 63 | 81 | 88 |
| | 12.9 | | 73.9 | 68.5 | 65.8 | 105 | 137 | 150 | | 52.1 | 47.7 | 45.2 | 74 | 95 | 103 |
| M12x1.5 | 8.8 | 88.1 | 48.2 | 45 | 43.2 | 65 | 87 | 96 | 65.8 | 35 | 32.6 | 31 | 48 | 63 | 69 |
| | 10.9 | | 70.8 | 66 | 63.5 | 96 | 128 | 141 | | 52 | 47.8 | 45.7 | 71 | 93 | 102 |
| | 12.9 | | 82.7 | 72.3 | 74.3 | 112 | 150 | 165 | | 61 | 56 | 53.4 | 83 | 108 | 119 |
| M16 | 8.8 | 157 | 81 | 75.3 | 72.4 | 147 | 194 | 214 | 117 | 58.4 | 53.4 | 51 | 106 | 137 | 150 |
| | 10.9 | | 119 | 111 | 106 | 216 | 285 | 314 | | 85.8 | 78.5 | 74.8 | 156 | 202 | 221 |
| | 12.9 | | 140 | 130 | 124 | 253 | 333 | 367 | | 100 | 91.8 | 87.5 | 182 | 236 | 258 |
| M16x1.5 | 8.8 | 167 | 88 | 82.2 | 79.2 | 154 | 207 | 229 | 128 | 65.5 | 60.2 | 57.4 | 115 | 151 | 166 |
| | 10.9 | | 129 | 121 | 116 | 227 | 304 | 336 | | 96.2 | 88.4 | 84.5 | 169 | 222 | 244 |
| | 12.9 | | 151 | 141 | 136 | 265 | 355 | 394 | | 113 | 104 | 99 | 197 | 260 | 285 |
| M20 | 8.8 | 245 | 131 | 121 | 117 | 297 | 391 | 430 | 182 | 92 | 86 | 82 | 215 | 278 | 304 |
| | 10.9 | | 186 | 173 | 166 | 423 | 557 | 615 | | 134 | 123 | 117 | 306 | 395 | 432 |
| | 12.9 | | 218 | 202 | 194 | 495 | 653 | 720 | | 157 | 144 | 137 | 358 | 462 | 505 |
| M20x1.5 | 8.8 | 272 | 149 | 138 | 134 | 320 | 433 | 482 | 210 | 113 | 104 | 100 | 242 | 322 | 355 |
| | 10.9 | | 212 | 200 | 190 | 455 | 618 | 685 | | 160 | 148 | 142 | 345 | 460 | 508 |
| | 12.9 | | 247 | 231 | 225 | 533 | 721 | 802 | | 188 | 173 | 166 | 402 | 540 | 594 |
| M24 | 8.8 | 353 | 188 | 175 | 168 | 512 | 675 | 743 | 262 | 136 | 124 | 118 | 370 | 480 | 523 |
| | 10.9 | | 268 | 250 | 238 | 730 | 960 | 1060 | | 193 | 177 | 168 | 527 | 682 | 745 |
| | 12.9 | | 313 | 291 | 280 | 855 | 1125 | 1240 | | 225 | 207 | 196 | 617 | 800 | 871 |
| M24x2 | 8.8 | 384 | 210 | 196 | 189 | 545 | 735 | 816 | 295 | 158 | 145 | 139 | 410 | 543 | 600 |
| | 10.9 | | 300 | 280 | 268 | 776 | 1046 | 1160 | | 224 | 207 | 198 | 582 | 775 | 852 |
| | 12.9 | | 350 | 327 | 315 | 908 | 1224 | 1360 | | 263 | 242 | 230 | 682 | 905 | 998 |

During assembly, the bolts are under tensile and torsional stress. The tightening torque $M_t$ utilizes approx. 90 % of the yield strength of the bolt material.

[1] $A_s$ stress area
[2] $A_w$ waist cross section
[3] $F$ property class of bolt
[4] $\mu = 0.08$: bolt $MoS_2$ lubricated
$\mu = 0.12$: bolt lightly oiled
$\mu = 0.14$: bolt secured with microencapsulated plastic

# Locking fasteners




**Vibration test DIN 65151 performed on various locking elements**

The locking behavior of screw joints under transverse loading on the bolt is tested ISO 4014-M10.

A locking fastener is generally not necessary for screw joints which are sufficiently dimensioned and securely mounted. The clamping forces prevent the slipping of the screwed parts or loosening of the bolts and nuts. In practice a loss of clamping force can still occur due to the following causes:

- **Loosening of the screw joint** caused by high surface contact pressures which initiate plastic deformation (so-called settling) and reduce the preload of the screw joint.

  Remedy: As little seperation as possible, minimal surface roughness, use of high-strength bolts (large preload).

- **Unscrewing of the screw joint**: For joints dynamically loaded transverse to the bolt axis a fully self-actuated unscrewing can occur.

  This is remedied with locking elements. These are divided into three groups based on their effectiveness.

  **Ineffective locking elements** (e.g. spring lock washers and tooth lock washers).

  **Captive fasteners**, which allow a partial unscrewing, but prevent the screw joint from coming completely apart.

  **Threadlocking** (e.g. glue or corrugated head screws). The preload remains approximately constant. The nut or bolt cannot loosen by itself (best method of locking).

**Overview of locking fasteners**

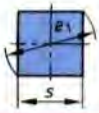
| Joint | Locking element | Standard | Type, property |
|---|---|---|---|
| Loaded together, spring loaded | spring lock washer<br>spring washer<br>tooth lock washer<br>serrated lock washer | withdrawn<br>withdrawn<br>withdrawn<br>withdrawn | ineffective<br>ineffective<br>ineffective<br>ineffective |
| Interlocking | lock washer<br>castle nut with cotter pin<br>lock wire | withdrawn<br>DIN 935-1+2<br>– | captive fastener<br>captive fastener<br>captive fastener |
| Force-fit (gripping) | jam nut | – | ineffective, loosening possible |
| | bolts and nuts with gripping polyamide coating | DIN 267-28<br>ISO 2320 | captive fastener or slight anti-rotation lock |
| Blocking (force-fit and interlocking) | bolts with teeth under the head | – | anti-rotation lock, not suitable for hardened parts |
| | detent edged ring<br>detent washer<br>self-locking pair of washers | –<br>– | anti-rotation lock, not suitable for hardened parts<br>anti-rotation lock |
| Bonded | microencapsulated adhesives in threads | DIN 267-27 | anti-rotation lock, sealing joint; temperature range –50 °C to 150 °C |
| | liquid adhesive | – | anti-rotation lock |

# Width across flats, Types of bolt and screw drives

## Width across flats for bolts, screws, valves and fittings

cf. DIN 475-1 (1984-01)




$e_1 = 1.4142 \cdot s$
$s = 0.7071 \cdot e_1$




$e_2 = 1.1547 \cdot s$
$s = 0.8660 \cdot e_2$




$e_3 = 1.0824 \cdot s$
$s = 0.9239 \cdot e_3$

| Width across flats (WAF) Nominal size $s$ | Length of diagonal: Two flats $d$ | Square $e_1$ | Hexagonal $e_2$ | Width across flats (WAF) Nominal size $s$ | Length of diagonal: Two flats $d$ | Square $e_1$ | Hexagonal $e_2$ | Octagonal $e_3$ |
|---|---|---|---|---|---|---|---|---|
| 3.2 | 3.7 | 4.5 | 3.5 | 21 | 24 | 29.7 | 23.4 | 22.7 |
| 3.5 | 4 | 4.9 | 3.8 | 22 | 25 | 31.1 | 24.5 | 23.8 |
| 4 | 4.5 | 5.7 | 4.4 | 23 | 26 | 32.5 | 25.6 | 24.9 |
| 4.5 | 5 | 6.4 | 4.9 | 24 | 28 | 33.9 | 26.8 | 26.0 |
| 5 | 6 | 7.1 | 5.5 | 25 | 29 | 35.5 | 27.9 | 27.0 |
| 5.5 | 7 | 7.8 | 6.0 | 26 | 31 | 36.8 | 29.0 | 28.1 |
| 6 | 7 | 8.5 | 6.6 | 27 | 32 | 38.2 | 30.1 | 29.1 |
| 7 | 8 | 9.9 | 7.7 | 28 | 33 | 39.6 | 31.3 | 30.2 |
| 8 | 9 | 11.3 | 8.8 | 30 | 35 | 42.4 | 33.5 | 32.5 |
| 9 | 10 | 12.7 | 9.9 | 32 | 38 | 45.3 | 35.7 | 34.6 |
| 10 | 12 | 14.1 | 11.1 | 34 | 40 | 48.0 | 37.7 | 36.7 |
| 11 | 13 | 15.6 | 12.1 | 36 | 42 | 50.9 | 40.0 | 39.0 |
| 12 | 14 | 17.0 | 13.3 | 41 | 48 | 58.0 | 45.6 | 44.4 |
| 13 | 15 | 18.4 | 14.4 | 46 | 52 | 65.1 | 51.3 | 49.8 |
| 14 | 16 | 19.8 | 15.5 | 50 | 58 | 70.7 | 55.8 | 54.1 |
| 15 | 17 | 21.2 | 16.6 | 55 | 65 | 77.8 | 61.3 | 59.5 |
| 16 | 18 | 22.6 | 17.8 | 60 | 70 | 84.8 | 67.0 | 64.9 |
| 17 | 19 | 24.0 | 18.9 | 65 | 75 | 91.9 | 72.6 | 70.3 |
| 18 | 21 | 25.4 | 20.0 | 70 | 82 | 99.0 | 78.3 | 75.7 |
| 19 | 22 | 26.9 | 21.1 | 75 | 88 | 106 | 83.9 | 81.2 |
| 20 | 23 | 28.3 | 22.2 | 80 | 92 | 113 | 89.6 | 86.6 |

⇒ **DIN 475 – WAF 16:** Width across flats with nominal size $s$ = 16 mm

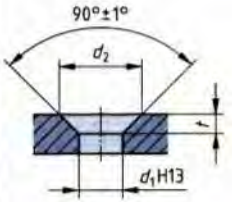
Table values as per DIN 475 apply to finished stamped wrought products, bolts, screws, nuts and fittings. Diagonal lengths calculated by the formula $e_2 = 1.1547 \cdot s$ are larger than the table values, since they are based on the sharp-edged hexagon. Calculation of regular polygons, page 27.

## Screw drive systems

| Type | Properties | Type | Properties |
|---|---|---|---|
|  hexagonal head | High torque transmission, no axial force required, relatively economical, identical tool for bolt and nut, many variations, tool relatively large |  internal torx drive | Higher torque transmission than with hexagon head |
|  hexagon socket | Like hexagon head except the torque transmission is slightly less, requires less space for tool than with hexagon head |  external torx drive | Very good torque transmission, little space required for tool |
|  tamper resistant hexagon drive | Safety screw, can only be loosened with a special tool, especially well-suited as protection against damage and theft, yet has good torque transmission |  tamper resistant torx drive | Safety screw, can only be loosened with a special tool, especially well-suited as protection against damage and theft, yet has good torque transmission |
|  slotted | Inexpensive and popular, but it is difficult to center the tool, low torque transmission, high contact pressure on the loaded driving flats |  cross recess Pozidriv | Higher torque than with slotted bolts & screws, better tool centering, lower contact pressure, available without diagonal notches and also with cross recess Phillips form H |

# Countersinks for countersunk head screws

## Countersinks for countersunk screws with head forms as per ISO 7721 cf. DIN EN ISO 15065 (2005-05) Replaces DIN 66

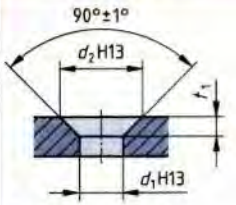



| Nominal sizes | 1.6 | 2 | 2.5 | 3 | 3.5 | 4 |
|---|---|---|---|---|---|---|
| Metric screws | M1.6 | M2 | M2.5 | M3 | M3.5 | M4 |
| Tapping screws | – | ST2.2 | – | ST2.9 | ST3.5 | ST4.2 |
| $d_1$ H13 | 1.8 | 2.4 | 2.9 | 3.4 | 3.9 | 4.5 |
| $d_2$ min. | 3.6 | 4.4 | 5.5 | 6.3 | 8.2 | 9.4 |
| $d_2$ max. | 3.7 | 4.5 | 5.6 | 6.5 | 8.4 | 9.6 |
| $t_1$ ≈ | 1.0 | 1.1 | 1.4 | 1.6 | 2.3 | 2.6 |
| **Nominal sizes** | **5** | **5.5** | **6** | **8** | **10** | – |
| Metric screws | M5 | – | M6 | M8 | M10 | – |
| Tapping screws | ST4.8 | ST5.5 | ST6.3 | ST8 | ST9.5 | – |
| $d_1$ H13 | 5.5 | 6 | 6.6 | 9 | 11 | – |
| $d_2$ min. | 10.4 | 11.5 | 12.6 | 17.3 | 20 | – |
| $d_2$ max. | 10.7 | 11.8 | 12.9 | 17.6 | 20.3 | – |
| $t_1$ ≈ | 2.6 | 2.9 | 3.1 | 4.3 | 4.7 | – |
| ⇒ | **Countersink ISO 15065-8:** Nominal size 8 (metric threads M8 or tapping screw threads ST8) | | | | | |

| Application for: | | |
|---|---|---|
| | Slotted flat head countersunk screws | DIN EN ISO 2009 |
| | Cross recessed flat head countersunk screws | DIN EN ISO 7046-1 |
| | Slotted raised head countersunk screws | DIN EN ISO 2010 |
| | Cross rec. raised head countersunk screws | DIN EN ISO 7047 |
| | Slotted flat head countersunk tapping screws | DIN ISO 1482 |
| | Cross rec. flat head counters. tapping screws | DIN ISO 7050 |
| | Slotted raised head countersunk tapping screws | DIN ISO 1483 |
| | Cross rec. raised head counters. tapping screws | DIN ISO 7051 |
| | Cross recessed flat head countersunk tapping screws | ISO 15482 |
| | Cross recessed raised head countersunk tapping screws | ISO 15483 |

Graphical representation, see page 83;

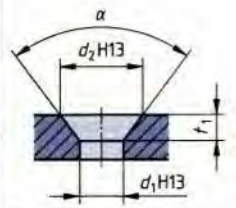
## Countersinks for countersunk head screws cf. DIN 74 (2003-04)




Form A and Form F

| Thread Ø | | 1.6 | 2 | 2.5 | 3 | 4 | 4.5 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Form A | $d_1$ H13[1] | 1.8 | 2.4 | 2.9 | 3.4 | 4.5 | 5 | 5.5 | 6.6 | 7.6 | 9 |
| | $d_2$ H13 | 3.7 | 4.6 | 5.7 | 6.5 | 8.6 | 9.5 | 10.4 | 12.4 | 14.4 | 16.4 |
| | $t_1$ ≈ | 0.9 | 1.1 | 1.4 | 1.6 | 2.1 | 2.3 | 2.5 | 2.9 | 3.3 | 3.7 |
| ⇒ | **Countersink DIN 74 – A4:** Form A, thread diameter 4 mm | | | | | | | | | | |

| Application of Form A for: | | |
|---|---|---|
| | Countersunk flat head wood screws | DIN 97 and DIN 7997 |
| | Raised head countersunk wood screws | DIN 95 and DIN 7995 |




Form E

| Thread Ø | | 10 | 12 | 16 | 20 | 22 | 24 |
|---|---|---|---|---|---|---|---|
| Form E | $d_1$ H13[1] | 10.5 | 13 | 17 | 21 | 23 | 25 |
| | $d_2$ H13 | 19 | 24 | 31 | 34 | 37 | 40 |
| | $t_1$ ≈ | 5.5 | 7 | 9 | 11.5 | 12 | 13 |
| | $\alpha$ | 75° ± 1° | | | 60° ± 1° | | |
| ⇒ | **Countersink DIN 74 – E12:** Form E, thread diameter 12 mm | | | | | | |

| Application of Form E for: | |
|---|---|
| Countersunk head bolts for steel structures | DIN 7969 |

| Thread Ø | | 3 | 4 | 5 | 6 | 8 | 10 | 12 | 14 | 16 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Shape F | $d_1$ H13[1] | 3.4 | 4.5 | 5.5 | 6.6 | 9 | 11 | 13.5 | 15.5 | 17.5 | 22 |
| | $d_2$ H13 | 6.9 | 9.2 | 11.5 | 13.7 | 18.3 | 22.7 | 27.2 | 31.2 | 34.0 | 40.7 |
| | $t_1$ ≈ | 1.8 | 2.3 | 3.0 | 3.6 | 4.6 | 5.9 | 6.9 | 7.8 | 8.2 | 9.4 |
| ⇒ | **Countersink DIN 74 – F12:** Form F, thread diameter 12 mm | | | | | | | | | | |

| Application of Form F for: | |
|---|---|
| Hexagon socket head countersunk screws | DIN EN ISO 10642 (replaces DIN 7991) |

Form E

Graphical representation, see page 83;

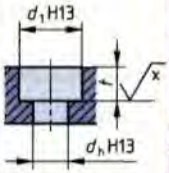
Forms B, C and D are no longer standardized

[1] Medium size clearance hole according to DIN EN 20273, page 211

# Counterbores for cap screws and Hexagon head bolts

## Counterbores for cap screws

cf. DIN 974-1 (1991-05)




$\sqrt{x} = \sqrt{Ra\ 3.2}$

| $d$ | | 3 | 4 | 5 | 6 | 8 | 10 | 12 | 16 | 20 | 24 | 27 | 30 | 36 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $d_h$ H13[1] | | 3.4 | 4.5 | 5.5 | 6.6 | 9 | 11 | 13.5 | 17.5 | 22 | 26 | 30 | 33 | 39 |
| $d_1$ H13 | Series 1 | 6.5 | 8 | 10 | 11 | 15 | 18 | 20 | 26 | 33 | 40 | 46 | 50 | 58 |
| | Series 2 | 7 | 9 | 11 | 13 | 18 | 24 | – | – | – | – | – | – | – |
| | Series 3 | 6.5 | 8 | 10 | 11 | 15 | 18 | 20 | 26 | 33 | 40 | 46 | 50 | 58 |
| | Series 4 | 7 | 9 | 11 | 13 | 16 | 20 | 24 | 30 | 36 | 43 | 46 | 54 | 63 |
| | Series 5 | 9 | 10 | 13 | 15 | 18 | 24 | 26 | 33 | 40 | 48 | 54 | 61 | 69 |
| | Series 6 | 8 | 10 | 13 | 15 | 20 | 24 | 33 | 43 | 48 | 58 | 63 | 73 | – |
| $t$[2] | ISO 1207 | 2.4 | 3.0 | 3.7 | 4.3 | 5.6 | 6.6 | – | – | – | – | – | – | – |
| | ISO 4762 | 3.4 | 4.4 | 5.4 | 6.4 | 8.6 | 10.6 | 12.6 | 16.6 | 20.6 | 24.8 | – | 31.0 | 37.0 |
| | DIN 7984 | 2.4 | 3.2 | 3.9 | 4.4 | 5.4 | 6.4 | 7.6 | 9.6 | 11.6 | 13.8 | – | – | – |

⇒ DIN 974 provides no code designations for counterbores.

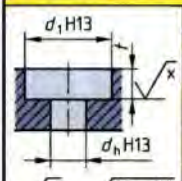
| Series | Cap screws without washer components | |
|---|---|---|
| 1 | Screws (bolts) ISO 1207, ISO 4762, DIN 6912, DIN 7984 | |
| 2 | Screws (bolts) ISO 1580, DIN 7985 | |
| | **Cap screws and the following washer components:** | |
| 3 | Screws (bolts) ISO 1207, ISO 4762, DIN 7984 with spring lock washers DIN 7980[3] | |
| 4 | Washers DIN EN ISO 7092<br>Spring washers DIN 137 Form A[3]<br>Spring lock washers DIN 128 + DIN 6905[3] | Tooth lock washers DIN 6797[3]<br>Serrated lock washers DIN 6798[3]<br>Serrated lock washers DIN 6907[3] |
| 5 | Washers DIN EN ISO 7090<br>Washers DIN 6902 Form A[3] | Spring washers DIN 137 Form B[3]<br>Spring washers DIN 6904[3] |
| 6 | Conical spring washers DIN 6796 | |

Graphical representation, see page 83;

[1] Clearance hole according to DIN EN 20273, series medium, page 211
[2] For screws/bolts without washer components [3] Standards withdrawn

## Counterbore for hexagon bolts/screws and hexagon nuts

cf. DIN 974-2 (1991-05)




$\sqrt{x} = \sqrt{Ra\ 3.2}$ or $\sqrt{Rz\ 25}$

| $d$ | | 4 | 5 | 6 | 8 | 10 | 12 | 14 | 16 | 20 | 24 | 27 | 30 | 33 | 36 | 42 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Width across flats* | | 7 | 8 | 10 | 13 | 16 | 18 | 21 | 24 | 30 | 36 | 41 | 46 | 50 | 55 | 65 |
| $d_h$ H13 | | 4.5 | 5.5 | 6.6 | 9 | 11 | 13.5 | 15.5 | 17.5 | 22 | 26 | 30 | 33 | 36 | 39 | 45 |
| $d_1$ H13 | Series 1 | 13 | 15 | 18 | 24 | 28 | 33 | 36 | 40 | 46 | 58 | 61 | 73 | 76 | 82 | 98 |
| | Series 2 | 15 | 18 | 20 | 26 | 33 | 36 | 43 | 46 | 54 | 73 | 76 | 82 | 89 | 93 | 107 |
| | Series 3 | 10 | 11 | 13 | 18 | 22 | 26 | 30 | 33 | 40 | 48 | 54 | 61 | 69 | 73 | 82 |
| $t$[1] | Hex bolt | 3.3 | 4.1 | 4.6 | 6.1 | 7.2 | 8.3 | 9.6 | 10.8 | 13.3 | 16.0 | 18.2 | 20.1 | 22.4 | 23.9 | 27.4 |

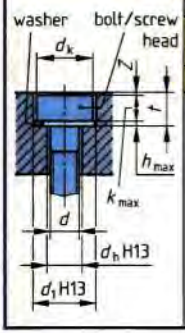
⇒ DIN 974 provides no code designations for counterbores.

Series 1: For socket wrench DIN 659, DIN 896, DIN 3112 or socket DIN 3124
Series 2: For box wrench DIN 838, DIN 897 or socket DIN 3129
Series 3: For recesses in tight space conditions (not suitable for conical spring washers)

Graphical representation, see page 83;

[1] For hexagon bolts/screws ISO 4014, ISO 4017, ISO 8765, ISO 8676 without washer components

## Calculation of counterbore depth for flush mounting (for DIN 974-1 and DIN 974-2)




**Determining the allowance *Z***

| Thread nominal ∅ $d$ | over 1 to 1.4 | over 1.4 to 6 | over 6 to 20 | over 20 to 27 | over 27 to 100 |
|---|---|---|---|---|---|
| Allowance $Z$ | 0.2 | 0.4 | 0.6 | 0.8 | 1.0 |

$t$ counterbore depth
$k_{max}$ maximum height of the screw/bolt head
$h_{max}$ maximum height of the washer component
$Z$ allowance based on thread nominal diameter (see table)

**Counterbore depth[1]**

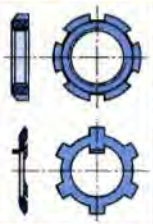
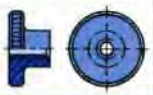
$$t = k_{max} + h_{max} + Z$$

[1] If values $k_{max}$ and $h_{max}$ are unavailable, values $k$ and $h$ can be used as approximations.

## Nuts – Overview

| Illustration | Design | Standard range from–to | Standard | Applications, properties |
|---|---|---|---|---|
| **Hexagon nuts, type 1** | | | | page 228 |
|  | with coarse threads | M1.6–M64 | DIN EN ISO 4032 | Most commonly used nuts, used with bolts up to equal property class<br>**Fine threads:** greater transmitted force than for coarse threads |
| | with fine threads | M8x1–M64x4 | DIN EN ISO 8673 | |
| **Hexagon nuts, type 2** | | | | page 229 |
|  | with coarse threads | M5–M36 | DIN EN ISO 4033 | Nut height *m* is approx. 10% higher than nuts of type 1, used with bolts up to equal property class<br>**Fine threads:** greater transmitted force than for coarse threads |
| | with fine threads | M8x1–M36x3 | DIN EN ISO 8674 | |
| **Low hexagon nuts** | | | | pages 229, 230 |
|  | with coarse threads | M1.6–M64 | DIN EN ISO 4035 | Use with low installation heights and low stresses<br>**Fine threads:** higher transmission of force than coarse threads |
| | with fine threads | M8x1–M64x4 | DIN EN ISO 8675 | |
| **Prevailing torque hexagon nuts with locking insert** | | | | page 230 |
|  | with coarse threads | M3–M36 | DIN EN ISO 7040 | Self-locking nuts with full loading capacity and non-metallic insert, up to operating temperatures of 120 °C<br>**Fine threads:** greater transmitted force than for coarse threads |
| | with fine threads | M8x1–M36x3 | DIN EN ISO 10512 | |
| | with coarse threads | M5–M36 | DIN EN ISO 7719 | Self-locking all-metal nuts with full loading capacity<br>**Fine threads:** greater transmitted force than for coarse threads |
| | with fine threads | M8x1–M36x3 | DIN EN ISO 10513 | |
| **Hexagon nuts, other forms** | | | | pages 230, 232 |
|  | with large width across flats, coarse threads | M12–M36 | DIN EN 14399-4 | Metal construction: high-strength custom preloaded joints (HV), with hexagon head bolts DIN EN 14999-4 (page 214) |
|  | with flange, coarse threads | M5–M20 | DIN EN 1661 | Might be used with large clearance holes or to reduce contact pressure |
|  | weld nuts, coarse threads | M3–M16<br>M8x1–M16x1.5 | DIN 929 | Used in sheet metal structures; nuts are usually joined to metal sheets by projection welding |
| **Castle nuts, cotter pins** | | | | page 232 |
|  | high form, coarse or fine threads | M4–M100<br>M8x1–M100x4 | DIN 935 | Might be used for axial fixing of bearings, hubs in safety joints (steering area of vehicles)<br>Locking with cotter pin and transverse hole in the bolt. At full load of the bolt, the cotter pin is sheared off above property class 8.8. |
| | low form, coarse or fine threads | M6–M48<br>M8x1–M48x3 | DIN 979 | |
|  | cotter pins | 0.6x12–20x280 | DIN EN ISO 1234 | |

# Nuts – Overview, Designation of nuts

| Illustration | Design | Standard range from–to | Standard | Application, properties |
|---|---|---|---|---|
| **Acorn nuts** | | | | page 231 |
|  | high form, coarse or fine threads | M4–M36<br>M8x1–M24x2 | DIN 1587 | Decorative and sealing external joint closures, protection for threads, protection from injuries |
| | low form, coarse or fine threads | M4–M48<br>M8x1–M48x3 | DIN 917 | |
| **Eye nuts, eye bolts** | | | | page 231 |
|  | eye nuts, coarse or fine threads | M8–M100x6<br>M20x2–<br>M100x4 | DIN 582 | Transport eyes on machines and equipment; stress depends on the angle of the applied load, milling of seating surface necessary |
| **Lock nuts, lock washers** | | | | page 231 |
|  | lock nuts with fine threads | M10x1–<br>M200x1.5 | DIN 70852 | For axial positioning, e.g. of hubs, with small mounting heights and low stresses, locking with lock washers |
| | lock washers | 10–200 | DIN 70952 | |
| | lock nuts with fine threads | M10x0.75–<br>M115x2<br>(KM0–KM23) | DIN 981 | For axial positioning of roller bearings, for adjustment of the bearing clearance, e.g. with tapered roller bearings that are locked with lock washers |
| | lock washers | 10–115<br>(MB0–MB23) | DIN 5406 | |
| **Knurled nuts** | | | | page 232 |
|  | high form, coarse threads | M1–M10 | DIN 466 | Used in joints that are opened frequently, e.g. in manufacturing of jigs and fixtures, in control cabinets |
| | low form, coarse threads | M1–M10 | DIN 467 | |
| **Hexagon turnbuckle nuts** | | | | |
|  | coarse threads | M6–M30 | DIN 1479 | For joining and adjusting, e.g. of threaded and connecting bars, with left-hand and right-hand threads; locked by jam nuts |

## Designation of nuts

cf. DIN 962 (2001-11)

**Examples:**

| | | | |
|---|---|---|---|
| **Hexagon nut** | **ISO 4032** | **– M12** | **– 8** |
| **Castle nut** | **DIN 929** | **– M8 x 1** | **– St** |
| **Hexagon nut** | **EN 1661** | **– M12** | **– 10** |

- Type
- Reference standard, e.g. ISO, DIN, EN; sheet number of the standard[1)]
- Nominal data, e.g.
  M → metric threads
  8 → nominal diameter *d*
  1 → thread pitch *P* for fine threads
- Property class, e.g. 05, 8, 10
  Material, e.g.: St steel
  GT malleable cast iron

[1)] Nuts standardized according to ISO or DIN EN ISO, have the code **ISO** in their designation.
Nuts standardized according to DIN, have the code **DIN** in their designation.
Nuts standardized according to DIN EN, have the code **EN** in their designation.

# Property classes, hexagon nuts with coarse threads

## Property classes of nuts

cf. DIN EN 20898-2 (1994-02), DIN EN ISO 3506-2 (1998-03)

**Examples:**

**Unalloyed and alloy steels** DIN EN 29898-2

nut height $m \geq 0.8 \cdot d$: **8**
nut height $m < 0.8 \cdot d$: **04**

**Stainless steels** DIN EN ISO 3506-2

nut height $m \geq 0.8 \cdot d$: **A 2 – 70**
nut height $m < 0.8 \cdot d$: **A 4 – 035**

| Code | Steel microstructure | Steel group | Code |
|---|---|---|---|
| 8 property class<br>04 low nuts, test load = 4 · 100 N/mm² | A austenitic<br>F ferritic | 1 free machining alloys<br>2 alloyed with Cr, Ni<br>4 alloyed with Cr, Ni, Mo | 70 proof stress = 70 · 10 N/mm²<br>035 low nut, proof stress = 35 · 10 N/mm² |

## Allowable combinations of nuts and bolts

cf. DIN EN 20898-2 (1994-02)




| Property class of the nut | Usable bolts up to property class | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Unalloyed and alloy steels | | | | | | | Stainless steels | | | |
| | 4.8 | 5.8 | 6.8 | 8.8 | 9.8 | 10.9 | 12.9 | A2-50 | A2-70 | A4-50 | A4-70 |
| 4 | | | | | | | | | | | |
| 5 | | | | | | | | | | | |
| 6 | | | | | | | | | | | |
| 8 | | | | | | | | | | | |
| 9 | | | | | | | | | | | |
| 10 | | | | | | | | | | | |
| 12 | | | | | | | | | | | |
| A2-50 | | | | | | | | | | | |
| A2-70 | | | | | | | | | | | |
| A4-50 | | | | | | | | | | | |
| A4-70 | | | | | | | | | | | |

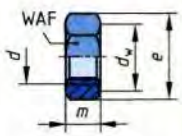
allowable combinations of property classes for nuts and bolts

| | |
|---|---|
| 04, 05, A2-025, A4-025 | Property classes for low nuts. The nuts are designed for smaller load capacity. Bolts and nuts of the same material group, e.g. stainless steel, can be combined with each other. |

## Hexagon nuts with coarse threads, Type [1]

cf. DIN EN ISO 4032 (2001-03)

| Valid standard DIN EN ISO | Replaces DIN EN | DIN |
|---|---|---|
| 4032 | 24032 | 934 |




| Thread $d$ | M1.6 | M2 | M2.5 | M3 | M4 | M5 | M6 | M8 | M10 |
|---|---|---|---|---|---|---|---|---|---|
| WAF | 3.2 | 4 | 5 | 5.5 | 7 | 8 | 10 | 13 | 16 |
| $d_w$ | 2.4 | 3.1 | 4.1 | 4.6 | 5.9 | 6.9 | 8.9 | 11.6 | 14.6 |
| $e$ | 3.4 | 4.3 | 5.5 | 6 | 7.7 | 8.8 | 11.1 | 14.4 | 17.8 |
| $m$ | 1.3 | 1.6 | 2 | 2.4 | 3.2 | 4.7 | 5.2 | 6.8 | 8.4 |
| Property classes | as per agreement | | | 6, 8, 10 | | | | | |
| | A2-70, A4-70 | | | | | | | | |

| Thread $d$ | M12 | M16 | M20 | M24 | M30 | M36 | M42 | M48 | M56 |
|---|---|---|---|---|---|---|---|---|---|
| WAF | 18 | 24 | 30 | 36 | 46 | 55 | 65 | 75 | 85 |
| $d_w$ | 16.6 | 22.5 | 27.7 | 33.3 | 42.8 | 51.1 | 60 | 69.5 | 78.7 |
| $e$ | 20 | 26.8 | 33 | 39.6 | 50.9 | 60.8 | 71.3 | 82.6 | 93.6 |
| $m$ | 10.8 | 14.8 | 18 | 21.5 | 25.6 | 31 | 34 | 38 | 45 |
| Property classes | 6, 8, 10 | | | | | | as per agreement | | |
| | A2-70, A4-70 | | | | A2-50, A4-50 | | – | | |

Product grades (page 211)

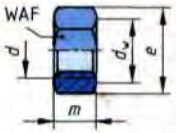
| Thread $d$ | Grade |
|---|---|
| M1.6–M16 | A |
| M20–M64 | B |

Explanation: [1] Type 1: Nut height $m \geq 0.8 \cdot d$

⇒ **Hexagon nut ISO 4032 – M10 – 10:** $d$ = M10, property class 10

# Hexagon nuts

## Hexagon nuts with coarse threads, type 2[1] cf. DIN EN ISO 4033 (2001-03), replaces DIN EN 24033

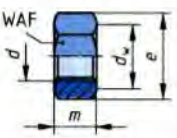



| Thread $d$ | M5 | M6 | M8 | M10 | M12 | M16 | M20 | M24 | M30 | M36 |
|---|---|---|---|---|---|---|---|---|---|---|
| WAF | 8 | 10 | 13 | 16 | 18 | 24 | 30 | 36 | 46 | 55 |
| $d_w$ | 6.9 | 8.9 | 11.6 | 14.8 | 14.6 | 22.5 | 27.7 | 33.2 | 42.7 | 51.1 |
| $e$ | 8.8 | 11.1 | 14.4 | 17.8 | 20 | 26.8 | 33 | 39.6 | 50.9 | 60.8 |
| $m$ | 5.1 | 5.7 | 7.5 | 9.3 | 12 | 16.4 | 20.3 | 23.9 | 28.6 | 34.7 |
| Property classes | 9, 12 | | | | | | | | | |
| Explanation | [1] Hexagon nuts of type 2 are approx. 10% higher than nuts of type 1. | | | | | | | | | |
| ⇒ | **Hexagon nut ISO 4033 – M24 – 9:** $d$ = M24, property class 9 | | | | | | | | | |

| Product grades (page 211) | |
|---|---|
| Thread $d$ | Grade |
| M1.6–M16 | A |
| M20–M64 | B |

## Hexagon nuts with fine threads, type 1 and type 2[1] cf. DIN EN ISO 8673 and 8674 (2001-03)

| Valid standard DIN EN ISO | Replaces DIN EN | Replaces DIN |
|---|---|---|
| 8673 | 28673 | 934 |
| 8674 | 28674 | 971 |

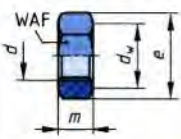



| Thread $d$ | M8 x1 | M10 x1 | M12 x1.5 | M16 x1.5 | M20 x1.5 | M24 x2 | M30 x2 | M36 x3 | M42 x3 | M48 x3 | M56 x4 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| WAF | 13 | 16 | 18 | 24 | 30 | 36 | 46 | 55 | 65 | 75 | 85 |
| $d_w$ | 11.6 | 14.6 | 16.6 | 22.5 | 27.7 | 33.3 | 42.8 | 51.1 | 60 | 69.5 | 78.6 |
| $e$ | 14.4 | 17.8 | 20 | 26.8 | 33 | 39.6 | 50.9 | 60.8 | 71.3 | 82.6 | 93.6 |
| $m_1$[1] | 6.8 | 8.4 | 10.8 | 14.8 | 18 | 21.5 | 25.6 | 31 | 34 | 38 | 45 |
| $m_2$[1] | 7.5 | 9.3 | 12 | 16.4 | 20.3 | 23.9 | 28.6 | 34.7 | – | – | – |
| Property classes Type 1 | 6, 8 | | | | | | | | as per agreement | | |
| Property classes Type 1 | A2-70, A4-70 | | | | | | | A2-50, A4-50 | | | |
| Property classes Type 2 | 8, 10, 12 | | | | | 10 | | | – | | |
| Explanation | [1] Hexagon nut type 1: DIN EN ISO 8673, nut height $m_1 \geq 0.8 \cdot d$<br>Hexagon nut type 2: DIN EN ISO 8674, nut height $m_2$ is approx. 10% larger than nuts of type 1. | | | | | | | | | | |
| ⇒ | **Hexagon nut ISO 8673 – M8x1 – 6:** $d$ = M8x1, property class 6 | | | | | | | | | | |

| Product grades (page 211) | |
|---|---|
| Thread $d$ | Grade |
| M8x1–M16x1.5 | A |
| M20x1.5–M64x3 | B |

## Low hexagon nuts with coarse threads[1] cf. DIN EN ISO 4035 (2001-03)

| Valid standard DIN EN ISO | Replaces DIN EN |
|---|---|
| 4035 | 24035 |




| Thread $d$ | M1.6 | M2 | M2.5 | M3 | M4 | M5 | M6 | M8 | M10 |
|---|---|---|---|---|---|---|---|---|---|
| WAF | 3.2 | 4 | 5 | 5.5 | 7 | 8 | 10 | 13 | 16 |
| $d_w$ | 2.4 | 3.1 | 4.1 | 4.6 | 5.9 | 6.9 | 8.9 | 11.6 | 14.6 |
| $e$ | 3.4 | 4.3 | 5.5 | 6 | 7.7 | 8.8 | 11.1 | 14.4 | 17.8 |
| $m$ | 1 | 1.2 | 1.6 | 1.8 | 2.2 | 2.7 | 3.2 | 4 | 5 |
| Property classes | as per agreement | | | 04, 05 | | | | | |
| Property classes | A2-035, A4-035 | | | | | | | | |

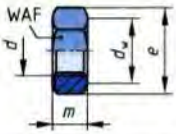
| Thread $d$ | M12 | M16 | M20 | M24 | M30 | M36 | M42 | M48 | M56 |
|---|---|---|---|---|---|---|---|---|---|
| WAF | 18 | 24 | 30 | 36 | 46 | 55 | 65 | 75 | 85 |
| $d_w$ | 16.6 | 22.5 | 27.7 | 33.2 | 42.8 | 51.1 | 60 | 69.5 | 78.7 |
| $e$ | 20 | 26.8 | 33 | 39.6 | 50.9 | 60.8 | 71.3 | 82.6 | 93.6 |
| $m$ | 6 | 8 | 10 | 12 | 15 | 18 | 21 | 24 | 28 |
| Property classes | 04, 05 | | | | | | as per agreement | | |
| Property classes | A2-035, A4-035 | | | | A2-025, A4-025 | | – | | |
| Explanation | [1] Low hexagon nuts (nut height $m < 0.8 \cdot d$) have a smaller load capacity as type 1 nuts. | | | | | | | | |
| ⇒ | **Hexagon nut ISO 4035 – M16 – A2-035:** $d$ = M16, property class A2-035 | | | | | | | | |

| Product grades (page 211) | |
|---|---|
| Thread $d$ | Grade |
| M1.6–M16 | A |
| M20–M36 | B |

# Hexagon nuts

## Low hexagon nuts with fine threads[1] cf. DIN EN ISO 8675 (2001-03)

| Valid standard DIN EN ISO | Replaces DIN EN |
|---|---|
| 8675 | 28675 |




| Product grades (page 211) | |
|---|---|
| Thread *d* | Grade |
| M8x1–M16x1.5 | A |
| M20x1.5–M64x3 | B |

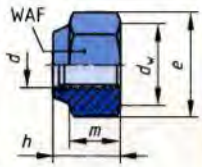
| Thread *d* | M8 x1 | M10 x1 | M12 x1.5 | M16 x1.5 | M20 x1.5 | M24 x2 | M30 x2 | M36 x3 | M42 x3 | M48 x4 | M56 x4 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| WAF | 13 | 16 | 18 | 24 | 30 | 36 | 46 | 55 | 65 | 75 | 85 |
| $d_w$ | 11.6 | 14.6 | 16.6 | 22.5 | 27.7 | 33.3 | 42.8 | 51.1 | 60 | 69.5 | 76.7 |
| *e* | 14.4 | 17.8 | 20 | 26.8 | 33 | 39.6 | 50.9 | 60.8 | 71.3 | 82.6 | 93.6 |
| *m* | 4 | 5 | 6 | 8 | 10 | 12 | 15 | 18 | 21 | 24 | 28 |
| Property classes | 04, 05 | | | | | | | | as per agreement | | |
| | A2-035, A4-035 | | | | | | [2] | | | | |

Explanations
[1] Low hexagon nuts (nut height $m < 0.8 \cdot d$) have a smaller load capacity of type 1 nuts (page 229).
[2] Property classes for stainless steels: A2-025, A4-025

⇒ **Hexagon nut ISO 8675 – M20x1.5 – A2-035:** *d* = M20x1.5, property class A2-035

## Hexagon nuts with insert, type 1[1] cf. DIN EN ISO 7040 and 10512 (2001-03)

| Valid standard DIN EN ISO | Replaces DIN EN | DIN |
|---|---|---|
| 7040 | 27040 | 982 |
| 10512 | | |



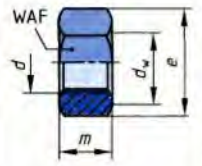

Product grades see DIN EN ISO 4032

| Thread *d* | M4 – | M5 – | M6 – | M8 M8 x1 | M10 M10 x1 | M12 M12 x1.5 | M16 M16 x1.5 | M20 M20 x1.5 | M24 M24 x2 | M30 M30 x2 | M36 M36 x3 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| WAF | 7 | 8 | 10 | 13 | 16 | 18 | 24 | 30 | 36 | 46 | 55 |
| $d_w$ | 5.9 | 8.9 | 8.9 | 11.6 | 14.6 | 16.6 | 22.5 | 27.7 | 33.3 | 42.8 | 51.1 |
| *e* | 7.7 | 8.8 | 11.1 | 14.4 | 17.8 | 20 | 26.8 | 33 | 39.6 | 50.9 | 60.8 |
| *h* | 6 | 6.8 | 8 | 9.5 | 11.9 | 14.9 | 19.1 | 22.8 | 27.1 | 32.6 | 38.9 |
| *m* | 2.9 | 4.4 | 4.9 | 6.4 | 8 | 10.4 | 14.1 | 16.9 | 20.2 | 24.3 | 29.4 |
| Property cl. | for DIN EN ISO 7040: 5, 8, 10 for DIN EN ISO 10512: 6, 8, 10 | | | | | | | | | | |

Explanation
[1] Hexagon nuts type 1 (nut height $m \geq 0.8 \cdot d$)
DIN EN ISO 7040: Nuts with coarse threads
DIN EN ISO 10512: Nuts with fine threads

⇒ **Hexagon nut ISO 7040 – M16-10:** *d* = M10, property class 10

## Hexagon nuts with large width across flats[1] cf. DIN EN 14399-4 (2006-06), replaces DIN 6915



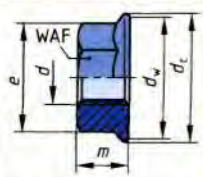

Product grade B

| Thread *d* | M12 | M16 | M20 | M22 | M24 | M27 | M30 | M36 |
|---|---|---|---|---|---|---|---|---|
| WAF | 22 | 27 | 32 | 36 | 41 | 46 | 50 | 60 |
| $d_w$ | 20.1 | 24.9 | 29.5 | 33.3 | 38 | 42.8 | 46.6 | 55.9 |
| *e* | 23.9 | 29.6 | 35 | 39.6 | 45.2 | 50.9 | 55.4 | 66.4 |
| *m* | 10 | 13 | 16 | 18 | 20 | 22 | 24 | 29 |
| Property cl., surface | 10 normal –> lightly oiled, hot-galvanized –> code: tZn | | | | | | | |

Explanation
[1] for high-strength structural bolting assemblies (HV) in metal construction. Used in combination with hexagon head bolts as per DIN EN 14399-4 (page 214).

⇒ **Hexagon nut DIN EN 14399-4 – M16 – 10 – HV:** *d* = M24, property class 10, high-strength preloaded

## Hexagon nuts with flange cf. DIN EN 1661 (1998-02)




Product grades see DIN EN ISO 4032

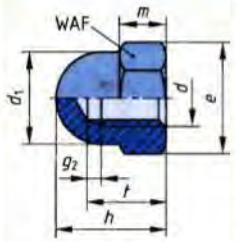
| Thread *d* | M5 | M6 | M8 | M10 | M12 | M16 | M20 |
|---|---|---|---|---|---|---|---|
| WAF | 8 | 10 | 13 | 16 | 18 | 24 | 30 |
| $d_w$ | 9.8 | 12.2 | 15.8 | 19.6 | 23.8 | 31.9 | 39.9 |
| $d_c$ | 11.8 | 14.2 | 17.9 | 21.8 | 26 | 34.5 | 42.8 |
| *e* | 8.8 | 11.1 | 14.4 | 17.8 | 20 | 26.8 | 33 |
| *m* | 5 | 6 | 8 | 10 | 12 | 16 | 20 |
| Property classes | 8, 10, A2-70 | | | | | | |

⇒ **Hexagon nut EN 1661 – M16-8:** *d* = M16, property class 8

# Hexagon acorn nuts, Lock nuts, Eye nuts

## Hexagon acorn nuts, high form

cf. DIN 1587 (2000-10)

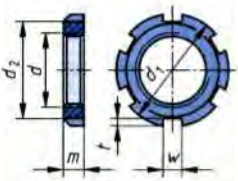



Product grade A or B by choice of manufacturer

| Thread $d$ | M4 – | M5 – | M6 – | M8 M8 x1 | M10 M10 x1 | M12 M12 x1.5 | M16 M16 x1.5 | M20 M20 x2 | M24 M24 x2 |
|---|---|---|---|---|---|---|---|---|---|
| WAF | 7 | 8 | 10 | 13 | 16 | 18 | 24 | 30 | 36 |
| $d_1$ | 6.5 | 7.5 | 9.5 | 12.5 | 15 | 17 | 23 | 28 | 34 |
| $m$ | 3.2 | 4 | 5 | 6.5 | 8 | 10 | 13 | 16 | 19 |
| $e$ | 7.7 | 8.8 | 11.1 | 14.4 | 17.8 | 20 | 26.8 | 33.5 | 40 |
| $h$ | 8 | 10 | 12 | 15 | 18 | 22 | 28 | 34 | 42 |
| $t$ | 5.3 | 7.2 | 7.8 | 10.7 | 13.3 | 16.3 | 20.6 | 25.6 | 30.5 |
| $g_2$ | $g \approx 2 \cdot P$ ($P$ thread pitch) | | | | | Thread undercut DIN 76-D | | | |
| Property classes | 6, A1-50 | | | | | | | | |
| ⇒ | **Acorn nut DIN 1587 – M20 – 6:** $d$ = M20, property class 6 | | | | | | | | |

## Lock nuts

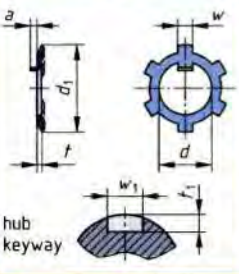
cf. DIN 70852 (1989-03)




| Thread $d$ | M12 x1.5 | M16 x1.5 | M20 x1.5 | M24 x1.5 | M30 x1.5 | M35 x1.5 | M40 x1.5 | M48 x1.5 | M55 x1.5 | M60 x1.5 | M65 x1.5 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $d_1$ | 22 | 28 | 32 | 38 | 44 | 50 | 56 | 65 | 75 | 80 | 85 |
| $d_2$ | 18 | 23 | 27 | 32 | 38 | 43 | 49 | 57 | 67 | 71 | 76 |
| $m$ | 6 | 6 | 6 | 7 | 7 | 8 | 8 | 8 | 8 | 9 | 9 |
| $w$ | 4.5 | 5.5 | 5.5 | 6.5 | 6.5 | 7 | 7 | 8 | 8 | 11 | 11 |
| $t$ | 1.8 | 2.3 | 2.3 | 2.8 | 2.8 | 3.3 | 3.3 | 3.8 | 3.8 | 4.3 | 4.3 |
| Material | St (steel) | | | | | | | | | | |
| ⇒ | **Lock nut DIN 70852 – M16x1.5 – St:** $d$ = M16x1.5, material steel | | | | | | | | | | |

## Lock washers

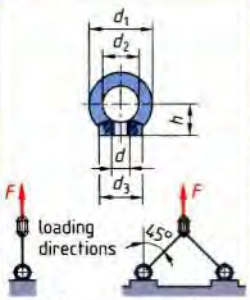
cf. DIN 70952 (1976-05)




| $d$ | 12 | 16 | 20 | 24 | 30 | 35 | 40 | 48 | 55 | 60 | 65 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $d_1$ | 24 | 29 | 35 | 40 | 48 | 53 | 59 | 67 | 79 | 83 | 88 |
| $t$ | 0.75 | 1 | 1 | 1 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.5 | 1.5 |
| $a$ | 3 | 3 | 4 | 4 | 5 | 5 | 5 | 5 | 6 | 6 | 6 |
| $w$ | 4 | 5 | 5 | 6 | 7 | 7 | 8 | 8 | 10 | 10 | 10 |
| $w_1$ C11 | 4 | 5 | 5 | 6 | 7 | 7 | 8 | 8 | 10 | 10 | 10 |
| $t_1$ | 1.2 | 1.2 | 1.2 | 1.2 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 2 | 2 |
| Material | St (steel sheet) | | | | | | | | | | |
| ⇒ | **Lock washer DIN 70952-16 – St:** $d$ = 16 mm, material steel | | | | | | | | | | |

## Eye nuts

cf. DIN 582 (2003-08)

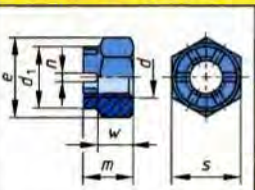



| Thread $d$ | M8 | M10 | M12 | M16 | M20 | M24 | M30 | M36 | M42 | M48 | M56 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $h$ | 18 | 22.5 | 26 | 30.5 | 35 | 45 | 55 | 65 | 75 | 85 | 95 |
| $d_1$ | 36 | 45 | 54 | 63 | 72 | 90 | 108 | 126 | 144 | 166 | 184 |
| $d_2$ | 20 | 25 | 30 | 35 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
| $d_3$ | 20 | 25 | 30 | 35 | 40 | 50 | 65 | 75 | 85 | 100 | 110 |
| | Load capacity[1] in t for direction of load application | | | | | | | | | | |
| Vertical | 0.14 | 0.23 | 0.34 | 0.70 | 1.20 | 1.80 | 3.20 | 4.60 | 6.30 | 8.60 | 11.5 |
| under 45° | 0.10 | 0.17 | 0.24 | 0.50 | 0.86 | 1.29 | 2.30 | 3.30 | 4.50 | 6.10 | 8.20 |
| Materials | Case hardened steel C15, A2, A3, A4, A5 | | | | | | | | | | |
| Explanation | [1] The values include a safety factor $\nu$ = 6, based on the ultimate load. | | | | | | | | | | |
| ⇒ | **Eye nut DIN 582 – M36 – C15E:** $d$ = M36x3, material C15E | | | | | | | | | | |

# Castle nuts, Cotter pins, Weld nuts, Knurled nuts

## Castle nuts, high form

cf. DIN 935-1 (2000-10)



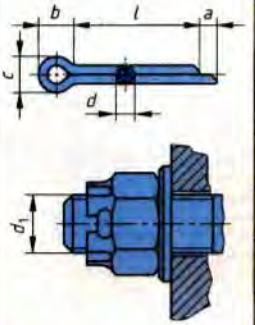

Product grades (page 211)

| Thread $d$ | Grade |
|---|---|
| M1.6–M16 | A |
| M20–M100 | B |

| Thread $d$ | M4 – | M5 – | M6 – | M8 M8 x1 | M10 M10 x1 | M12 M12 x1.5 | M16 M16 x1.5 | M20 M20 x2 | M24 M24 x2 | M30 M30 x2 |
|---|---|---|---|---|---|---|---|---|---|---|
| $s$ | 7 | 8 | 10 | 13 | 16 | 18 | 24 | 30 | 36 | 46 |
| $e$ | 7.7 | 8.8 | 11.1 | 14.4 | 17.8 | 20 | 26.8 | 33 | 39.6 | 50.9 |
| $m$ | 5 | 6 | 7.5 | 9.5 | 12 | 15 | 19 | 22 | 27 | 33 |
| $d_1$ | no cylindrical shoulder | | | | | 15.6 | 21.5 | 27.7 | 33.2 | 42.7 |
| $n$ | 1.2 | 1.4 | 2 | 2.5 | 2.8 | 3.5 | 4.5 | 4.5 | 5.5 | 7 |
| $w$ | 3.2 | 4 | 5 | 6.5 | 8 | 10 | 13 | 16 | 19 | 24 |
| Property classes | 6, 8, 10 | | | | | | | | | |
| | A2-70 | | | | | | | | A2-50 | |
| ⇒ | **Castle nut DIN 935 – M20 – 8:** $d$ = M20, property class 8 | | | | | | | | | |

## Cotter pins

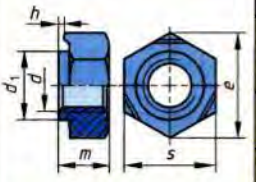
cf. DIN EN ISO 1234 (1998-02)




| $d$[1] | 1 | 1.2 | 1.6 | 2 | 2.5 | 3.2 | 4 | 5 | 6.3 | 8 |
|---|---|---|---|---|---|---|---|---|---|---|
| $b$ | 3 | 3 | 3.2 | 4 | 5 | 6.4 | 8 | 10 | 12.6 | 16 |
| $c$ | 1.6 | 2 | 2.8 | 3.6 | 4.6 | 5.8 | 7.4 | 9.2 | 11.8 | 15 |
| $a$ | 1.6 | 2.5 | 2.5 | 2.5 | 2.5 | 3.2 | 4 | 4 | 4 | 4 |
| $l$ from | 6 | 8 | 8 | 10 | 12 | 14 | 18 | 22 | 28 | 36 |
| $l$ to | 20 | 25 | 32 | 40 | 50 | 63 | 80 | 100 | 125 | 160 |
| $d_1$[2] over | 3.5 | 4.5 | 5.5 | 7 | 9 | 11 | 14 | 20 | 27 | 39 |
| $d_1$[2] to | 4.5 | 5.5 | 7 | 9 | 11 | 14 | 20 | 27 | 39 | 56 |
| Nominal lengths | 6, 8, 10, 12, 14, 16, 18, 20, 22, 25, 28, 32, 36, 40, 45, 50, 56, 63, 71, 80, 90, 100, 112, 125, 140, 160 mm | | | | | | | | | |
| Explanations | [1] $d$ Nominal sizes = cotter pin hole diameter<br>[2] $d_1$ applicable bolt diameter | | | | | | | | | |
| ⇒ | **Cotter pin ISO 1234 – 2.5x32 – St:**<br>$d$ = 2.5 mm, $l$ = 32 mm, material steel | | | | | | | | | |

## Hexagon weld nuts

cf. DIN 929 (2000-01)

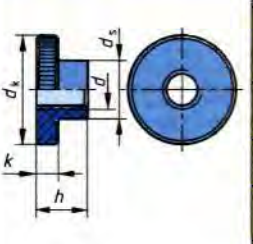



Product grade A

| Thread $d$ | M3 | M4 | M5 | M6 | M8 | M10 | M12 | M16 |
|---|---|---|---|---|---|---|---|---|
| $s$ | 7.5 | 9 | 10 | 11 | 14 | 17 | 19 | 24 |
| $d_1$ | 4.5 | 6 | 7 | 8 | 10.5 | 12.5 | 14.8 | 18.8 |
| $e$ | 8.2 | 9.8 | 11 | 12 | 15.4 | 18.7 | 20.9 | 26.5 |
| $m$ | 3 | 3.5 | 4 | 5 | 6.5 | 8 | 10 | 13 |
| $h$ | 0.3 | 0.3 | 0.3 | 0.4 | 0.4 | 0.5 | 0.6 | 0.8 |
| Material | St – steel with a maximum carbon content of 0.25% | | | | | | | |
| ⇒ | **Weld nut DIN 929 – M16 – St:** $d$ = M16, material steel | | | | | | | |

## Knurled nuts

cf. DIN 466 and 467 (2006-08)




| Thread $d$ | M1.2 | M1.6 | M2 | M2.5 | M3 | M4 | M5 | M6 | M8 | M10 |
|---|---|---|---|---|---|---|---|---|---|---|
| $d_k$ | 6 | 7.5 | 9 | 11 | 12 | 16 | 20 | 24 | 30 | 36 |
| $d_s$ | 3 | 3.8 | 4.5 | 5 | 6 | 8 | 10 | 12 | 16 | 20 |
| $k$ | 1.5 | 2 | 2 | 2.5 | 2.5 | 3.5 | 4 | 5 | 6 | 8 |
| $h$[1] | 4 | 5 | 5.3 | 6.5 | 7.5 | 9.5 | 11.5 | 15 | 18 | 23 |
| $h$[2] | 2 | 2.5 | 2.5 | 3 | 3 | 4 | 5 | 6 | 8 | 10 |
| Property classes | St (steel), A1-50 | | | | | | | | | |
| Explanations | [1] Nut height for DIN 466 high form<br>[2] Nut height for DIN 467 low form | | | | | | | | | |
| ⇒ | **Knurled nut DIN 467 – M6 – A1-50:** $d$ = M6, property class A1-50 | | | | | | | | | |

# Flat washers, Overview

**Designation example:** Washer ISO 7090 – 8 – 300 HV – A2[1]

| Name | Standard | Nominal size (Thread nominal ∅) | Hardness grade | Material |
|---|---|---|---|---|
| Washer | ISO 7090 | 8 | 300 HV | A2[1] |

[1] Stainless steel, steel group A2

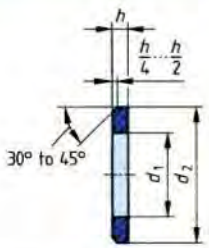
## Overview

| Illustration | Design Standard range from–to | M[1] | Standard | Illustration | Design Standard range from–to | M[1] | Standard |
|---|---|---|---|---|---|---|---|
|  | Flat washers with chamfer Product grade A[2] M5–M64 table below | Steel, stainless steel | DIN EN ISO 7090 |  | Flat washers with chamfer, for HV bolts M12–M30 page 235 | Steel | DIN EN 14399-6 |
|  | Flat washers small series Product grade A[2] M1.6–M36 page 234 | Steel, stainless steel | DIN EN ISO 7092 |  | Washers, square, for channels and *I* beams M8–M27 page 235 | Steel | DIN 434 DIN 435 |
|  | Flat washers normal series Product grade C[2] M1.6–M64 page 234 | Steel | DIN EN ISO 7091 |  | Plain washers for clevis pins Product grade A[2] $d$ = 3–100 mm page 235 | Steel | DIN EN 28738 |
|  | Washers for steel structures Product grade A[2], C[2] M10–M30 page 234 | Steel | DIN 7989-1 |  | Conical spring washers for screw joints $d$ = 2–30 mm page 235 | Spring steel | DIN 6796 |

[1] Material is steel with corresponding hardness grade (e. g. 200 HV; 300 HV); other materials as agreed upon.
[2] Product grades are differentiated by tolerance and by manufacturing process.

## Flat washers with chamfer, normal series

cf. DIN EN ISO 7090 (2000-11), replaces for DIN 125-1+2




| For threads | M5 | M6 | M8 | M10 | M12 | M16 | M20 |
|---|---|---|---|---|---|---|---|
| Nominal size | 5 | 6 | 8 | 10 | 12 | 16 | 20 |
| $d_1$ min.[1] | 5.3 | 6.4 | 8.4 | 10.5 | 13.0 | 17.0 | 21.0 |
| $d_2$ max.[1] | 10.0 | 12.0 | 16.0 | 20.0 | 24.0 | 30.0 | 37.0 |
| $h$[1] | 1 | 1.6 | 1.6 | 2 | 2.5 | 3 | 3 |
| **For threads** | **M24** | **M30** | **M36** | **M42** | **M48** | **M56** | **M64** |
| Nominal size | 24 | 30 | 36 | 42 | 48 | 56 | 64 |
| $d_1$ min.[1] | 25.0 | 31.0 | 37.0 | 45.0 | 52.0 | 62.0 | 70.0 |
| $d_2$ max.[1] | 44.0 | 56.0 | 66.0 | 78.0 | 92.0 | 105.0 | 115.0 |
| $h$[1] | 4 | 4 | 5 | 8 | 8 | 10 | 10 |

| Material[2] | Steel | | Stainless steel |
|---|---|---|---|
| Type | – | – | A2, A4, F1, C1, C4 (ISO 3506)[3] |
| Hardness grade | 200 HV | 300 HV (quenched and tempered) | 200 HV |
| ⇒ | **Washer ISO 7090-20-200 HV:** Nominal size (= thread nominal ∅) = 20 mm, hardness grade 200 HV, steel | | |

**Hardness grade 200 HV suitable for:**
- Hexagon bolts and nuts of property classes ≤ 8.8 or ≤ 8 (nut)
- Hexagon bolts and nuts made of stainless steel

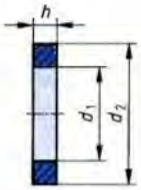
**Hardness grade 300 HV suitable for:**
- Hexagon bolts and nuts of property classes ≤ 10.9 or ≤ 10 (nut)

[1] These are all nominal dimensions
[2] Non-ferrous metals and other materials as per agreement
[3] Compare to page 211

# Flat washers, Washers for steel structures

## Flat washers, small series

cf. DIN EN ISO 7092 (2000-11), replaces DIN 433-1+2




| For threads | M1.6 | M2 | M2.5 | M3 | M4 | M5 | M6 | M8 |
|---|---|---|---|---|---|---|---|---|
| Nominal size | 1.6 | 2 | 2.5 | 3 | 4 | 5 | 6 | 8 |
| $d_1$ min.[1] | 1.7 | 2.2 | 2.7 | 3.2 | 4.3 | 5.3 | 6.4 | 8.4 |
| $d_2$ max.[1] | 3.5 | 4.5 | 5 | 6 | 8 | 9 | 11 | 15 |
| $h_{max}$ | 0.35 | 0.35 | 0.55 | 0.55 | 0.55 | 1.1 | 1.8 | 1.8 |

| For threads | M10 | M12 | M14[2] | M16 | M20 | M24 | M30 | M36 |
|---|---|---|---|---|---|---|---|---|
| Nominal size | 10 | 12 | 14 | 16 | 20 | 24 | 30 | 36 |
| $d_1$ min.[1] | 10.5 | 13.0 | 15.0 | 17.0 | 21.0 | 25.0 | 31.0 | 37.0 |
| $d_2$ max.[1] | 18.0 | 20.0 | 24.0 | 28.0 | 34.0 | 39.0 | 50.0 | 60.0 |
| $h_{max}$ | 1.8 | 2.2 | 2.7 | 2.7 | 3.3 | 4.3 | 4.3 | 5.6 |

| Material[3] | Steel | | Stainless steel |
|---|---|---|---|
| Type | – | – | A2, A4, F1, C1, C4 (ISO 3506)[4] |
| Hardness grade | 200 HV | 300 HV (quenched and tempered) | 200 HV |
| ⇒ | **Washer ISO 7092-8-200 HV-A2:** Nominal size (= thread nominal ∅) = 8 mm, small series, hardness grade 200 HV, of stainless steel A2 | | |

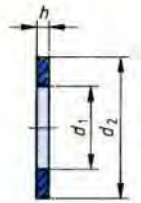
**Hardness grade 200 HV suitable for:**
- Cap screws with property classes ≤ 8.8 or of stainless steel
- Cap screws with hexagon socket and property classes ≤ 8.8 or of stainless steel

**Hardness grade 300 HV suitable for:**
- Cap screws with hexagon socket and property classes ≤ 10.9

1) These are all nominal dimensions
2) Avoid this size if at all possible
3) Non-ferrous metals and other materials as per agreement
4) Compare to page 211

## Flat washers, normal series

cf. DIN EN ISO 7091 (2000-11), replaces DIN 126




| For threads | M2 | M3 | M4 | M5 | M6 | M8 | M10 | M12 |
|---|---|---|---|---|---|---|---|---|
| Nominal size | 2 | 3 | 4 | 5 | 6 | 8 | 10 | 12 |
| $d_1$ min.[1] | 2.4 | 3.4 | 4.5 | 5.5 | 6.6 | 9.0 | 11.0 | 13.5 |
| $d_2$ max.[1] | 5.0 | 7.0 | 9.0 | 10.0 | 12.0 | 16.0 | 20.0 | 24.0 |
| $h$[1] | 0.3 | 0.5 | 0.8 | 1.0 | 1.6 | 1.6 | 2 | 2.5 |

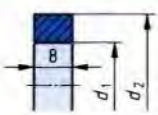
| For threads | M16 | M20 | M24 | M30 | M36 | M42 | M48 | M64 |
|---|---|---|---|---|---|---|---|---|
| Nominal size | 16 | 20 | 24 | 30 | 36 | 42 | 48 | 64 |
| $d_1$ min.[1] | 17.5 | 22.0 | 26.0 | 33.0 | 39.0 | 45.0 | 52.0 | 70.0 |
| $d_2$ max.[1] | 30.0 | 37.0 | 44.0 | 56.0 | 66.0 | 78.0 | 92.0 | 115.0 |
| $h$[1] | 3 | 3 | 4 | 4 | 5 | 8 | 8 | 10 |
| ⇒ | **Washer ISO 7091-12-100 HV:** Nominal size (= thread nominal ∅), $d$ = 12 mm, hardness grade 100 HV | | | | | | | |

**Hardness grade 100 HV suitable for:**
- Hexagon bolts/screws, product grade C, with property classes ≤ 6.8
- Hexagon nuts, product grade C, with property classes ≤ 6

1) These are all nominal dimensions

## Washers for steel structures

cf. DIN 7989-1 and DIN 7989-2 (2000-04)




| For threads[1] | M10 | M12 | M16 | M20 | M24 | M27 | M30 |
|---|---|---|---|---|---|---|---|
| $d_1$ min. | 11.0 | 13.5 | 17.5 | 22.0 | 26.0 | 30.0 | 33.0 |
| $d_2$ max. | 20.0 | 24.0 | 30.0 | 37.0 | 44.0 | 50.0 | 56.0 |
| ⇒ | **Washer DIN 7989-16-C-100 HV:** Thread nominal ∅ $d$ = 16 mm, product grade C, hardness grade 100 | | | | | | |

Suitable for bolts according to DIN 7968, DIN 7969, DIN 7990 joined with nuts according to ISO 4032 and ISO 4034.

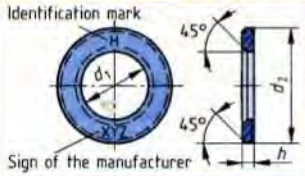
Versions: Product grade C (stamped version) thickness $h$ = (8 ± 1.2) mm
Product grade A (turned version) thickness $h$ = (8 ± 1) mm

1) Nominal dimensions

# Washers for HV bolts, Channels and I beams, Clevis pins, Conical spring washers

## Flat washers with chamfer for HV screw joints

cf. DIN EN 14399-6 (2006-06)

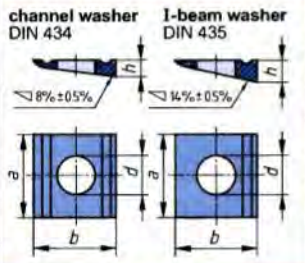



| For threads | M12 | M16 | M20 | M22 | M24 | M27 | M30 |
|---|---|---|---|---|---|---|---|
| $d_1$ min. | 13 | 17 | 21 | 23 | 25 | 28 | 31 |
| $d_2$ max. | 24 | 30 | 37 | 39 | 44 | 50 | 56 |
| $h$ | 3 | 4 | 4 | 4 | 4 | 5 | 5 |
| ⇒ | **Washer DIN EN 14399-6 – 20:** Nominal size $d$ = 20 mm (the nominal size $d$ corresponds to thread diameter) | | | | | | |

**Material:** steel, quenched and tempered to 300 HV–370 HV.

## Square, tapered washers for channels and I beams

cf. DIN 434 (2000-04), DIN 435 (2000-01)



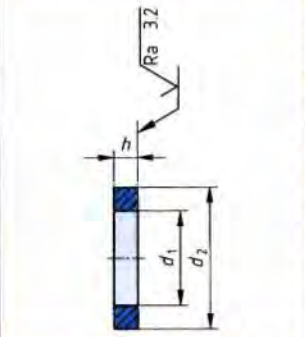

| For threads | M8 | M10 | M12 | M16 | M20 | M22 | M24 |
|---|---|---|---|---|---|---|---|
| $d_1$ min.[1] | 9 | 11 | 13.5 | 17.5 | 22 | 24 | 26 |
| $a$ | 22 | 22 | 26 | 32 | 40 | 44 | 56 |
| $b$ | 22 | 22 | 30 | 36 | 44 | 50 | 56 |
| $h$ DIN 434 | 3.8 | 3.8 | 4.9 | 5.8 | 7 | 8 | 8.5 |
| $h$ DIN 435 | 4.6 | 4.6 | 6.2 | 7.5 | 9.2 | 10 | 10.8 |
| ⇒ | **I-Washer DIN 435-13.5:** Nominal sizes $d_1$ = 13.5 mm | | | | | | |

**Material:** Steel, hardness 100 HV 10 to 250 HV 10

[1] Nominal diameter

## Washers for clevis pins, product grade A[1]

cf. DIN EN 28738 (1992-10)




| $d_1$ min.[2] | 3 | 4 | 5 | 6 | 8 | 10 | 12 |
|---|---|---|---|---|---|---|---|
| $d_2$ max. | 6 | 8 | 10 | 12 | 15 | 18 | 20 |
| $h$ | 0.8 | | 1 | 1.6 | 2 | 2.5 | 3 |
| $d_1$ min.[2] | 14 | 16 | 18 | 20 | 22 | 24 | 27 |
| $d_2$ max. | 22 | 24 | 28 | 30 | 34 | 37 | 39 |
| $h$ | 3 | | | 4 | | | 5 |
| $d_1$ min.[2] | 30 | 36 | 40 | 50 | 60 | 80 | 100 |
| $d_2$ max. | 44 | 50 | 56 | 66 | 78 | 98 | 120 |
| $h$ | 5 | 6 | | 8 | 10 | 12 | |
| ⇒ | **Washer ISO 8738-14-160 HV:** $d_1$ min. = 14 mm, hardness grade 160 HV | | | | | | |

**Material:** Steel, hardness 160 to 250 HV

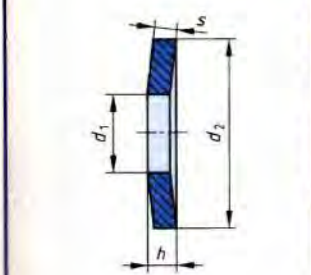
**Application:** For clevis pins according to ISO 2340 and ISO 2341 (page 238), used only on the cotter pin end.

[1] Product grades are differentiated by tolerance and manufacturing process

[2] nominal dimensions

## Conical spring washers for screw joints

cf. DIN 6796 (1987-10)




| For threads | M2 | M3 | M4 | M5 | M6 | M8 | M10 |
|---|---|---|---|---|---|---|---|
| $d_1$ H14 | 2.2 | 3.2 | 4.3 | 5.3 | 6.4 | 8.4 | 10.5 |
| $d_2$ h14 | 5 | 7 | 9 | 11 | 14 | 18 | 23 |
| $h$ max. | 0.6 | 0.85 | 1.3 | 1.55 | 2 | 2.6 | 3.2 |
| $s$ | 0.4 | 0.6 | 1 | 1.2 | 1.5 | 2 | 2.5 |
| **For threads** | **M12** | **M16** | **M20** | **M22** | **M24** | **M27** | **M30** |
| $d_1$ H14 | 13 | 17 | 21 | 23 | 25 | 28 | 31 |
| $d_2$ h14 | 29 | 39 | 45 | 49 | 56 | 60 | 70 |
| $h$ max. | 3.95 | 5.25 | 6.4 | 7.05 | 7.75 | 8.35 | 9.2 |
| $s$ | 3 | 4 | 5 | 5.5 | 6 | 6.5 | 7 |
| ⇒ | **Conical spring washer DIN 6796-10-FSt:** for threads M10, of spring steel | | | | | | |

**Material:** Spring steel (FSt) according to DIN 267-26

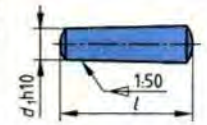
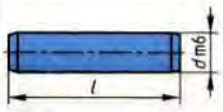
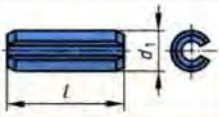
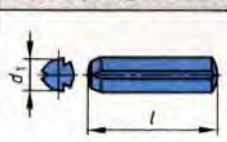
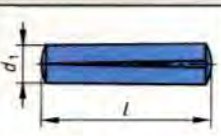
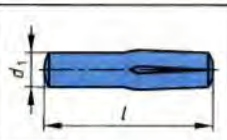
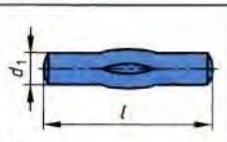
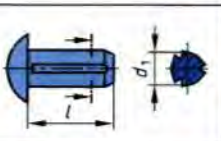
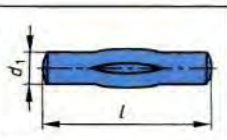
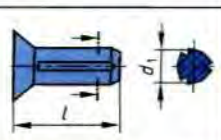
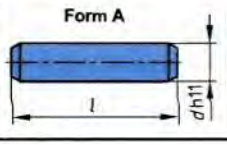
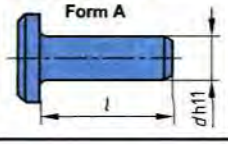
**Application:** Conical spring washers should counteract loosening of the screw joints. This does not apply to alternating transverse loads. Its application is therefore limited to predominantly axially loaded, short bolts/screws of property classes 8.8 to 10.9.

# Pins and clevis pins, Overview

**Designation example:** Taper pin ISO 2339 – A – 10x40 – St

| Name | Standard | Form or Type[1] | Nominal Ø x nominal length | Material |
|---|---|---|---|---|
| | | | | e.g. St = steel<br>Stainless steels:<br>A1 = austenitic<br>C1 = martensitic |

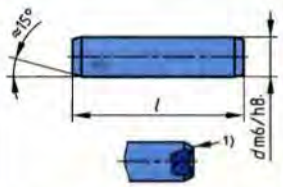
Pins with DIN-EN main numbers are designated with ISO numbers.
ISO number = DIN-EN number – 20000; example: DIN EN 22338 = ISO 2338
[1] if available

| Illustration | Designation, Standard range from–to | Standard | Illustration | Designation, Standard range from–to | Standard |
|---|---|---|---|---|---|
| **Pins** | | | | | |
|  1) tolerance m6 or h8 | Dowel pin, not hardened<br>$d$ = 1–50 mm | DIN EN ISO 2338 |  | Taper pin<br>$d_1$ = 0.6–50 mm | DIN EN 22339 |
|  | Dowel pin, hardened<br>$d$ = 0.8–20 mm | DIN EN ISO 8734 |  | Spring pin (clamping sleeves), slotted<br>$d_1$ = 1–50 mm | DIN EN ISO 8752<br>DIN EN ISO 13337 |
| **Grooved pins, grooved drive studs** | | | | | |
|  | Straight grooved pin with chamfer<br>$d_1$ = 1.5–25 mm | DIN EN ISO 8740 |  | Tapered grooved pin<br>$d_1$ = 1.5–25 mm | DIN EN ISO 8744 |
|  | Half length reversed taper grooved pin<br>$d_1$ = 1.5–25 mm | DIN EN ISO 8741 |  | Half length taper grooved pin<br>$d_1$ = 1.2–25 mm | DIN EN ISO 8745 |
|  | Center grooved pin, grooved 1/3 the length<br>$d_1$ = 1.2–25 mm | DIN EN ISO 8742 |  | Round head grooved pin<br>$d_1$ = 1.4–20 mm | DIN EN ISO 8746 |
|  | Center grooved pin, with long grooves<br>$d_1$ = 1.2–25 mm | DIN EN ISO 8743 |  | Grooved pin with countersunk head<br>$d_1$ = 1.4–20 mm | DIN EN ISO 8747 |
| **Clevis pins** | | | | | |
|  | Clevis pins without head, form A without cotter pin hole, form B with<br>$d$ = 3–100 mm | DIN EN 22340 |  | Clevis pins with head, form A without cotter pin hole, form B with<br>$d$ = 3–100 mm | DIN EN 22341 |

# Dowel, Taper and spring pins

## Dowel pins of unhardened steel and austenitic stainless steel

cf. DIN EN ISO 2338 (1998-02)




1) Radius and hollow allowed at end of pin

| d m6/h8[2] | 0.6 | 0.8 | 1 | 1.2 | 1.5 | 2 | 2.5 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|---|---|---|
| l from | 2 | 2 | 4 | 4 | 4 | 6 | 6 | 8 | 8 | 10 |
| l to | 6 | 8 | 10 | 12 | 16 | 20 | 24 | 30 | 40 | 50 |
| **d m6/h8[2]** | **6** | **8** | **10** | **12** | **16** | **20** | **25** | **30** | **40** | **50** |
| l from | 12 | 14 | 18 | 22 | 26 | 35 | 50 | 60 | 80 | 95 |
| l to | 60 | 80 | 95 | 140 | 180 | 200 | 200 | 200 | 200 | 200 |

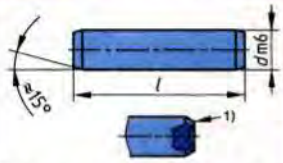
Nominal lengths *l*: 2, 3, 4, 5, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30, 32, 35, 40–95, 100, 120, 140, 160, 180, 200 mm.

⇒ **Dowel pin ISO 2338 – 6 m6 x 30 – St:** $d$ = 6 mm, tolerance class m6, $l$ = 30 mm, of steel

2) Available in tolerance classes m6 and h8

## Dowel pins, hardened

cf. DIN EN ISO 8734 (1998-03)




1) Radius and hollow allowed on end of pin

| d m6 | 1 | 1.5 | 2 | 2.5 | 3 | 4 | 5 | 6 | 8 | 10 | 12 | 16 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| l from | 3 | 4 | 5 | 6 | 8 | 10 | 12 | 14 | 18 | 22 | 26 | 40 | 50 |
| l to | 10 | 16 | 20 | 24 | 30 | 40 | 50 | 60 | 80 | 100 | | | |

Nominal lengths *l*: 3, 4, 5, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30, 32, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, 100 mm

Materials:
- Steel: Type A pin fully hardened, type B case hardened
- Stainless steel type C1

⇒ **Dowel pin ISO 8734 – 6 x 30 – C1:** $d$ = 6 mm, $l$ = 30 mm, of stainless steel of type C1

## Taper pin, unhardened

cf. DIN EN 22339 (1992-10)




Type A ground, $Ra$ = 0.8 µm;
Type B turned, $Ra$ = 3.2 µm

| d h10 | 1 | 2 | 3 | 4 | 5 | 6 | 8 | 10 | 12 | 16 | 20 | 25 | 30 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| l from | 6 | 10 | 12 | 14 | 18 | 22 | 22 | 26 | 32 | 40 | 45 | 50 | 55 |
| l to | 10 | 35 | 45 | 55 | 60 | 90 | 120 | 160 | 180 | 200 | | | |

Nominal lengths *l*: 2, 3, 4, 5, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30, 32, 35, 40, 45–95, 100, 120–180, 200 mm

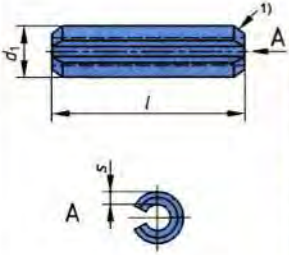
⇒ **Taper pin ISO 2339 – A – 10 x 40 – St:** Type A, $d$ = 10 mm, $l$ = 40 mm, of steel

## Spring pins (clamping sleeves), slotted, heavy duty

cf. DIN EN ISO 8752 (1998-03)

## Spring pins (clamping sleeves), slotted, light duty

cf. DIN EN ISO 13337 (1998-02)




1) Only one chamfer is allowed for spring pins with nominal diameter $d_1 \geq 10$ mm.

| Nominal Ø $d_1$ | 2 | 2.5 | 3 | 4 | 5 | 6 | 8 | 10 | 12 |
|---|---|---|---|---|---|---|---|---|---|
| $d_1$ max. | 2.4 | 2.9 | 3.5 | 4.6 | 5.6 | 6.7 | 8.8 | 10.8 | 12.8 |
| s ISO 8752 | 0.4 | 0.5 | 0.6 | 0.8 | 1 | 1.2 | 1.5 | 2 | 2.5 |
| s ISO 13337 | 0.2 | 0.25 | 0.3 | 0.5 | 0.5 | 0.75 | 0.75 | 1 | 1 |
| l from | 4 | 4 | 4 | 4 | 5 | 10 | 10 | 10 | 10 |
| l to | 20 | 30 | 40 | 50 | 80 | 100 | 120 | 160 | 180 |

| **Nominal Ø $d_1$** | **14** | **16** | **20** | **25** | **30** | **35** | **40** | **45** | **50** |
|---|---|---|---|---|---|---|---|---|---|
| $d_1$ max. | 14.8 | 16.8 | 20.9 | 25.9 | 30.9 | 35.9 | 40.9 | 45.9 | 50.9 |
| s ISO 8752 | 3 | 3 | 4 | 5 | 6 | 7 | 7.5 | 8.5 | 9.5 |
| s ISO 13337 | 1.5 | 1.5 | 2 | 2 | 2.5 | 3.5 | 4 | 4 | 5 |
| l from | 10 | | | 14 | | 20 | | | |
| l to | 200 | | | 200 | | 200 | | | |

Nominal lengths *l*: 4, 5, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30, 32, 35, 40, 45–95, 100, 120, 140, 160, 180, 200 mm

Materials:
- Steel: Hardened and tempered 420 HV 30–520 HV 30
- Stainless steel: Type A or type C

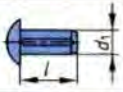
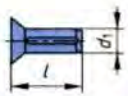
Application: The diameter of the location hole (tolerance class H12) must have the same nominal diameter $d_1$ as the mating pin. After installing the pin in the smallest receiving hole, the slot should not be completely closed.

⇒ **Spring pin ISO 8752 – 6 x 30 – St:** $d_1$ = 6 mm, $l$ = 30 mm, of steel

# Grooved pins, Grooved drive studs, Clevis pins

## Grooved pins, grooved drive studs

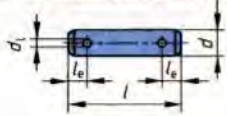
cf. DIN EN ISO 8740–8747 (1998-03)

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Full length straight grooved pin with chamfer** ISO 8740  | $d_1$ | **1.5** | **2** | **2.5** | **3** | **4** | **5** | **6** | **8** | **10** | **12** | **16** | **20** | **25** |
| | $l$ from | 8 | 8 | 10 | 10 | 10 | 14 | 14 | 14 | 14 | 18 | 22 | 26 | 26 |
| | $l$ to | 20 | 30 | 30 | 40 | 60 | 60 | 80 | 100 | 100 | 100 | 100 | 100 | 100 |
| **1/2 length reverse-taper grooved pin** ISO 8741  | $l$ from | 8 | 8 | 8 | 8 | 10 | 10 | 12 | 14 | 18 | 26 | 26 | 26 | 26 |
| | $l$ to | 20 | 30 | 30 | 40 | 60 | 60 | 80 | 100 | 160 | 200 | 200 | 200 | 200 |
| **1/3–1/2 length center grooved pins** ISO 8742+8743  | $l$ from | 8 | 12 | 12 | 12 | 18 | 18 | 22 | 26 | 32 | 40 | 45 | 45 | 45 |
| | $l$ to | 20 | 30 | 30 | 40 | 60 | 60 | 80 | 100 | 160 | 200 | 200 | 200 | 200 |
| **Tapered groove pin** ISO 8744  | $l$ from | 8 | 8 | 8 | 8 | 8 | 8 | 10 | 12 | 14 | 14 | 24 | 26 | 26 |
| | $l$ to | 20 | 30 | 30 | 40 | 60 | 60 | 80 | 100 | 120 | 120 | 120 | 120 | 120 |
| **Full length taper grooved pins** ISO 8745  | $l$ from | 8 | 8 | 8 | 8 | 10 | 10 | 10 | 14 | 14 | 18 | 26 | 26 | 26 |
| | $l$ to | 20 | 30 | 30 | 40 | 60 | 60 | 80 | 100 | 200 | 200 | 200 | 200 | 200 |
| **Grooved pins with round head** ISO 8746  | $d_1$ | **1.4** | **1.6** | **2** | **2.5** | **3** | **4** | **5** | **6** | **8** | **10** | **12** | **16** | **20** |
| | $l$ from | 3 | 3 | 3 | 3 | 4 | 5 | 6 | 8 | 10 | 12 | 16 | 20 | 25 |
| | $l$ to | 6 | 8 | 10 | 12 | 16 | 20 | 25 | 30 | 40 | 40 | 40 | 40 | 40 |
| **Grooved pins with countersunk head** ISO 8747  | $l$ from | 3 | 3 | 4 | 4 | 5 | 6 | 8 | 8 | 10 | 12 | 16 | 20 | 25 |
| | $l$ to | 6 | 8 | 10 | 12 | 16 | 20 | 25 | 30 | 40 | 40 | 40 | 40 | 40 |
| | Nominal lengths $l$ | Pins: 8, 10–30, 32, 35, 40–100, 120, 140–180, 200 mm<br>Studs: 3, 4, 5, 6, 8, 10, 12, 16, 20, 25, 30, 35, 40 mm | | | | | | | | | | | | |
| | ⇒ | **Grooved pin ISO 8740 – 6 x 50 – St:** $d_1$ = 6 mm, $l$ = 50 mm, of steel | | | | | | | | | | | | |

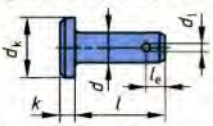
## Clevis pins with and without head

cf. DIN EN 22340, 22341 (1992-10)

**Clevis pins without head** ISO 2340



**Clevis pins with head** ISO 2341

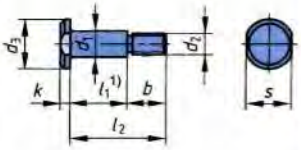


**Form A** without cotter pin hole
**Form B** with cotter pin hole

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $d$ **h11** | **3** | **4** | **5** | **6** | **8** | **10** | **12** | **14** | **16** | **18** | **20** | **22** | **24** |
| $d_1$ H13 | 0.8 | 1 | 1.2 | 1.6 | 2 | 3.2 | 3.2 | 4 | 4 | 5 | 5 | 5 | 6.3 |
| $d_k$ h14 | 5 | 6 | 8 | 10 | 14 | 18 | 20 | 22 | 25 | 28 | 30 | 33 | 36 |
| $k$ js14 | 1 | 1 | 1.6 | 2 | 3 | 4 | 4 | 4 | 4.5 | 5 | 5 | 5.5 | 6 |
| $l_e$ | 1.6 | 2.2 | 2.9 | 3.2 | 3.5 | 4.5 | 5.5 | 6 | 6 | 7 | 8 | 8 | 9 |
| $l$ from | 6 | 8 | 10 | 12 | 16 | 20 | 24 | 28 | 30 | 35 | 40 | 45 | 50 |
| $l$ to | 30 | 40 | 50 | 60 | 80 | 100 | 120 | 140 | 160 | 180 | 200 | 200 | 200 |
| Nominal lengths $l$ | 6, 8, 10–30, 32, 35, 40–95, 100, 120, 140–180, 200 mm | | | | | | | | | | | | |
| ⇒ | **Clevis pin ISO 2340 – B – 20 x 100 – St:** Form B, $d$ = 20 mm, $l$ = 100 mm, of free-cutting steel | | | | | | | | | | | | |

## Clevis pins with head and threaded stud end

cf. DIN 1445 (1977-02)



| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $d_1$ **h11** | **8** | **10** | **12** | **14** | **16** | **18** | **20** | **24** | **30** | **40** | **50** |
| $b$ min | 11 | 14 | 17 | 20 | 20 | 20 | 25 | 29 | 36 | 42 | 49 |
| $d_2$ | M6 | M8 | M10 | M12 | M12 | M12 | M16 | M20 | M24 | M30 | M36 |
| $d_3$ h14 | 14 | 18 | 20 | 22 | 25 | 28 | 30 | 36 | 44 | 55 | 66 |
| $k$ js14 | 3 | 4 | 4 | 4 | 4.5 | 5 | 5 | 6 | 8 | 8 | 9 |
| $s$ | 11 | 13 | 17 | 19 | 22 | 24 | 27 | 32 | 36 | 50 | 60 |
| Nominal lengths $l_2$ | 16, 20, 25, 30, 35–125, 130, 140, 150–190, 200 mm | | | | | | | | | | |
| ⇒ | **Clevis pin DIN 1445 – 12h11 x 30 x 50 – St:** $d_1$ = 12 mm, tolerance class h11, $l_1$ = 30 mm, $l_2$ = 50 mm, of 9SMnPb28 (St) | | | | | | | | | | |

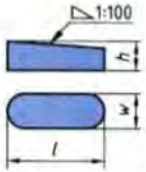
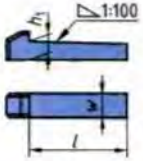
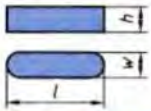
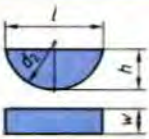
[1] gripping length

# Keys, Gib-head keys

**Designation example:**

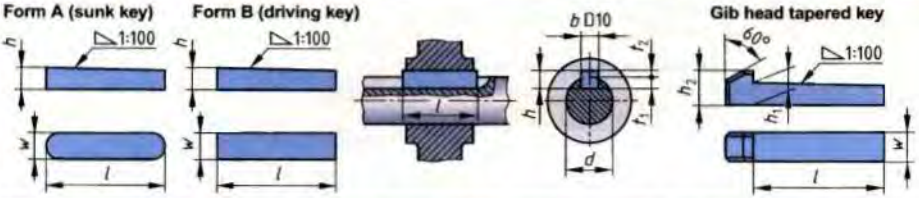
Feather key DIN 6885 – A – 12x8x56 – E295

| Name | Standard | Form or Type | Width x height x length | Material, e.g. steel |
|---|---|---|---|---|

| Illustration | Designation, Standard range from–to | Standard | Illustration | Designation, Standard range from–to | Standard |
|---|---|---|---|---|---|
| **Overview of tapered keys** | | | | | table below |
|  | Tapered key $w \times h =$ 2 x 2–100 x 50 | DIN 6886<br>Form A: sunk key<br>Form B: driving key |  | Gib-head tapered key $w \times h =$ 4 x 4–100 x 50 | DIN 6887 |
| **Overview of feather keys** | | | | | page 240 |
| Form A  | Feather key $w \times h =$ 2 x 2–100 x 50 | DIN 6885<br>Form A–J |  | Woodruff keys $w \times h =$ 2.5x3.7–10x16 | DIN 6888 |

**Tapered keys, Gib-head tapered keys** cf. DIN 6886 (1967-12) or DIN 6887 (1968-04)

Form A (sunk key) Form B (driving key) Gib head tapered key



| For shaft diameter $d$ | over | 10 | 12 | 17 | 22 | 30 | 38 | 44 | 50 | 58 | 65 | 75 | 85 | 95 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | to | 12 | 17 | 22 | 30 | 38 | 44 | 50 | 58 | 65 | 75 | 85 | 95 | 110 |
| Tapered keys | $w$ D10 | 4 | 5 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 25 | 28 |
| | $h$ | 4 | 5 | 6 | 7 | 8 | 8 | 9 | 10 | 11 | 12 | 14 | 14 | 16 |
| Gib-head tapered keys | $h_1$ | 4.1 | 5.1 | 6.1 | 7.2 | 8.2 | 8.2 | 9.2 | 10.2 | 11.2 | 12.2 | 14.2 | 14.2 | 16.2 |
| | $h_2$ | 7 | 8 | 10 | 11 | 12 | 12 | 14 | 16 | 18 | 20 | 22 | 22 | 25 |
| Shaft keyway depth | $t_1$ | 2.5 | 3 | 3.5 | 4 | 5 | 5 | 5.5 | 6 | 7 | 7.5 | 9 | 9 | 10 |
| Hub keyway depth | $t_2$ | 1.2 | 1.7 | 2.2 | 2.4 | 2.4 | 2.4 | 2.9 | 3.4 | 3.4 | 3.9 | 4.4 | 4.4 | 5.4 |
| Allow. deviation | $t_1$, $t_2$ | +0.1 | | | +0.2 | | | | | | | | | |
| Key length $l$ | from | 10[1] | 12[1] | 16 | 20 | 25 | 32 | 40 | 45 | 50 | 56 | 63 | 70 | 80 |
| | to | 45 | 56 | 70 | 90 | 110 | 140 | 160 | 180 | 200 | 220 | 250 | 280 | 320 |
| Nominal lengths $l$ | | 6, 8–20, 22, 25, 28, 32, 40, 45, 50, 56, 63, 70, 80–100, 110, 125, 140, 160–200, 220, 250, 280, 320, 360, 400 mm | | | | | | | | | | | | |

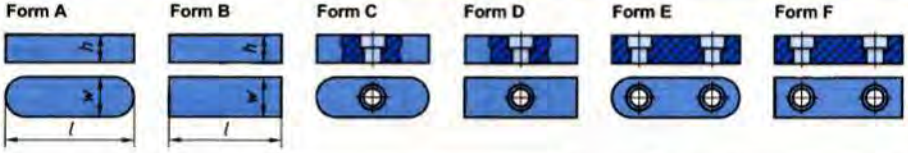
| Length tolerances | Key length $l$, from–to | 6–28 | 32–80 | 90–400 |
|---|---|---|---|---|
| Tolerances for | Key length | –0.2 | –0.3 | –0.5 |
| | Keyway length (sunk key) | +0.2 | +0.3 | +0.5 |

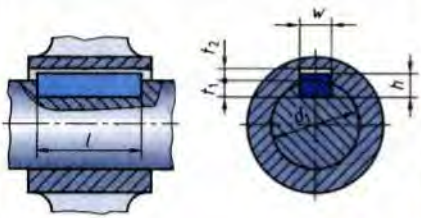
[1] Gib-head key lengths from 14 mm

# Feather keys, Woodruff keys

## Feather keys (high form)

cf. DIN 6885-1 (1968-08)




| Tolerances for feather keyways | | | |
|---|---|---|---|
| Shaft keyway width $w$ | tight fit<br>normal fit | | P 9<br>N 9 |
| Hub keyway width $w$ | tight fit<br>normal fit | | P 9<br>JS 9 |
| Allow. deviation for $d_1$ | ≤ 22 | ≤ 130 | > 130 |
| Shaft keyway depth $t_1$<br>Hub keyway depth $t_2$ | +0.1<br>+0.1 | +0.2<br>+0.2 | +0.3<br>+0.3 |
| Alllow. deviation for length $l$ | 6 – 28 | 32 – 80 | 90 – 400 |
| Length tolerances for key | –0.2 | –0.3 | –0.5 |
| Length tolerances for keyway | +0.2 | +0.3 | +0.5 |

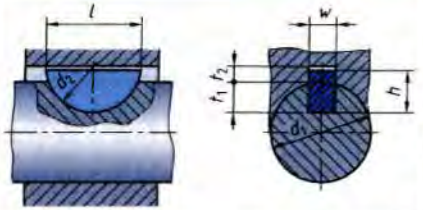
| $d_1$ over / to | 6 / 8 | 8 / 10 | 10 / 12 | 12 / 17 | 17 / 22 | 22 / 30 | 30 / 38 | 38 / 44 | 44 / 50 | 50 / 58 | 58 / 65 | 65 / 75 | 75 / 85 | 85 / 95 | 95 / 110 | 110 / 130 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $w$ | 2 | 3 | 4 | 5 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 25 | 28 | 32 |
| $h$ | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 8 | 9 | 10 | 11 | 12 | 14 | 14 | 16 | 18 |
| $t_1$ | 1.2 | 1.8 | 2.5 | 3 | 3.5 | 4 | 5 | 5 | 5.5 | 6 | 7 | 7.5 | 9 | 9 | 10 | 11 |
| $t_2$ | 1 | 1.4 | 1.8 | 2.3 | 2.8 | 3.3 | 3.3 | 3.3 | 3.8 | 4.3 | 4.4 | 4.9 | 5.4 | 5.4 | 6.4 | 7.4 |
| $l$ from | 6 | 6 | 8 | 10 | 14 | 18 | 20 | 28 | 36 | 45 | 50 | 56 | 63 | 70 | 80 | 90 |
| $l$ to | 20 | 36 | 45 | 56 | 70 | 90 | 110 | 140 | 160 | 180 | 200 | 220 | 250 | 280 | 320 | 360 |

Nominal lengths $l$: 6, 8, 10, 12, 14, 16, 18, 20, 22, 25, 28, 32, 36, 40, 45, 50, 56, 63, 70, 80, 90, 100, 110, 125, 140, 160, 180, 200, 220, 250, 280, 320 mm

⇒ **Feather key DIN 6885 – A – 12 x 8 x 56**: Form A, $b$ = 12 mm, $h$ = 8 mm, $l$ = 56 mm

## Woodruff keys

cf. DIN 6888 (1956-08)




| Tolerances for Woodruff keyways | | | | | | |
|---|---|---|---|---|---|---|
| Shaft keyway width $w$ | tight fit<br>normal fit | | | P 9 (P 8)[1]<br>N 9 (N 8)[1] | | |
| Hub keyway width $w$ | tight fit<br>normal fit | | | P 9 (P 8)[1]<br>J 9 (J 8)[1] | | |
| Allow. devia. for $w$ and $h$ | ≤ 5<br>≤ 7.5 | 5<br>> 7.5 | 6<br>≤ 9 | 6<br>> 9 | 8<br>– | 10<br>– |
| Shaft keyway depth $t_1$<br>Hub keyway depth $t_2$ | +0.1<br>+0.1 | +0.2<br>+0.1 | +0.1<br>+0.1 | +0.2<br>+0.1 | +0.2<br>+0.1 | +0.2<br>+0.2 |

| $d_1$ over / to | 8 / 10 | | | 10 / 12 | | | 12 / 17 | | | 17 / 22 | | | 22 / 30 | | | 30 / 38 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $w$ h9 | 2.5 | 3 | | 4 | | | 5 | | | 6 | | | 8 | | | 10 | | |
| $h$ h12 | 3.7 | 3.7 | 5 | 6.5 | 5 | 6.5 | 7.5 | 6.5 | 7.5 | 9 | 7.5 | 9 | 11 | 9 | 11 | 13 | 11 | 13 | 16 |
| $d_2$ | 10 | 10 | 13 | 16 | 13 | 16 | 19 | 16 | 19 | 22 | 19 | 22 | 28 | 22 | 28 | 32 | 28 | 32 | 45 |
| $t_1$ | 2.9 | 2.5 | 3.8 | 5.3 | 3.5 | 5 | 6 | 4.5 | 5.5 | 7 | 5.1 | 6.6 | 8.6 | 6.2 | 8.2 | 10.2 | 7.8 | 9.8 | 12.8 |
| $t_2$ | 1 | 1.4 | | | 1.7 | | | 2.2 | | | 2.6 | | | 3 | | | 3.4 | | |
| $l \approx$ | 9.7 | 9.7 | 12.7 | 15.7 | 12.7 | 15.7 | 18.6 | 15.7 | 18.6 | 21.6 | 18.6 | 21.6 | 27.4 | 21.6 | 27.4 | 31.4 | 27.4 | 31.4 | 43.1 |

⇒ **Woodruff key DIN 6888 – 6 x 9**: $w$ = 6 mm, $h$ = 9 mm

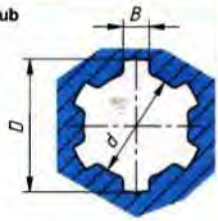
[1] Tolerance class for broached keyways

# Splined shaft joints and blind rivets

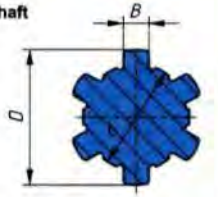
## Splined shaft joints with straight flanks and internal centering

cf. DIN ISO 14 (1986-12)

Hub




Shaft




Internal centering



| d | Light series N[1] | D | B | Medium series N[1] | D | B | d | Light series N[1] | D | B | Medium series N[1] | D | B |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11 | – | – | – | 6 | 14 | 3 | 42 | 8 | 46 | 8 | 8 | 48 | 8 |
| 13 | – | – | – | 6 | 16 | 3.5 | 46 | 8 | 50 | 9 | 8 | 54 | 9 |
| 16 | – | – | – | 6 | 20 | 4 | 52 | 8 | 58 | 10 | 8 | 60 | 10 |
| 18 | – | – | – | 6 | 22 | 5 | 56 | 8 | 62 | 10 | 8 | 65 | 10 |
| 21 | – | – | – | 6 | 25 | 5 | 62 | 8 | 68 | 12 | 8 | 72 | 12 |
| 23 | 6 | 26 | 6 | 6 | 28 | 6 | 72 | 10 | 78 | 12 | 10 | 82 | 12 |
| 26 | 6 | 30 | 6 | 6 | 32 | 6 | 82 | 10 | 88 | 12 | 10 | 92 | 12 |
| 28 | 6 | 32 | 7 | 6 | 34 | 7 | 92 | 10 | 98 | 14 | 10 | 102 | 14 |
| 32 | 8 | 36 | 6 | 8 | 38 | 6 | 102 | 10 | 108 | 16 | 10 | 112 | 16 |
| 36 | 8 | 40 | 7 | 8 | 42 | 7 | 112 | 10 | 120 | 18 | 10 | 125 | 18 |

| Tolerance classes for the hub | | | | | | Tolerance classes for the shaft | | | |
|---|---|---|---|---|---|---|---|---|---|
| Not heat treated dimensions | | | Heat treated dimensions | | | Dimen. | Type of fit: Sliding fit | Transition fit | Press fit |
| B | D | d | B | D | d | | | | |
| H9 | H10 | H7 | H11 | H10 | H7 | B | d10 | f9 | h10 |
| | | | | | | D | a11 | a11 | a11 |
| | | | | | | d | f7 | g7 | h7 |

⇒ **Shaft (or hub) DIN ISO 14 – 6 x 23 x 26:** $N = 6$, $d = 23$ mm, $D = 26$ mm

[1] N number of splines

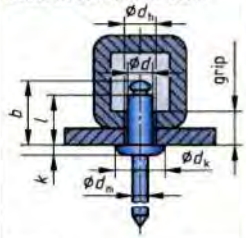
## Open end blind rivets with break mandrel and flat head

cf. DIN EN ISO 15977 (2003-04)

## Open end blind rivets with break mandrel and countersunk head

cf. DIN EN ISO 15978 (2003-08)

Blind rivet with flat head

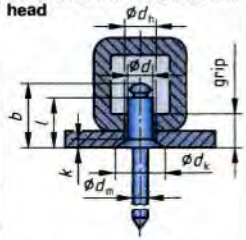


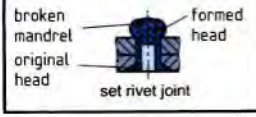




set rivet joint

Blind rivet with countersunk head




set rivet joint

| Rivet Ø d (Nominal size) | | 3 | 4 | 5 | 6[1] |
|---|---|---|---|---|---|
| Head Ø $d_k$ max. | | 6.3 | 8.4 | 10.5 | 12.6 |
| Head height $k$ | | 1.3 | 1.7 | 2.1 | 2.5 |
| Rivet mandrel Ø $d_m$ max. | | 2 | 2.45 | 2.95 | 3.4 |
| Rivet hole Ø $d_{h1}$ | min. | 3.1 | 4.1 | 5.1 | 6.1 |
| | max. | 3.2 | 4.2 | 5.2 | 6.2 |
| Fitting length $b$ | | $l_{max} + 3.5$ | $l_{max} + 4$ | $l_{max} + 4.5$ | $l_{max} + 5$ |
| Shaft length $l$ min. | max. | Recommended grip range | | | |
| 4 | 5 | 0.5–1.5[1] | – | – | – |
| 6 | 7 | 2.0–3.5<br>1.5–3.5[1] | 1–3[1] | 1.5–2.5[1] | – |
| 8 | 9 | 3.5–5.0 | 2–5<br>3–5[1] | 2.5–4.0 | 2–3 |
| 10 | 11 | 5–7 | 5.0–6.5 | 4–6 | 3–5 |
| 12 | 13 | 7–9 | 6.5–8.5 | 6–8 | 5–7 |
| 16 | 17 | 9–13 | 8.5–12.5 | 8–12 | 7–11 |
| 20 | 21 | 13–17 | 12.5–16.5 | 12–15 | 11–15 |
| 25 | 26 | 17–22 | 16.5–21.0 | 15–20 | 15–20 |
| 30 | 31 | – | – | 20–25 | 20–25 |
| Property classes | | L (low) and H (high) are differentiated by the minimum shear and minimum tensile forces of the rivet. | | | |
| Materials[2] | | Rivet body of aluminum alloy (AlA)<br>Rivet mandrel of steel (St) | | | |
| ⇒ | | **Blind rivet ISO 15977 – 4 x 12 – AlA/St – L:** Blind rivet with flat head; $d = 4$ mm, $l = 12$ mm, rivet body of aluminum alloy, rivet mandrel of steel, property class L (low) | | | |

[1] Only for flat head rivets ISO 15977

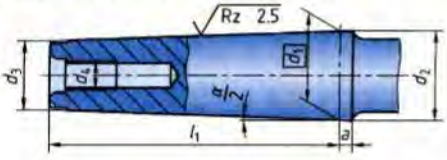
[2] Other standardized material combinations for rivet body/mandrel include: St/St; AlA/AlA; A2/A2; Cu/St; NiCu/St etc.

# Metric tapers, Morse tapers, Steep tapers

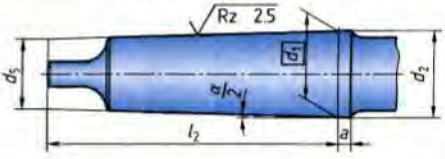
## Morse tapers and metric tapers

cf. DIN 228-1 (1987-05)

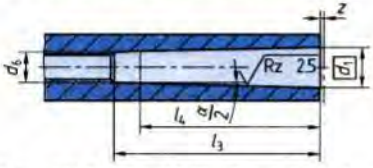
**Form A:** Taper shank with tightening thread



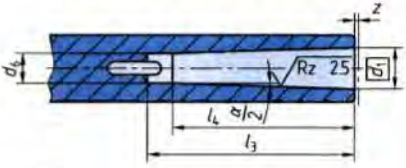

**Form B:** Taper shank with tang




**Form C:** Taper sleeve for taper shanks with draw-in threads




**Form D:** Taper sleeve for taper shanks with tang




The **Forms AK, BK CK** and **DK** each have a feed for cooling lubricants.

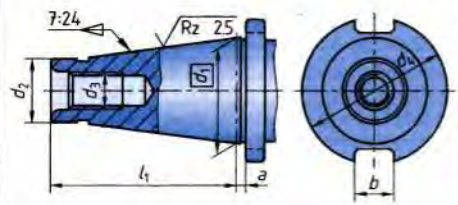
| Type of taper | Size | Taper shank | | | | | | | | Taper shank | | | | Taper | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $d_1$ | $d_2$ | $d_3$ | $d_4$ | $d_5$ | $l_1$ | $a$ | $l_2$ | $d_6$ H11 | $l_3$ | $l_4$ | $z$ [1] | Taper ratio | $\frac{\alpha}{2}$ |
| Metric taper (ME) | 4 | 4 | 4.1 | 2.9 | – | – | 23 | 2 | – | 3 | 25 | 20 | 0.5 | 1 : 20 | 1.432° |
| | 6 | 6 | 6.2 | 4.4 | – | – | 32 | 3 | – | 4.6 | 34 | 28 | 0.5 | | |
| Morse taper (MT) | 0 | 9.045 | 9.2 | 6.4 | – | 6.1 | 50 | 3 | 56.5 | 6.7 | 52 | 45 | 1 | 1 : 19.212 | 1.491° |
| | 1 | 12.065 | 12.2 | 9.4 | M6 | 9 | 53.5 | 3.5 | 62 | 9.7 | 56 | 47 | 1 | 1 : 20.047 | 1.429° |
| | 2 | 17.780 | 18.0 | 14.6 | M10 | 14 | 64 | 5 | 75 | 14.9 | 67 | 58 | 1 | 1 : 20.020 | 1.431° |
| | 3 | 23.825 | 24.1 | 19.8 | M12 | 19.1 | 81 | 5 | 94 | 20.2 | 84 | 72 | 1 | 1 : 19.922 | 1.438° |
| | 4 | 31.267 | 31.6 | 25.9 | M16 | 25.2 | 102.5 | 6.5 | 117.5 | 26.5 | 107 | 92 | 1 | 1 : 19.254 | 1.488° |
| | 5 | 44.399 | 44.7 | 37.6 | M20 | 36.5 | 129.5 | 6.5 | 149.5 | 38.2 | 135 | 118 | 1 | 1 : 19.002 | 1.507° |
| | 6 | 63.348 | 63.8 | 53.9 | M24 | 52.4 | 182 | 8 | 210 | 54.8 | 188 | 164 | 1 | 1 : 19.180 | 1.493° |
| Metric taper (MT) | 80 | 80 | 80.4 | 70.2 | M30 | 69 | 196 | 8 | 220 | 71.5 | 202 | 170 | 1.5 | 1 : 20 | 1.432° |
| | 100 | 100 | 100.5 | 88.4 | M36 | 87 | 232 | 10 | 260 | 90 | 240 | 200 | 1.5 | | |
| | 120 | 120 | 120.6 | 106.6 | M36 | 105 | 268 | 12 | 300 | 108.5 | 276 | 230 | 1.5 | | |
| | 160 | 160 | 160.8 | 143 | M48 | 141 | 340 | 16 | 380 | 145.5 | 350 | 290 | 2 | | |
| | 200 | 200 | 201.0 | 179.4 | M48 | 177 | 412 | 20 | 460 | 182.5 | 424 | 350 | 2 | | |

⇒ **Taper shank DIN 228 – ME – B 80 AT6:** Metric taper shank, Form B, Size 80, Taper angle tolerance quality AT6

[1] Control dimension $d_1$ may lie a maximum distance $z$ in front of the taper sleeve.

## Steep taper shanks for tools and chucks form A

cf. DIN 2080-1 (1978-12)

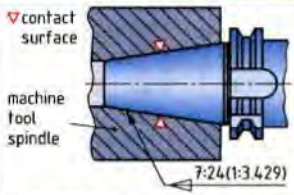
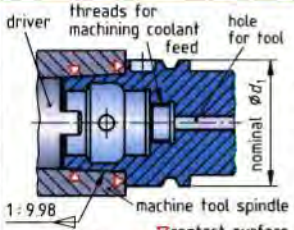



| No. | $d_1$ | $d_2$ a10 | $d_3$ | $d_4$ – 0.4 | $l_1$ | $a$ ± 0.2 | $b$ H12 |
|---|---|---|---|---|---|---|---|
| 30 | 31.75 | 17.4 | M12 | 50 | 68.4 | 1.6 | 16.1 |
| 40 | 44.45 | 25.3 | M16 | 63 | 93.4 | 1.6 | 16.1 |
| 50 | 69.85 | 39.6 | M24 | 97.5 | 126.8 | 3.2 | 25.7 |
| 60 | 107.95 | 60.2 | M30 | 156 | 206.8 | 3.2 | 25.7 |
| 70 | 165.1 | 92 | M36 | 230 | 296 | 4 | 32.4 |
| 80 | 254 | 140 | M48 | 350 | 469 | 6 | 40.5 |

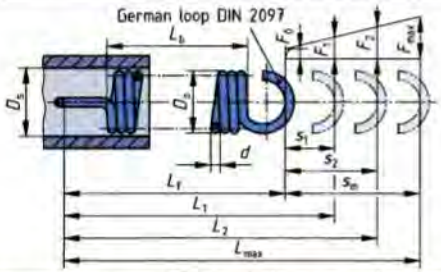
⇒ **Steep taper shank DIN 2080 – A 40 AT4:** Form A, No. 40, Taper angle tolerance quality AT4

# Tool holding fixtures

Tool holding fixtures join the tool with the spindle of the machine tool. They transmit the torque and are responsible for precise concentric running.

| Type of design | Function, advantages (+) and disadvantages (–) | Application, sizes |
|---|---|---|
| **Metric taper (ME) and Morse taper (MT)** | | cf. DIN 228-1 and -2 (1987-05) |
|  Metric taper 1 : 20; Morse taper 1 : 19.002 to 1 : 20.047 | Torque transmission:<br>• force-fit over the taper surface<br>+ reduction sleeves fit different taper diameters<br>– not suitable for automatic tool change | Clamping device for conventional drilling and milling.<br>Taper shank numbers:<br>• ME 4; 6<br>• MT 0; 1; 2; 3; 4; 5; 6<br>• ME 80; 100; 120; (140); 160; (180); 200 |
| **Steep taper shank (SK)** | | cf. DIN 2080-1 (1978-12) and -2 (1979-09) and DIN 69871-1 (1995-10) |
|  Fastening in the machine spindle:<br>Form A: with draw-in bar<br>Form B: by front fastener<br>Taper 7 : 24 (1 : 3.429) according to DIN 254 | Torque transmission:<br>• grooves on taper edge produce interlock. The steep taper is not meant for transmission of forces, it only centers the tool. Axial locking is achieved by the thread or the ring groove.<br>+ DIN 69871-1 suitable for automatic tool change<br>– high weight, therefore less suited for quick tool change with high axial repeating clamping accuracy and for high revolution speeds | Use with CNC machine tools, especially machining centers; less suited for high-speed cutting (HSC)<br>Steep taper numbers:<br>• DIN 2080-1 (form A): 30; 40; 45; 50; 55; 60; 65; 70; 75; 80<br>• DIN 69871-1: 30; 40; 45; 50; 60 |
| **Hollow taper shanks (designation HSK)** | | cf. DIN 69893-1 and -2 (2003-05) |
|  Taper 1 : 9.98 | Torque transmission:<br>• force-fit using the taper and contact surfaces<br>• drive slots on shaft end produce interlock.<br>+ low weight, therefore<br>+ high static and dynamic rigidity<br>+ high repeated clamping accuracy (3 µm)<br>+ high rotational speeds<br>– more expensive than steep taper | Safer use with high-speed cutting<br>Nominal sizes: $d_1$ = 32; 40; 50; 63; 80; 100; 125; 160 mm<br>**Form A:** with shoulder and clamping keyway for automatic tool change<br>**Form C:** only manual change is possible |
| **Shrinkage chucks** | | |
|  available with HSK or steep taper | Torque transmission like HSK.<br>Clamping the tool by quick, inductive heating (approx. 340 °C) of the holding shank in the shrinkage chuck. A shrinkage joint is formed by the oversize of the tool (approx. 3–7 µm) after the joining and cooling.<br>+ transmission of high torques<br>+ high radial rigidity<br>+ higher cutting values possible<br>+ shorter machining times<br>+ good runout<br>+ greater running smoothness<br>+ better surface quality<br>+ reliable tool changes<br>– relatively expensive<br>– additional induction and cooling devices required | Universally applicable in machine tools with steep taper or hollow shank tool holders; suitable for tools with cylindrical shank of HSS or carbide.<br>Shank diameters: 6; 8; 10; 12; 14; 16; 18; 20; 25 mm |

# Cylindrical helical tension springs



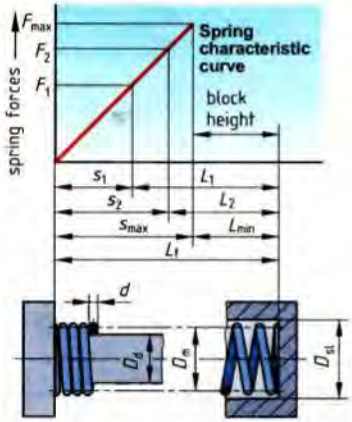

$d$ wire diameter in mm
$D_o$ outside coil diameter
$D_s$ minimum sleeve diameter in mm
$L_f$ free length, with no load on spring in mm
$L_b$ length of spring body with no load in mm
$L_{max}$ maximum spring length
$F_0$ internal prestress in N
$F_{max}$ maximum allowable spring force in N
$R$ spring rate in N/mm
$s_m$ maximum allowable spring displacement for $F_{max}$ in mm

| $d$ | $D_o$ | $D_s$ | $L_f$ | $L_b$ | $F_0$ | $F_{max}$ | $R$ | $s_m$ |
|---|---|---|---|---|---|---|---|---|
| **Tension springs of patented drawn unalloyed spring steel wire[1]** | | | | | | cf. DIN EN 10270-1 (2001-12) | | |
| 0.20 | 3.00 | 3.50 | 8.6 | 4.35 | 0.06 | 1.26 | 0.036 | 33.37 |
| 0.25 | 5.00 | 5.70 | 10.0 | 2.63 | 0.03 | 1.46 | 0.039 | 36.51 |
| 0.32 | 5.50 | 6.30 | 10.0 | 2.08 | 0.08 | 2.71 | 0.140 | 18.85 |
| 0.36 | 6.00 | 6.90 | 11.0 | 2.34 | 0.16 | 3.50 | 0.173 | 19.23 |
| 0.40 | 7.00 | 8.00 | 12.7 | 2.60 | 0.16 | 4.06 | 0.165 | 23.67 |
| 0.45 | 7.50 | 8.60 | 13.7 | 3.04 | 0.25 | 5.31 | 0.207 | 24.41 |
| 0.50 | 10.00 | 11.10 | 20.0 | 5.25 | 0.02 | 5.40 | 0.078 | 68.79 |
| 0.55 | 6.00 | 7.10 | 13.9 | 5.78 | 0.88 | 11.66 | 0.606 | 17.78 |
| 0.63 | 8.60 | 9.90 | 19.9 | 7.88 | 0.79 | 12.13 | 0.276 | 41.15 |
| 0.70 | 10.00 | 11.40 | 23.6 | 9.63 | 0.83 | 14.13 | 0.239 | 55.78 |
| 0.80 | 10.80 | 12.30 | 25.1 | 10.20 | 1.22 | 19.10 | 0.355 | 50.36 |
| 0.90 | 10.00 | 11.70 | 23.0 | 9.45 | 1.99 | 28.59 | 0.934 | 28.49 |
| 1.00 | 13.50 | 15.40 | 31.4 | 12.50 | 1.77 | 28.63 | 0.454 | 59.22 |
| 1.10 | 12.00 | 14.00 | 27.8 | 11.83 | 2.99 | 41.95 | 1.181 | 32.98 |
| 1.25 | 17.20 | 19.50 | 39.8 | 15.63 | 2.77 | 42.35 | 0.533 | 74.25 |
| 1.30 | 11.30 | 13.50 | 134.0 | 118.95 | 5.771 | 70.59 | 0.322 | 201.60 |
| 1.40 | 15.00 | 17.50 | 34.9 | 15.05 | 5.44 | 66.08 | 1.596 | 38.00 |
| 1.50 | 20.00 | 22.70 | 48.9 | 21.75 | 3.99 | 60.54 | 0.603 | 93.72 |
| 1.60 | 21.60 | 24.50 | 50.2 | 20.00 | 3.99 | 67.40 | 0.726 | 87.38 |
| 1.80 | 20.00 | 23.20 | 46.0 | 19.35 | 6.88 | 100.90 | 1.819 | 51.70 |
| 2.00 | 27.00 | 30.50 | 62.8 | 25.00 | 6.88 | 101.20 | 0.907 | 104.00 |
| 2.20 | 24.00 | 27.80 | 55.6 | 23.10 | 9.81 | 148.00 | 2.425 | 57.02 |
| 2.50 | 34.50 | 38.90 | 79.7 | 31.25 | 9.88 | 148.50 | 1.056 | 131.33 |
| 2.80 | 30.00 | 34.70 | 69.8 | 29.40 | 17.77 | 233.40 | 3.257 | 65.85 |
| 3.00 | 40.00 | 45.10 | 140.0 | 86.25 | 11.50 | 214.20 | 0.587 | 345.31 |
| 3.20 | 43.20 | 46.60 | 100.0 | 40.00 | 11.88 | 238.40 | 1.451 | 156.13 |
| 3.60 | 40.00 | 46.00 | 92.1 | 37.80 | 19.60 | 357.10 | 3.735 | 90.38 |
| 4.00 | 44.00 | 50.60 | 117.0 | 58.00 | 24.50 | 436.30 | 3.019 | 136.43 |
| 4.50 | 50.00 | 57.60 | 194.0 | 128.25 | 28.00 | 532.30 | 1.613 | 312.74 |
| 5.00 | 50.00 | 58.30 | 207.0 | 142.50 | 47.00 | 707.90 | 2.541 | 260.12 |
| 5.50 | 60.00 | 69.30 | 236.0 | 156.75 | 38.00 | 774.50 | 2.094 | 351.72 |
| 6.30 | 70.00 | 80.00 | 272.0 | 179.55 | 45.00 | 968.50 | 2.258 | 429.00 |
| 7.00 | 80.00 | 92.00 | 306.0 | 199.50 | 70.00 | 1132.00 | 2.286 | 464.83 |
| 8.00 | 80.00 | 94.00 | 330.0 | 228.00 | 120.00 | 1627.00 | 4.065 | 370.91 |
| **Tension springs of stainless steel spring steel wire[1]** | | | | | | cf. DIN EN 10270-3 (2001-08) | | |
| 0.20 | 3.00 | 3.50 | 8.60 | 4.35 | 0.05 | 0.99 | 0.031 | 30.54 |
| 0.40 | 7.00 | 8.00 | 12.70 | 2.60 | 0.121 | 3.251 | 0.142 | 22.11 |
| 0.63 | 8.60 | 9.90 | 19.90 | 7.88 | 0.631 | 9.861 | 0.237 | 38.97 |
| 0.80 | 10.80 | 12.30 | 25.1 | 10.20 | 0.971 | 15.67 | 0.305 | 48.19 |
| 1.00 | 13.50 | 15.40 | 31.4 | 12.50 | 1.411 | 23.77 | 0.390 | 57.40 |
| 1.25 | 17.20 | 19.50 | 39.8 | 15.63 | 2.211 | 35.50 | 0.458 | 72.73 |
| 1.40 | 15.00 | 17.50 | 34.9 | 15.05 | 4.351 | 55.72 | 1.371 | 37.48 |
| 1.60 | 21.60 | 24.50 | 50.2 | 20.00 | 3.211 | 56.93 | 0.623 | 86.19 |
| 2.00 | 27.00 | 30.50 | 62.8 | 25.00 | 5.501 | 84.86 | 0.779 | 101.86 |
| 4.00 | 44.00 | 50.60 | 117.0 | 58.00 | 19.600 | 366.50 | 2.593 | 133.83 |

[1] In addition to the springs listed, other springs with different outside diameters and lengths are commercially available for each wire diameter.

# Cylindrical helical compression springs

cf. DIN 2098-1 (1968-10), -2 (1970-08)




| | |
|---|---|
| $d$ | wire diameter |
| $D_m$ | mean coil diameter |
| $D_d$ | mandrel diameter |
| $D_{sl}$ | sleeve diameter |
| $L_f$ | free length, unloaded spring |
| $L_1$, $L_2$ | length of loaded spring at $F_1$, $F_2$ |
| $L_{min}$ | minimum allowable test length of the spring |
| $F_1$, $F_2$ | spring force at $L_1$, $L_2$ |
| $F_{max}$ | maximum allowable spring force at $s_{max}$ |
| $s_1$, $s_2$ | spring displacement at $F_1$, $F_2$ |
| $s_{max}$ | maximum allowable spring displacement at $F_{max}$ |
| $i_s$ | number of spring coils |
| $i_t$ | total number of coils (ends ground) |
| $R$ | spring rate in N/mm |

**Total number of coils**

$i_t = i_s + 2$

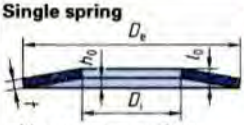
⇒ **Compression spring DIN 2098 – 2 x 20 x 94:**
$d$ = 2 mm, $D_m$ = 20 mm and $L_f$ = 94 mm

| $d$ | $D_m$ | $D_d$ max. | $D_{sl}$ min. | $F_{max}$ in N | $i_s$ = 3.5 | | | $i_s$ = 5.5 | | | $i_s$ = 8.5 | | | $i_s$ = 12.5 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | $L_f$ | $s_{max}$ | $R$ | $L_f$ | $s_{max}$ | $R$ | $L_f$ | $s_{max}$ | $R$ | $L_f$ | $s_{max}$ | $R$ |
| 0.2 | 2.5 | 2.0 | 3.1 | 1.00 | 5.4 | 3.8 | 0.26 | 8.2 | 6.0 | 0.17 | 12.4 | 9.3 | 0.11 | 17.9 | 13.7 | 0.07 |
| | 2 | 1.5 | 2.6 | 1.24 | 4.0 | 2.4 | 0.51 | 5.9 | 3.8 | 0.33 | 8.7 | 5.9 | 0.21 | 12.6 | 8.6 | 0.15 |
| | 1.6 | 1.1 | 2.1 | 1.50 | 3.0 | 1.5 | 1.0 | 4.4 | 2.4 | 0.65 | 6.4 | 3.6 | 0.42 | 9.2 | 5.4 | 0.28 |
| 0.5 | 6.3 | 5.3 | 7.5 | 6.6 | 13.5 | 9.2 | 0.73 | 20.0 | 14.0 | 0.46 | 30.0 | 21.3 | 0.30 | 44.0 | 31.8 | 0.21 |
| | 4 | 3.1 | 5.0 | 9.3 | 7.0 | 3.3 | 2.84 | 10.0 | 4.9 | 1.81 | 15.0 | 7.9 | 1.17 | 21.5 | 11.7 | 0.79 |
| | 2.5 | 1.7 | 3.4 | 10.4 | 4.4 | 0.9 | 11.6 | 6.1 | 1.4 | 7.43 | 8.7 | 2.2 | 4.80 | 12.0 | 3.0 | 3.27 |
| 1 | 12.5 | 10.8 | 14.4 | 22 | 24.0 | 14.6 | 1.49 | 36.5 | 23.1 | 0.95 | 55.5 | 36.1 | 0.61 | 80.5 | 53.1 | 0.41 |
| | 8 | 6.5 | 9.6 | 33.2 | 13.0 | 5.7 | 5.68 | 19.0 | 8.9 | 3.61 | 28.5 | 14.2 | 2.33 | 40.5 | 20.6 | 1.59 |
| | 5 | 3.6 | 6.5 | 43.8 | 8.5 | 1.9 | 23.2 | 12.0 | 3.0 | 14.8 | 17.0 | 4.4 | 9.57 | 24.0 | 6.6 | 6.51 |
| 1.6 | 20 | 17.5 | 22.6 | 84.9 | 48.0 | 35.6 | 2.38 | 73.5 | 55.9 | 1.52 | 110 | 84.5 | 0.99 | 165 | 129 | 0.67 |
| | 12.5 | 10.3 | 14.7 | 135 | 24.0 | 14.0 | 9.76 | 36.0 | 21.9 | 6.23 | 53.5 | 33.4 | 4.0 | 78.0 | 50.0 | 2.73 |
| | 8 | 5.9 | 10.1 | 212 | 14.5 | 5.5 | 37.3 | 21.5 | 8.9 | 23.7 | 31.5 | 13.6 | 15.4 | 45.0 | 20.2 | 10.4 |
| 2 | 25 | 22.0 | 28.0 | 128 | 58.0 | 43.0 | 2.98 | 88.5 | 67.1 | 1.90 | 135 | 104 | 1.23 | 195 | 151 | 0.83 |
| | 16 | 13.4 | 18.6 | 198 | 30.0 | 17.5 | 11.4 | 45.0 | 27.3 | 7.24 | 68.0 | 42.5 | 4.69 | 98 | 62.1 | 3.19 |
| | 10 | 7.5 | 12.5 | 318 | 18.0 | 6.8 | 46.6 | 26.5 | 10.9 | 29.7 | 38.5 | 16.5 | 19.2 | 55 | 24.4 | 13.0 |
| 2.5 | 32 | 28.3 | 36.0 | 182 | 71.5 | 52.2 | 3.48 | 110 | 82.1 | 2.22 | 170 | 129 | 1.43 | 245 | 187 | 0.97 |
| | 25 | 21.6 | 28.4 | 233 | 49.0 | 32.2 | 7.29 | 74.5 | 50.5 | 4.64 | 115 | 80.2 | 3.0 | 165 | 116 | 2.04 |
| | 20 | 16.8 | 23.2 | 292 | 36.0 | 20.5 | 14.2 | 54.0 | 32.1 | 9.05 | 81.5 | 50.0 | 5.86 | 120 | 75.7 | 3.98 |
| | 16 | 12.9 | 19.1 | 365 | 27.5 | 12.9 | 27.8 | 41.0 | 20.5 | 17.7 | 61.0 | 31.7 | 11.5 | 88.0 | 49.9 | 7.78 |
| 3.2 | 40 | 35.6 | 44.6 | 288 | 82.0 | 60.8 | 4.76 | 125 | 95.3 | 3.03 | 190 | 148 | 1.96 | 275 | 216 | 1.33 |
| | 32 | 27.6 | 36.5 | 361 | 58.5 | 38.7 | 9.3 | 88.5 | 61.1 | 5.92 | 135 | 96.2 | 3.82 | 190 | 136 | 2.61 |
| | 25 | 21.1 | 28.9 | 461 | 42.5 | 23.4 | 19.4 | 63.5 | 37.2 | 12.4 | 94.5 | 57.4 | 8.0 | 135 | 83.4 | 5.45 |
| | 20 | 16.1 | 23.9 | 577 | 33.5 | 15.0 | 38.2 | 49.5 | 23.6 | 24.2 | 74.0 | 36.9 | 15.7 | 105 | 53.4 | 10.7 |
| 4 | 50 | 44.0 | 56.0 | 427 | 99.0 | 71.6 | 5.95 | 150 | 111 | 3.79 | 230 | 175 | 2.45 | 335 | 257 | 1.65 |
| | 40 | 34.8 | 45.2 | 533 | 71.0 | 45.8 | 11.7 | 105 | 69.9 | 7.41 | 160 | 110 | 4.79 | 235 | 165 | 3.26 |
| | 32 | 27.0 | 37.0 | 666 | 53.5 | 29.5 | 22.8 | 79.5 | 46.2 | 14.4 | 120 | 72.8 | 9.35 | 170 | 104 | 6.36 |
| | 25 | 20.3 | 29.7 | 852 | 41.0 | 18.1 | 47.7 | 60.5 | 28.3 | 30.3 | 89.5 | 43.5 | 19.6 | 130 | 65.5 | 13.3 |
| 5 | 63 | 56.0 | 70.0 | 623 | 120 | 87.7 | 7.27 | 180 | 135 | 4.63 | 275 | 210 | 2.99 | 395 | 304 | 2.03 |
| | 50 | 43.0 | 57.0 | 785 | 85.0 | 54.1 | 14.5 | 130 | 86.8 | 9.25 | 195 | 133 | 5.98 | 280 | 194 | 4.07 |
| | 40 | 34.0 | 46.0 | 981 | 64.0 | 34.4 | 28.4 | 95.5 | 54.5 | 18.1 | 140 | 81.6 | 11.7 | 205 | 124 | 7.95 |
| | 32 | 26.0 | 38.0 | 1226 | 51.0 | 22.3 | 55.4 | 75.0 | 34.8 | 35.3 | 110 | 52.5 | 22.9 | 160 | 79.5 | 15.5 |
| 6.3 | 80 | 71.0 | 89.0 | 932 | 145 | 103 | 8.96 | 220 | 160 | 5.70 | 335 | 250 | 3.69 | 490 | 370 | 2.51 |
| | 63 | 55.0 | 71.5 | 1177 | 105 | 65.0 | 18.3 | 155 | 99.0 | 11.7 | 235 | 155 | 7.55 | 340 | 277 | 5.13 |
| | 50 | 42.0 | 58.0 | 1481 | 80.0 | 42.0 | 36.7 | 115 | 62.0 | 23.3 | 175 | 100 | 15.1 | 250 | 145 | 10.3 |
| | 40 | 32.6 | 47.5 | 1854 | 60.0 | 24.0 | 71.7 | 90.0 | 39.7 | 45.6 | 135 | 63.2 | 29.5 | 195 | 95.0 | 20.1 |
| 8 | 100 | 89.0 | 111 | 1413 | 170 | 118 | 11.9 | 260 | 187 | 7.58 | 390 | 286 | 4.9 | 570 | 423 | 3.34 |
| | 80 | 69.0 | 91.0 | 1766 | 125 | 76.0 | 23.2 | 180 | 111 | 14.8 | 285 | 186 | 9.58 | 410 | 271 | 6.51 |
| | 63 | 53.0 | 73.0 | 2237 | 95.0 | 48.0 | 47.0 | 140 | 74.0 | 30.3 | 205 | 112 | 19.6 | 300 | 169 | 13.3 |
| | 50 | 40.5 | 60.0 | 2825 | 75.0 | 30.0 | 95.4 | 110 | 46.8 | 60.8 | 160 | 70.0 | 39.2 | 230 | 103 | 26.7 |

# Disc springs

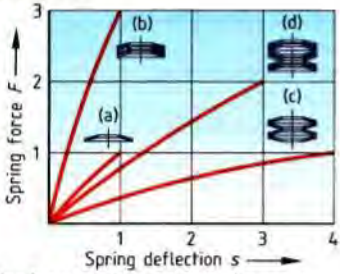
cf. DIN 2093 (2006-03)

**Single spring**




$h_0 \approx l_0 - t$

without contact surface:
Groups 1 & 2




**Spring force graph for various disc spring combinations: (a)** single spring; **(b)** parallel stack of 3 single springs: 3 times force; **(c)** series stack of 4 single springs: 4-fold deflection; **(d)** series stack of 3 parallel stacks with 2 single springs each: 3-fold deflection, 2-fold force

| | |
|---|---|
| $D_e$ | outside diameter |
| $D_i$ | inside diameter |
| $t$ | thickness of the single disc spring |
| $h_0$ | spring height (theoretic spring displacement to flat position) |
| $l_0$ | overall height of the unloaded single spring |
| $s$ | spring deflection of a single spring |
| $s_{total}$ | spring deflection of stack of disc springs |
| $F$ | load generated by a single disc spring |
| $F_{total}$ | total load generated by stack of disc springs |
| $L_0$ | length of unloaded spring stack |
| $n$ | number of disc springs in parallel stack |
| $i$ | number of disc springs in series stack |

**Series stack**



Spring force: $F_{total} = F$ — Spring deflection: $s_{total} = i \cdot s$

Spring length: $L_0 = i \cdot l_0$

**Parallel stack**



Spring force: $F_{total} = n \cdot F$ — Spring deflection: $s_{total} = s$

Spring length: $L_0 = l_0 + (n-1) \cdot t$

| Group[3] | $D_e$ h12 | $D_i$ H12 | Series A: hard springs $D_e/t \approx 18$; $h_0/t \approx 0.4$ | | | | Series B: medium hard springs $D_e/t \approx 28$; $h_0/t \approx 0.75$ | | | | Series C: soft springs $D_e/t \approx 40$; $h_0/t \approx 1.3$ | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $t$ | $l_0$ | $F$ in kN[1] | $s$[2] | $t$ | $l_0$ | $F$ in kN[1] | $s$[2] | $t$ | $l_0$ | $F$ in kN[1] | $s$[2] |
| **Group 1:** $t < 1.25$ mm without contact surface | 8 | 4.2 | 0.4 | 0.6 | 0.21 | 0.15 | 0.3 | 0.55 | 0.12 | 0.19 | 0.2 | 0.45 | 0.04 | 0.19 |
| | 10 | 5.2 | 0.5 | 0.75 | 0.33 | 0.19 | 0.4 | 0.7 | 0.21 | 0.23 | 0.25 | 0.55 | 0.06 | 0.23 |
| | 14 | 7.2 | 0.8 | 1.1 | 0.81 | 0.23 | 0.5 | 0.9 | 0.28 | 0.30 | 0.35 | 0.8 | 0.12 | 0.34 |
| | 16 | 8.2 | 0.9 | 1.25 | 1.00 | 0.26 | 0.6 | 1.05 | 0.41 | 0.34 | 0.4 | 0.9 | 0.16 | 0.38 |
| | 20 | 10.2 | 1.1 | 1.55 | 1.53 | 0.34 | 0.8 | 1.35 | 0.75 | 0.41 | 0.5 | 1.15 | 0.25 | 0.49 |
| | 25 | 12.2 | – | – | – | – | 0.9 | 1.6 | 0.87 | 0.53 | 0.7 | 1.6 | 0.60 | 0.68 |
| | 28 | 14.2 | – | – | – | – | 1.0 | 1.8 | 1.11 | 0.60 | 0.8 | 1.8 | 0.80 | 0.75 |
| | 40 | 20.4 | – | – | – | – | – | – | – | – | 1 | 2.3 | 1.02 | 0.98 |
| **Group 2:** $t = 1.25$–6 mm without contact surface | 25 | 12.2 | 1.5 | 2.05 | 2.91 | 0.41 | – | – | – | – | – | – | – | – |
| | 28 | 14.2 | 1.5 | 2.15 | 2.85 | 0.49 | – | – | – | – | – | – | – | – |
| | 40 | 20.4 | 2.2 | 3.15 | 6.54 | 0.68 | 1.5 | 2.6 | 2.62 | 0.86 | – | – | – | – |
| | 45 | 22.4 | 2.5 | 4.1 | 7.72 | 0.75 | 1.7 | 3.0 | 3.66 | 0.98 | 1.25 | 2.85 | 1.89 | 1.20 |
| | 50 | 25.4 | 3 | 4.3 | 12.0 | 0.83 | 2 | 3.4 | 4.76 | 1.05 | 1.25 | 2.85 | 1.55 | 1.20 |
| | 56 | 28.5 | 3 | 4.9 | 11.4 | 0.98 | 2 | 3.6 | 4.44 | 1.20 | 1.5 | 3.45 | 2.62 | 1.46 |
| | 63 | 31 | 3.5 | 5.6 | 15.0 | 1.05 | 2.5 | 4.2 | 7.18 | 1.31 | 1.8 | 4.15 | 4.24 | 1.76 |
| | 71 | 36 | 4 | 6.7 | 20.5 | 1.20 | 2.5 | 4.5 | 6.73 | 1.50 | 2 | 4.6 | 5.14 | 1.95 |
| | 80 | 41 | 5 | 7 | 33.7 | 1.28 | 3 | 5.3 | 10.5 | 1.73 | 2.25 | 5.2 | 6.61 | 2.21 |
| | 90 | 46 | 5 | 8.2 | 31.4 | 1.50 | 3.5 | 6 | 14.2 | 1.88 | 2.5 | 5.7 | 7.68 | 2.40 |
| | 100 | 51 | 6 | 8.5 | 48.0 | 1.65 | 3.5 | 6.3 | 13.1 | 2.10 | 2.7 | 6.2 | 8.61 | 2.63 |
| | 125 | 64 | – | – | – | – | 5 | 8.5 | 30.0 | 2.63 | 3.5 | 8 | 15.4 | 3.38 |
| | 140 | 72 | – | – | – | – | 5 | 9 | 27.9 | 3.00 | 3.8 | 8.7 | 17.2 | 3.68 |
| | 160 | 82 | – | – | – | – | 6 | 10.5 | 41.1 | 3.38 | 4.3 | 9.9 | 21.8 | 4.20 |
| | 180 | 92 | – | – | – | – | 6 | 11.1 | 37.5 | 3.83 | 4.8 | 11 | 26.4 | 4.65 |

⇒ **Disc spring DIN 2093 – A 16:** Series A, outside diameter $D_e = 16$ mm

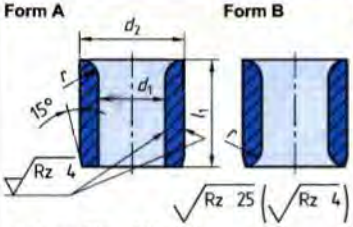
1) Spring force $F$ of a single disc with spring deflection $s \approx 0.75 \cdot h_0$
2) $s \approx 0{,}75 \cdot h_0$
3) Size 3: $t > 6$–14 mm, with contact surface, $D_e = 125, 140, 160, 180, 200, 225, 250$ mm

# Drill bushings

## Press-fit drill bushings

cf. DIN 179 (1992-11); Standard sheet withdrawn

Form A Form B




Hardness 780 + 80 HV 10

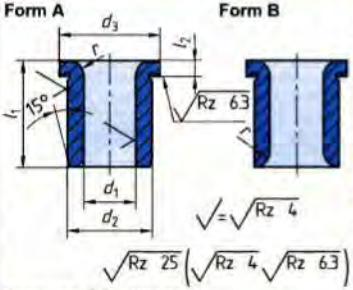
| $d_1$ F7 over / to | 1 / 1.8 | 1.8 / 2.6 | 2.6 / 3.3 | 3.3 / 4 | 4 / 5 | 5 / 6 | 6 / 8 | 8 / 10 | 10 / 12 | 12 / 15 | 15 / 18 | 18 / 22 | 22 / 26 | 26 / 30 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $l_1$ short | 6 | | 8 | | | 10 | | 12 | | 16 | | 20 | | 25 |
| $l_1$ medium | 9 | | 12 | | | 16 | | 20 | | 28 | | 36 | | 45 |
| $l_1$ long | – | | 16 | | | 20 | | 25 | | 36 | | 45 | | 56 |
| $d_2$ n6 | 4 | 5 | 6 | 7 | 8 | 10 | 12 | 15 | 18 | 22 | 26 | 30 | 35 | 42 |
| $r$ | 1 | | 1 | | | 1.5 | | 2 | | | | 3 | | |

⇒ **Drill bushing DIN 179 – A 18 x 16:** Form A, $d_1$ = 18 mm, $l_1$ = 16 mm

## Headed press-fit drill bushings

cf. DIN 172 (1992-11); Standard sheet withdrawn

Form A Form B




Hardness 780 + 80 HV 10

| $d_1$ F7 over / to | 1 / 1.8 | 1.8 / 2.6 | 2.6 / 3.3 | 3.3 / 4 | 4 / 5 | 5 / 6 | 6 / 8 | 8 / 10 | 10 / 12 | 12 / 15 | 15 / 18 | 18 / 22 | 22 / 26 | 26 / 30 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $l_1$ short | 6 | | 8 | | | 10 | | 12 | | 16 | | 20 | | 25 |
| $l_1$ medium | 9 | | 12 | | | 16 | | 20 | | 28 | | 36 | | 45 |
| $l_1$ long | – | | 16 | | | 20 | | 25 | | 36 | | 45 | | 56 |
| $d_2$ n6 | 4 | 5 | 6 | 7 | 8 | 10 | 12 | 15 | 18 | 22 | 26 | 30 | 35 | 42 |
| $d_3$ | 7 | 8 | 9 | 10 | 11 | 13 | 15 | 18 | 22 | 26 | 30 | 34 | 39 | 46 |
| $l_2$ | 2 | | 2.5 | | | 3 | | 4 | | | | 5 | | |
| $r$ | 1 | | 1 | | | 1.5 | | 2 | | | | 3 | | |

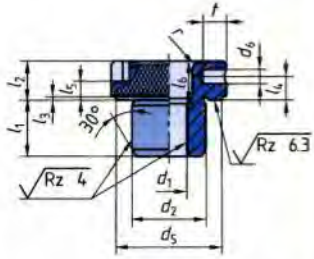
⇒ **Drill bushing DIN 172 – A 22 x 36:** Form A, $d_1$ = 22 mm, $l_1$ = 36 mm

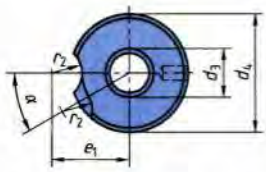
## Slip type jig bushings

cf. DIN 173-1 (1992-11); Standard sheet withdrawn

**Form K** Quick-change bushings for right hand cutting tools

**Form L** Removable bushings (dimensions same as form K)




Rz 25 (Rz 4 Rz 6.3)

Hardness 780 + 80 HV 10

| $d_1$ F7 over / to | 4 / 6 | 6 / 8 | 8 / 10 | 10 / 12 | 12 / 15 | 15 / 18 | 18 / 22 | 22 / 26 | 26 / 30 | 30 / 35 | 35 / 42 | 42 / 48 | 48 / 55 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $d_2$ m6 | 10 | 12 | 15 | 18 | 22 | 26 | 30 | 35 | 42 | 48 | 55 | 62 | 70 |
| $l_1$ short | 12 | | 17 | | 20 | | 25 | | 30 | | | 35 | |
| $l_1$ medium | 20 | | 28 | | 36 | | 45 | | 56 | | | 67 | |
| $l_1$ long | 25 | | 36 | | 45 | | 56 | | 67 | | | 78 | |
| $d_3$ | 6.5 | 8.5 | 10.5 | 12.5 | 15.5 | 19 | 23 | 27 | 31 | 36 | 43 | 50 | 57 |
| $d_4$ | 18 | 22 | 26 | 30 | 34 | 39 | 46 | 52 | 59 | 66 | 74 | 82 | 90 |
| $d_5$ | 15 | 18 | 22 | 26 | 30 | 35 | 42 | 46 | 53 | 60 | 68 | 76 | 84 |
| $d_6$ H7 | 2.5 | | 3 | | 5 | | | 6 | | | | 8 | |
| $l_2$ | 8 | | 10 | | 12 | | | | | 16 | | | |
| $\alpha$ | 65° | 60° | 50° | | 35° | | 30° | | | | 25° | | |
| $l_3$ | 1 | | | | | | 1.5 | | 2 | | | | |
| $l_4$ | 4.25 | | 6 | | 7 | | | | 9 | | 8 | | |
| $l_5$ | 3 | | 4 | | 5.5 | | | | 7 | | | | |
| $l_6$ medium | 8 | | 12 | | 16 | | 20 | | 26 | | | 32 | |
| $l_6$ long | 13 | | 20 | | 25 | | 31 | | 37 | | | 43 | |
| $t$ | 4 | | 5 | 6 | 7 | | 8 | | 9 | 10 | 12 | | 14 |
| $r_1$ | 2 | | | | 3 | | | | | | | 3.5 | |
| $r_2$ | 7 | | 8.5 | | 10.5 | | | | | 12.5 | | | |
| $e_1$ | 13 | 16.5 | 18 | 20 | 23.5 | 26 | 29.5 | 32.5 | 36 | 41.5 | 45.5 | 49 | 53 |

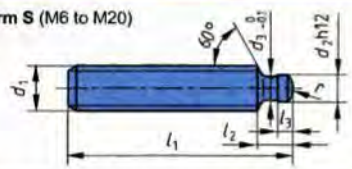
⇒ **Drill bushing DIN 173 – K 15 x 22 x 36:** Form K, $d_1$ = 15 mm, $d_2$ = 22 mm, $l_1$ = 36 mm

# Grub screws, Thrust pads, Ball knobs

## Grub screws with thrust point

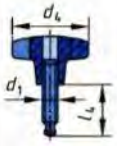
cf. DIN 6332 (2003-04)

**Form S** (M6 to M20)

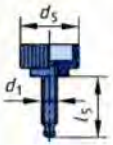



**Application examples as clamping screws**

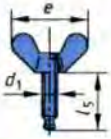
with star knob[1] DIN 6335 M6 to M20




with knurled nut DIN 6303 M6 to M10




with wing nut DIN 315 M6 to M10




| $d_1$ | M6 | | M8 | | M10 | | M12 | | | M16 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $d_2$ | 4.8 | | 6 | | 8 | | 8 | | | 12 | | |
| $d_3$ | 4 | | 5.4 | | 7.2 | | 7.2 | | | 11 | | |
| $r$ | 3 | | 5 | | 6 | | 6 | | | 9 | | |
| $l_2$ | 6 | | 7.5 | | 9 | | 10 | | | 12 | | |
| $l_3$ | 2.5 | | 3 | | 4.5 | | 4.5 | | | 5 | | |
| $d_4$ | 32 | | 40 | | 50 | | 63 | | | 80 | | |
| $d_5$ | 24 | | 30 | | 36 | | – | | | – | | |
| $e$ | 33 | | 39 | | 51 | | 65 | | | 73 | | |
| $l_1$ | 30 | 50 | 40 | 60 | 60 | 80 | 60 | 80 | 100 | 80 | 100 | 125 |
| $l_4$ | 20 | 40 | 27 | 47 | 44 | 64 | 40 | 60 | 80 | – | – | – |
| $l_5$ | 22 | 42 | 30 | 50 | 48 | 68 | – | – | – | – | – | – |

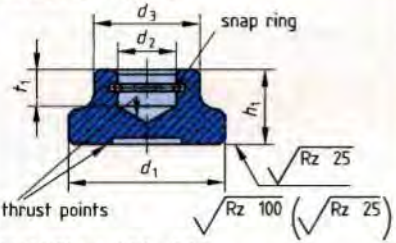
⇒ **Grub screw DIN 6332 – S M 12 x 60:** Form S with threads $d_1$ = M12, $l_1$ = 60 mm

[1] or scallop knob DIN 6336 M6 to M16

## Thrust pads

cf. DIN 6311 (2002-06)

**Form S** with snap ring




EHT (450 HV 1) 0.3 + 0.2mm, surface hardness 550 + 100 HV 10

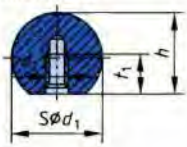
| $d_1$ | $d_2$ H12 | $d_3$ | $h_1$ | $t_1$ | Snap ring DIN 7993 | Grub screw DIN 6332 |
|---|---|---|---|---|---|---|
| 12 | 4.6 | 10 | 7 | 4 | – | M6 |
| 16 | 6.1 | 12 | 9 | 5 | – | M8 |
| 20 | 8.1 | 15 | 11 | 6 | 8 | M10 |
| 25 | 8.1 | 18 | 13 | 7 | 8 | M12 |
| 32 | 12.1 | 22 | 15 | 7.5 | 12 | M16 |
| 40 | 15.6 | 28 | 16 | 8 | 16 | M20 |

⇒ **Thrust pad DIN 6311 – S 40:** Form S, $d_1$ = 40 mm, with inserted snap ring

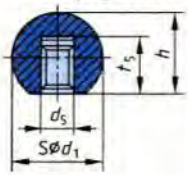
## Ball knobs

cf. DIN 319 (2002-04)

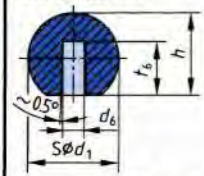
**Form C** with threads



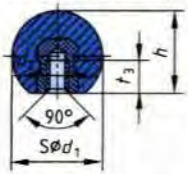

**Form L** with clamping sleeve




**Form M** with conical hole




**Form E** with threaded bushing




Other forms no longer standardized.

| $d_1$ | 16 | 20 | 25 | | | 32 | | | 40 | | | 50 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $d_2$ | M4 | M5 | M6 | | | M8 | | | M10 | | | M12 | | |
| $t_1$ | 7 | 9 | 11 | | | 14.5 | | | 18 | | | 21 | | |
| $t_3$ | 6 | 7.5 | 9 | | | 12 | | | 15 | | | 18 | | |
| $d_5$ | 4 | 5 | 6 | 8 | 10 | 8 | 10 | 12 | 10 | 12 | 16 | 12 | 16 | 20 |
| $t_5$ | 11 | 13 | 16 | 15 | 15 | 15 | 20 | 20 | 20 | 23 | 23 | 20 | 23 | 28 |
| $d_6$ | 4 | 5 | 6 | 8 | – | 8 | 10 | – | 10 | 12 | – | 12 | 16 | – |
| $t_6$ | 9 | 12 | 15 | 15 | – | 15 | 15 | – | 20 | 20 | – | 22 | 22 | – |
| $h$ | 15 | 18 | 22.5 | | | 29 | | | 37 | | | 46 | | |

⇒ **Ball knob DIN 319 – E 25 PF:** Form E, $d_1$ = 25 mm, of phenolic molding compound PF (thermoset plastic)

**Material:** Ball knob of phenolic molding compound PF (thermoset plastic); threaded bushing of steel (St) by choice of manufacturer; other materials by agreement.

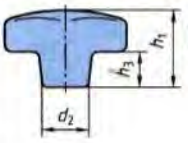
**Color:** black

# Knobs, Locating and seating pins

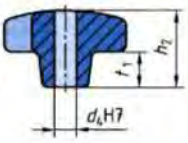
## Star knobs

cf. DIN 6335 (1996-01)

Form A

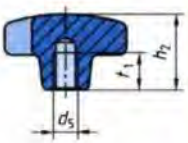


Form B

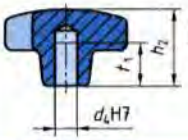


Form E





Form C



Form K



| $d_1$ | $d_2$ | $d_3$ | $d_4$ | $d_5$ | $h_1$ | $h_2$ | $h_3$ | $t_1$ |
|---|---|---|---|---|---|---|---|---|
| 32 | 12 | 18 | 6 | M6 | 21 | 20 | 10 | 12 |
| 40 | 14 | 21 | 8 | M8 | 26 | 25 | 14 | 15 |
| 50 | 18 | 25 | 10 | M10 | 34 | 32 | 20 | 18 |
| 63 | 20 | 32 | 12 | M12 | 42 | 40 | 25 | 22 |
| 80 | 25 | 40 | 16 | M16 | 52 | 50 | 30 | 28 |
| 100[1] | 32 | 48 | 20 | M20 | 65 | 60 | 38 | 36 |

| Form | Description |
|---|---|
| A to E | Metal knobs |
| A | rough part of metal |
| B | with through bore $d_4$ |
| C | with blind bore $d_4$ |
| D | with through threaded bore $d_5$ |
| E | with blind threaded bore $d_5$ |
| K[2] | of molding mat. (plastic) with threaded bushing $d_5$ (of metal) |
| L[2] | of molding material (plastic) with threaded pin $d_5$ (of metal) |

⇒ **Star knob DIN 6335 – A 50 AL:** Form A, $d_1$ = 50 mm, of aluminum

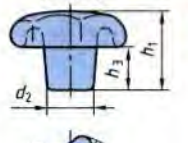
[1] This size is not available in molding material.

[2] Sometimes with insignificant other dimensions; material like fluted knobs DIN 6336

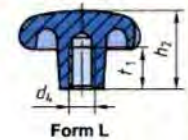
## Fluted knobs

cf. DIN 6336 (1996-01)

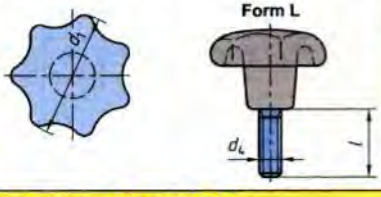
Form A



Form E



Form L



| $d_1$ | $d_2$ | $d_4$ | $h_1$ | $h_2$ | $h_3$ | $t_1$ | $l$ | |
|---|---|---|---|---|---|---|---|---|
| 32 | 12 | M6 | 21 | 20 | 10 | 12 | 20 | 30 |
| 40 | 14 | M8 | 26 | 25 | 13 | 15 | 20 | 30 |
| 50 | 18 | M10 | 34 | 32 | 17 | 18 | 25 | 30 |
| 63 | 20 | M12 | 42 | 40 | 21 | 22 | 30 | 40 |
| 80 | 25 | M16 | 52 | 50 | 25 | 28 | 30 | 40 |

⇒ **Fluted knob DIN 6336 – L 40 x 30:** Form L (molding material) $d_1$ = 40 mm, $l$ = 30 mm

Forms A to E (metal knobs) as well as K and L (knobs of molding material) correspond to star knobs DIN 6335.

**Materials:** Cast iron, aluminum, molding compounds (PF 31 N RAL 9005 DIN 7708-2)

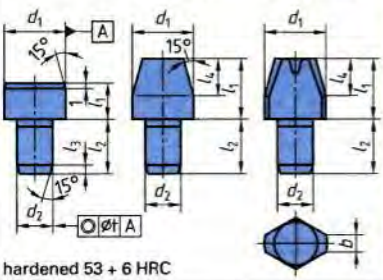
## Locating and seating pins

cf. DIN 6321 (2002-10)

**Form A** Seating pin

**Form B** Locating pin cylindrical

**Form C** Locating pin truncated



hardened 53 + 6 HRC

| $d_1$ g6 | $l_1$ Form A h9 | $l_1$ Form B and C short | $l_1$ Form B and C long | $b$ | $d_2$[1] n6 | $l_2$ | $l_3$ | $l_4$ | $t$ |
|---|---|---|---|---|---|---|---|---|---|
| 6 | 5 | 7 | 12 | 1 | 4 | 6 | 1.2 | 4 | 0.02 |
| 8 | – | 10 | 16 | 1.6 | 6 | 9 | 1.6 | 6 | |
| 10 | 6 | | 18 | 2.5 | | | | | |
| 12 | – | | | | | | | | |
| 16 | 8 | 13 | 22 | 3.5 | 8 | 12 | 2 | 8 | 0.04 |
| 20 | – | 15 | 25 | 5 | 12 | 18 | 2.5 | 9 | |
| 25 | 10 | | | | | | | | |

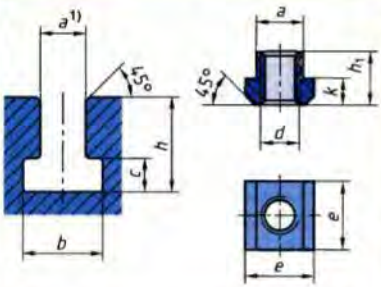
⇒ **Clevis pins DIN 6321 – C 20 x 25:** Form C, $d_1$ = 20 mm, $l_1$ = 25 mm

[1] Appropriate bore tolerance: H7

# T-slots and accessories, Spherical washers, Conical seats

## T-slots and nuts for T-slots

cf. DIN 650 (1989-10) and 508 (2002-06)

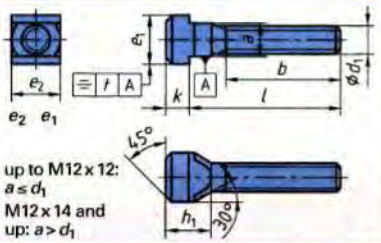



1) Tolerance class H8 for pilot T-slots and clamping slots; H12 for clamping slots

| Width $a$ | 8 | 10 | 12 | 14 | 18 | 22 | 28 | 36 | 42 |
|---|---|---|---|---|---|---|---|---|---|
| Deviation from $a$ | −0.3/−0.5 | | −0.3/−0.6 | | | | | −0.4/−0.7 | |
| $b$ | 14.5 | 16 | 19 | 23 | 30 | 37 | 46 | 56 | 68 |
| Deviation from $b$ | 1.5/0 | +2/0 | | | | +3/0 | +4/0 | | |
| $c$ | 7 | 7 | 8 | 9 | 12 | 16 | 20 | 25 | 32 |
| Deviation from $c$ | +1/0 | | +2/0 | | | | | +3/0 | |
| $h$ max. | 18 | 21 | 25 | 28 | 36 | 45 | 56 | 71 | 85 |
| $h$ min. | 15 | 17 | 20 | 23 | 30 | 38 | 48 | 61 | 74 |
| Thread $d$ | M6 | M8 | M10 | M12 | M16 | M20 | M24 | M30 | M36 |
| $e$ | 13 | 15 | 18 | 22 | 28 | 35 | 44 | 54 | 65 |
| $h_1$ | 10 | 12 | 14 | 16 | 20 | 28 | 36 | 44 | 52 |
| $k$ | 6 | 6 | 7 | 8 | 10 | 14 | 18 | 22 | 26 |
| Deviation from $k$ | 0/−0.5 | | | | | 0/−1 | | | |
| ⇒ | **Nut DIN 508 – M10 x 12:** $d$ = M10, $a$ = 12 mm | | | | | | | | |

## Bolts for T-slots

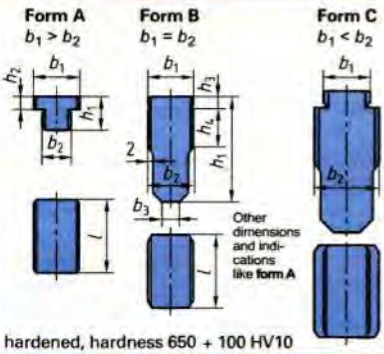
cf. DIN 787 (2005-02)




| $d_1$ | M8 | M10 | M12 | | M16 | M20 | M24 | M30 |
|---|---|---|---|---|---|---|---|---|
| $a$ | 8 | 10 | 12 | 14 | 18 | 22 | 28 | 36 |
| $b$ from | 22 | 30 | 35 | | 45 | 55 | 70 | 80 |
| $b$ to | 50 | 60 | 120 | | 150 | 190 | 240 | 300 |
| $e_1$ | 13 | 15 | 18 | 22 | 28 | 35 | 44 | 54 |
| $h_1$ | 12 | 14 | 16 | 20 | 24 | 32 | 41 | 50 |
| $k$ | 6 | 6 | 7 | 8 | 10 | 14 | 18 | 22 |
| Nominal lengths $l$ | 25, 32, 40, 50, 63, 80, 100, 125, 160, 200, 250, 315, 400, 500 mm | | | | | | | |
| ⇒ | **Bolt DIN 787 – M10 x 10 x 100 – 8.8:** $d_1$ = M10, $a$ = 10 mm, $l$ = 100 mm, property class 8.8 | | | | | | | |

## Loose slot tenons

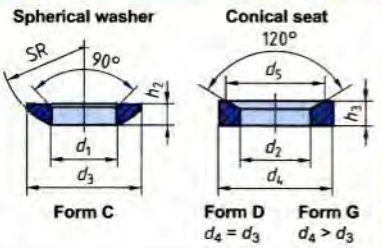
vgl. DIN 6323 (2003-08)




| $b_1$ h6 | $b_2$ h6 | Form | $b_3$ | $h_1$ | $h_2$ | $h_3$ | $h_4$ | $l$ |
|---|---|---|---|---|---|---|---|---|
| 12 | 6 | A | – | 12 | 3.6 | – | – | 20 |
| | 8 | | | | | | | |
| | 10 | | | | | | | |
| | 12 | B | 5 | 28.6 | – | 5.5 | 9 | 20 |
| 20 | 12 | A | – | 14 | 5.5 | – | – | 32 |
| | 14 | | | | | | | |
| | 18 | | | | | | | |
| | 22 | C | 9 | 50.5 | – | 7 | 18 | 40 |
| | 28 | | 12 | 61.5 | | | 24 | |
| | 36 | | 16 | 76.5 | | | 30 | 50 |
| | 42 | | 19 | 90.5 | | | 36 | |
| ⇒ | **Slot tenon DIN 6323 – C 20 x 28:** Form C, $b_1$ = 20 mm, $b_2$ = 28 mm | | | | | | | |

## Spherical washers and conical seats

cf. DIN 6319 (2001-10)



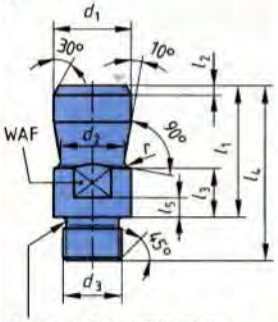

| $d_1$ H13 | $d_2$ H13 | $d_3$ | $d_4$ Form D | $d_4$ Form G | $d_5$ | $h_2$ | $h_3$ Form D | $h_3$ Form G | $R$ Sphere |
|---|---|---|---|---|---|---|---|---|---|
| 6.4 | 7.1 | 12 | 12 | 17 | 11 | 2.3 | 2.8 | 4 | 9 |
| 8.4 | 9.6 | 17 | 17 | 24 | 14.5 | 3.2 | 3.5 | 5 | 12 |
| 10.5 | 12 | 21 | 21 | 30 | 18.5 | 4 | 4.2 | 5 | 15 |
| 13 | 14.2 | 24 | 24 | 36 | 20 | 4.6 | 5 | 6 | 17 |
| 17 | 19 | 30 | 30 | 44 | 26 | 5.3 | 6.2 | 7 | 22 |
| 21 | 23.2 | 36 | 36 | 50 | 31 | 6.3 | 7.5 | 8 | 27 |
| ⇒ | **Spherical washer DIN 6319 – C 17:** Form C, $d_1$ = 17 mm | | | | | | | | |

# Punch holder shanks, Punches, Machined plates

## Punch holder shanks form A[1]

cf. DIN ISO 10242-1 and -2 (2000-03)

Form A




thread undercut DIN 76-A

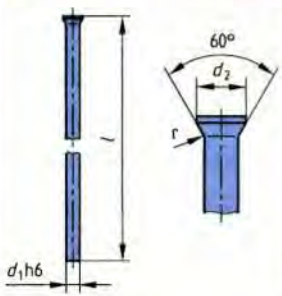
| $d_1$ f9 | $d_2$ | $d_3$ | $l_1$ | $l_2$ | $l_3$ | $l_4$ | $l_5$ | WAF |
|---|---|---|---|---|---|---|---|---|
| 20 | 15 | M16 × 1.5 | 40 | 2 | 12 | 58 | 4 | 17 |
| 25 | 20 | M16 × 1.5<br>M20 × 1.5 | 45 | 2.5 | 16 | 68 | 6 | 21 |
| 32 | 25 | M20 × 1.5<br>M24 × 1.5 | 56 | 3 | 16 | 79 | 6 | 27 |
| 40 | 32 | M24 × 1.5<br>M27 × 2<br>M30 × 2 | 70 | 4 | 26 | 93 | 12 | 36 |
| 50 | 42 | M30 × 2 | 80 | 5 | 26 | 108 | 12 | 41 |

⇒ **Punch holder shanks ISO 10242-1 A – 40 x M30 x 2:** Form A, $d_1$ = 40 mm, $d_3$ = M30 × 2

[1] Form C with mounting flange instead of screw threads

## Round punch Form D[1]

cf. DIN 9861-1 (1992-07)




$d_2 \approx (1.1–1.8) \cdot d_1$ (depending on ∅ $d_1$)

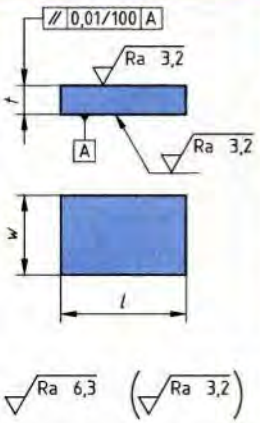
| $d_1$ h6 from–to | Graduation | $l$ 0/+0.5 | | | Material | Hardness Shank | Hardness Head |
|---|---|---|---|---|---|---|---|
| 0.5–0.95 | 0.05 | 71 | 80 | – | WS[2] | 62 ± 2 HRC | 45 ± 5 HRC |
| 1.0–2.9 | 0.1 | | | | HWS[3] | | |
| 3.0–6.4 | 0.1 | 71 | 80 | 100 | | | |
| 6.5–20 | 0.5 | | | | HSS[4] | 64 ± 2 HRC | 50 ± 5 HRC |

⇒ **Punch DIN 9861 D – 5.6 x 71 HWS:** Form D, $d_1$ = 5.6 mm, $l$ = 71 mm, of high-alloyed cold-work steel

[1] Form DA with allowable enlargement below the head
[2] WS alloyed cold-work steel
[3] HWS high-alloyed cold-work steels
[4] HSS high-speed steels

## Machined plates for press tools and for fixtures

cf. DIN ISO 6753-1 (2006-09)




Ra 6,3 (Ra 3,2)

Note: These surface roughness values only apply to milled edges.

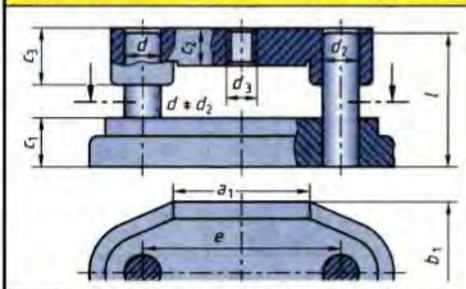
| $l$ | Plate thickness $t$ for plate dimension $w$ 80 | 100 | 125 | 160 | 200 | 250 | 315 | 400 | 500 | 630 |
|---|---|---|---|---|---|---|---|---|---|---|
| 160 | 20, 25, 32 | | | | – | – | – | – | – | – |
| 200 | – | 25, 32, 40 | | | | – | – | – | – | – |
| 250 | – | – | 25, 32, 40 | | | | – | – | – | – |
| 315 | – | – | – | 32, 40, 50 | | | | – | – | – |
| 400 | – | – | – | – | 32, 40, 50 | | | | – | – |
| 500 | – | – | – | – | – | 32, 40, 50 | | | | – |
| 630 | – | – | – | – | – | – | 32, 40, 50, 63 | | | |

⇒ **Machined plate ISO 6753-1 1 – 315 x 200 x 32:** Fabricated by flame cutting (1), $l$ = 315 mm, $w$ = 200 mm, $t$ = 32 mm

| Code | Fabrication method | Limit deviations for length $l$ and width $w$ ($w \le 630$ mm) | Limit deviations for thickness $t$ |
|---|---|---|---|
| 1 | Flame cutting<br>Beam cutting | +4<br>+1 | ±2 |
| 2 | Milling | +0.4<br>+0.2 | +0.5<br>+0.3 |

# Pillar die sets

## Pillar die sets with rectangular working surface forms C and CG[1] cf. DIN 9812 (1981-12)

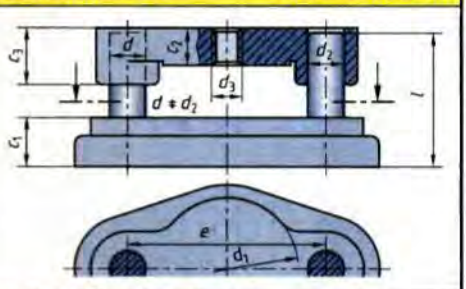



| $a_1 \times b_1$ | $c_1$ | $c_2$ | $c_3$ | $d_2$ | $d_3$ | $e$ | $l$ |
|---|---|---|---|---|---|---|---|
| 80 × 63<br>100 × 63 | 50 | 30 | 80 | 19 | M20 × 1.5 | 125<br>145 | 160 |
| 100 × 80<br>160 × 80 | 50 | 30 | 80 | 25 | M20 × 1.5 | 155<br>215 | 160 |
| 125 × 100<br>250 × 100 | 50 | 40 | 90 | 25<br>32 | M24 × 1.5 | 180<br>315 | 170<br>180 |
| 160 × 125<br>315 × 125 | 56 | 40 | 90 | 32 | M24 × 1.5 | 225<br>380 | 180 |
| 200 × 160<br>315 × 160 | 56<br>63 | 50 | 100 | 32<br>40 | M30 × 2 | 265<br>395 | 200<br>220 |
| 250 × 200<br>315 × 250 | 63 | 50 | 100 | 40 | M30 × 2 | 330<br>395 | 220 |

⇒ **Center pillar die set DIN 9812 – C 100 x 80:** Form C, $a_1 \times b_1$ = 100 mm × 80 mm

[1] Form C without threads; form CG with threads $d_3$

## Pillar die sets with circular working surface forms D and DG[2] cf. DIN 9812 (1981-12)

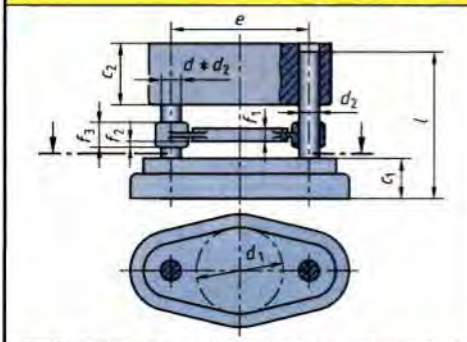



| $d_1$ | $c_1$ | $c_2$ | $c_3$ | $d_2$ | $d_3$ | $e$ | $l$ |
|---|---|---|---|---|---|---|---|
| 50<br>63 | 40 | 25 | 65 | 16 | M16 × 1.5 | 80<br>95 | 125<br>140 |
| 80 | 50 | 30 | 80 | 19 | M20 × 1.5 | 125 | 160 |
| 100 | | | | 25 | | 155 | |
| 125 | | | | 25 | | 180 | |
| 160 | 56 | 40 | 90 | 32 | M24 × 1.5 | 225 | 180 |
| 180 | | | | | | 245 | 180 |
| 200 | | | | | | 265 | 190 |
| 250<br>315 | 56<br>63 | 50 | 100 | 40 | M30 × 2 | 330<br>395 | 200<br>220 |

⇒ **Pillar die set DIN 9812 – D 160:** Form D, $d$ = 160 mm

[2] Form D without threads; form DG with threads $d_3$

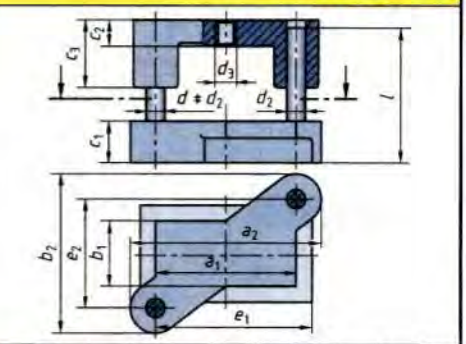
## Pillar die sets with centrally positioned pillars and thick pillar guide plate, form DF cf. DIN 9816 (1981-12)




| $d_1$ | $c_1$ | $c_2$ | $d_2$ | $e$ | $f_1$ | $f_2$ | $f_3$ | $l$ |
|---|---|---|---|---|---|---|---|---|
| 80 | 50 | 80 | 19 | 125 | 16 | 10 | 36 | 170 |
| 100 | 50 | 85 | 25 | 155 | 18 | 11 | 40 | 180 |
| 125 | | 90 | | 180 | | | | 190 |
| 160 | 56 | 100 | 32 | 225 | 23 | 11 | 45 | 220 |
| 200 | | 110 | | 265 | | | | 240 |

⇒ **Pillar die set DIN 9816 – DF 100 GG:** Form DF, $d_1$ = 100 mm, cast iron slide guide

## Pillar die sets with diagonal pillars, forms C and CG[3] cf. DIN 9819 (1981-12)




| $a_1 \times b_1$ | $a_2$ | $b_2$ | $c_1$ | $c_2$ | $c_3$ | $d_2$ | $e_1$ | $e_2$ | $l$ |
|---|---|---|---|---|---|---|---|---|---|
| 80 × 63 | 135 | 180 | 50 | 30 | 80 | 19 | 75 | 103 | 160 |
| 125 × 80 | 190 | 215 | | | | 25 | 120 | 128 | |
| 125 × 100 | | 235 | | 40 | 90 | 25 | | 148 | 170 |
| 250 × 100 | 325 | 255 | 56 | 40 | 90 | 32 | 245 | 158 | 180 |
| 160 × 125 | 235 | 280 | | | | | 155 | 183 | |
| 315 × 125 | 390 | | | | | | 310 | | |

⇒ **Pillar die set DIN 9819 – C 160 x 80 GG:** Form C, $a_1$ = 160 mm, $b_1$ = 80 mm, cast iron

[3] Form C without threads; form CG with threads $d_3$

# V-belts, Positive drive belts

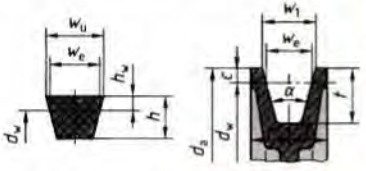
## Design types

| Designation<br>Standard for the belts | Range of dimensions<br>h[1] in mm<br>Standard for pulleys | <br>L[2] in mm<br> | Speed range<br>$v_{max}$ in m/s | Power range<br>$P'_{max}$ in kW[3] | Properties, application |
|---|---|---|---|---|---|
| Classic V-belts<br>  <br>DIN 2215, ISO 4184 | 4–25<br>DIN 2217, ISO 4183 | 185–19000 | 30 | 65 | For higher maximum tensile strengths, reliable tractive power; construction equipment, variable drives for the mining industry, agricultural machinery, conveyors, general machine construction |
| Narrow V-belts<br>  <br>DIN 7753, ISO 4184 | 8–18<br>DIN 2211, ISO 4183 | 630–12500 | 40 | 70 | Good power transmission, twice the power with the same width as classic V-belts; gearbox manufacturing, machine tools, HVAC |
| Cogged V-belts<br>  <br>DIN 2215, DIN 7753 | 4–25<br>DIN 2211, DIN 2217 | 800–3150 | 50 | 70 | Low elongation, small pulley diameter, high temperature resistance from –30°C to +80°C; automotive alternator drives, transmission design, pumps, HVAC |
| Joined V-belts<br>(Power Band)<br>  | 10–26<br>DIN 2211, DIN 2217 | 1250–15000 | 30 | 65 | Insensitive to vibration or impact, no twisting of single belts in the pulleys, absolutely uniform force distribution, high tensile strength, for long distances between axles; paper machines |
| V-ribbed belts<br>(ribbed belts)<br>  <br>DIN 7867 | 3–17<br>DIN 7867 | 600–15000 | 60 | 20 | Large transmission ratios possible, low vibration running behavior; automotive alternator drives, compressor drives in HVAC, small machines |
| Wide V-belts<br>  <br>DIN 7719 | 6–18<br>DIN 7719 | 468–2500 | 30 | 85 | Excellent transverse strength, very high tensile strength, flexible; speed control gears, machine tools, textile machines, printing machines, agricultural machinery |
| Double V-belts<br>(Hexagonal belts)<br>  <br>DIN 7722, ISO 5289 | 10–25<br>DIN 2217 | 2000–6900 | 30 | 20 | Good power transmission for drives with several pulleys and alternating direction of rotation, 10% less efficiency than classic V-belts; agricultural machinery, textile machines, general machine building |
| Positive drive belts<br>  <br>DIN 7721, DIN ISO 5296 | 0.7–5.0<br>DIN ISO 5294 | 100–3620 | 40–80 | 0.5–900 | Efficiency $\eta_{max} \geq 0.98$, synchronous running, low prestress forces, therefore lower bearing load; precision machine drives, office machine drives, automotive industry, CNC spindle drives |

[1] Belt height (pages 254, 255) [2] Belt length [3] Transmittable power per belt

# Narrow V-belts

Narrow V-belts DIN 7753-1 (1988-01) — Narrow V-belt pulley DIN 2211-1 (1984-03)




**Effective diameter** $d_e = d_a - 2 \cdot c$

⇒ **Narrow V-belt DIN 7753 – XPZ 710:** Narrow V-belt, cogged profile, reference length 710 mm

| Designations | | Narrow V-belts, V-belt pulleys | | | |
|---|---|---|---|---|---|
| Belt profile (ISO designation codes) | | SPZ | SPA | SPB | SPC |
| $w_u$ upper belt width<br>$w_e$ effective width | | 9.7<br>8.5 | 12.7<br>11 | 16.3<br>14 | 22<br>19 |
| $h$ belt height<br>$h_w$ distance | | 8<br>2 | 10<br>2.8 | 13<br>3.5 | 18<br>4.8 |
| $d_{min}$ minimum allowable effective ∅<br>$w_1$ upper groove width | | 63<br>9.7 | 90<br>12.7 | 140<br>16.3 | 224<br>22 |
| $c$ distance from effective ∅ to outer ∅<br>$t$ minimum allowable groove depth | | 2<br>11 | 2.8<br>13.8 | 3.5<br>17.5 | 4.8<br>23.8 |
| $e$ groove spacing for multi-groove pulleys<br>$f$ groove spacing from outer edge | | 12<br>8 | 15<br>10 | 19<br>12.5 | 25.5<br>17 |
| $\alpha$ | 34° for effective ∅ up to | 80 | 118 | 190 | 315 |
| | 38° for effective ∅ over | 80 | 118 | 190 | 315 |




| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Angle factor $c_1$ | 1 | 1.02 | 1.05 | 1.08 | 1.12 | 1.16 | 1.22 | 1.28 | 1.37 | 1.47 |
| Wrap angle $\beta$ | 180° | 170° | 160° | 150° | 140° | 130° | 120° | 110° | 100° | 90° |

**Service factor $c_2$**

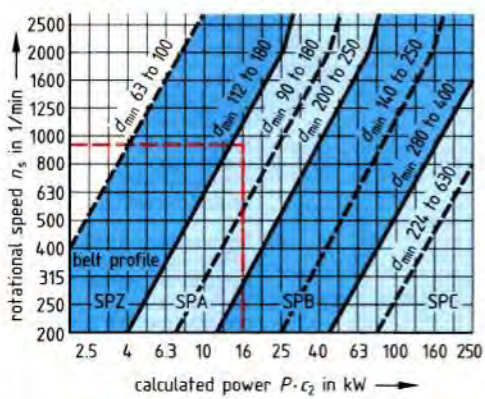
| Daily operating time in hours | | | Driven machines (examples) |
|---|---|---|---|
| up to 10 | from 10 to 16 | over 16 | |
| 1.0<br>1.1 | 1.1<br>1.2 | 1.2<br>1.3 | Centrifugal pumps, fans, conveyor belts for light material<br>Machine tools, presses, sheet metal shearers, printing machines |
| 1.2<br>1.3 | 1.3<br>1.4 | 1.4<br>1.5 | Grinding gears, piston pumps, textile and paper machines<br>Stone crushers, mixers, winches, cranes, excavators |

## Efficiency values for narrow V-belts

cf. DIN 7753-2 (1976-04)

| Belt profile | SPZ | | | SPA | | | SPB | | | SPC | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| smaller pulley $d_{min}$ | 63 | 100 | 180 | 90 | 160 | 250 | 140 | 250 | 400 | 224 | 400 | 630 |
| smaller pulley $n_s$ | Power rating $P_{rated}$ in kW per belt | | | | | | | | | | | |
| 400 | 0.35 | 0.79 | 1.71 | 0.75 | 2.04 | 3.62 | 1.92 | 4.86 | 8.64 | 5.19 | 12.56 | 21.42 |
| 700 | 0.54 | 1.28 | 2.81 | 1.17 | 3.30 | 5.88 | 3.02 | 7.84 | 13.82 | 8.13 | 19.79 | 32.37 |
| 950 | 0.68 | 1.66 | 3.65 | 1.48 | 4.27 | 7.60 | 3.83 | 10.04 | 17.39 | 10.19 | 24.52 | 37.37 |
| 1450 | 0.93 | 2.36 | 5.19 | 2.02 | 6.01 | 10.53 | 5.19 | 13.66 | 22.02 | 13.22 | 29.46 | 31.74 |
| 2000 | 1.17 | 3.05 | 6.63 | 2.49 | 7.60 | 12.85 | 6.31 | 16.19 | 22.07 | 14.58 | 25.81 | – |
| 2800 | 1.45 | 3.90 | 8.20 | 3.00 | 9.24 | 14.13 | 7.15 | 16.44 | 9.37 | 11.89 | – | – |

**Profile selection for narrow V-belts**




$P$ power to be transmitted
$P_{rated}$ power rating per belt
$N$ number of belts
$c_1$ angle factor
$c_2$ service factor

**Number of belts**

$$N = \frac{P \cdot c_1 \cdot c_2}{P_{rated}}$$

**Example:**

Transmission parameters $P = 12$ kW with $c_1 = 1.12$; $c_2 = 1.4$; $d_{min} = 160$ mm, $n_s = 950$ 1/min; $\beta_s = ?$, $N = ?$

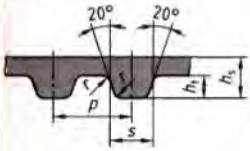
1. $P \cdot c_2 = 12$ kW · 1.4 = 16.8 kW
2. From the diagram $n_s = 950$ 1/min and $P \cdot c_2 = 16.8$ kW → profile **SPA**
3. $P_{rated} = 4.27$ kW from the table
4. $N = \frac{P \cdot c_1 \cdot c_2}{P_{rated}} = \frac{12 \text{ kW} \cdot 1.12 \cdot 1.4}{4.27 \text{ kW}} = 4.4$
5. Selected: $N =$ **5 belts**

# Positive drive belts

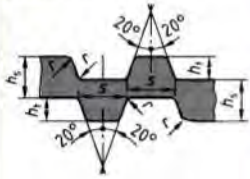
## Positive drive belts (timing belts)

cf. DIN 7721-1 (1989-06)

**Single-sided**




**Double-sided**




**Non-standardized tooth forms**



HT profile LAHN profile

| Code | Tooth spacing $p$ | Tooth size $s$ | $h_t$ | $r$ | Nominal thickness $h_s$ | Positive drive belt width $w$ | | | |
|---|---|---|---|---|---|---|---|---|---|
| T2.5 | 2.5 | 1.5 | 0.7 | 0.2 | 1.3 | – | 4 | 6 | 10 |
| T5 | 5 | 2.7 | 1.2 | 0.4 | 2.2 | 6 | 10 | 16 | 25 |
| T10 | 10 | 5.3 | 2.5 | 0.6 | 4.5 | 16 | 25 | 32 | 50 |

| Effective length[1] | No. of teeth for T2.5 | T5 | Effective length[1] | No. of teeth for T5 | T10 | Effective length[1] | No. of teeth for T10 |
|---|---|---|---|---|---|---|---|
| 120 | 48 | – | 530 | – | 53 | 1010 | 101 |
| 150 | – | 30 | 560 | 112 | 56 | 1080 | 108 |
| 160 | 64 | – | 610 | 122 | 61 | 1150 | 115 |
| 200 | 80 | 40 | 630 | 126 | 63 | 1210 | 121 |
| 245 | 98 | 49 | 660 | – | 66 | 1250 | 125 |
| 270 | – | 54 | 700 | – | 70 | 1320 | 132 |
| 285 | 114 | – | 720 | 144 | 72 | 1390 | 139 |
| 305 | – | 61 | 780 | 156 | 78 | 1460 | 146 |
| 330 | 132 | 66 | 840 | 168 | 84 | 1560 | 156 |
| 390 | – | 78 | 880 | – | 88 | 1610 | 161 |
| 420 | 168 | 84 | 900 | 180 | – | 1780 | 178 |
| 455 | – | 91 | 920 | 184 | 92 | 1880 | 188 |
| 480 | 192 | 96 | 960 | – | 96 | 1960 | 196 |
| 500 | 200 | 100 | 990 | 198 | – | 2250 | 225 |

⇒ **Belt DIN 7721 – 6 T2.5 x 480:** $w = 6$ mm, spacing $p = 2.5$ mm, effective length = 480 mm, single-sided

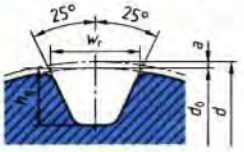
The code letter D is added for double-sided positive drive belts.

[1] Effective lengths from 100–3620 mm, in custom-made products up to 25000 mm

## Timing belt pulleys

cf. DIN 7721-2 (1989-06)

**Pulley groove dimensions**




| Pulley groove | Pulley outer Ø $d_0$ for T2.5 | T5 | T10 | Pulley groove | Pulley outer Ø $d_0$ for T2.5 | T5 | T10 | Pulley groove | Pulley outer Ø $d_0$ for T2.5 | T5 | T10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 10 | 7.4 | 15.0 | – | 17 | 13.0 | 26.2 | 52.2 | 32 | 24.9 | 50.1 | 100.0 |
| 11 | 8.2 | 16.6 | – | 18 | 13.8 | 27.8 | 55.4 | 36 | 28.1 | 56.4 | 112.7 |
| 12 | 9.0 | 18.2 | 36.3 | 19 | 14.6 | 29.4 | 58.6 | 40 | 31.3 | 62.8 | 125.4 |
| 13 | 9.8 | 19.8 | 39.5 | 20 | 15.4 | 31.0 | 61.8 | 48 | 37.7 | 75.5 | 150.9 |
| 14 | 10.6 | 21.4 | 42.7 | 22 | 17.0 | 34.1 | 68.2 | 60 | 47.2 | 94.6 | 189.1 |
| 15 | 11.4 | 23.0 | 45.9 | 25 | 19.3 | 38.9 | 77.7 | 72 | 56.8 | 113.7 | 227.3 |
| 16 | 12.2 | 24.6 | 49.1 | 28 | 21.7 | 43.7 | 87.2 | 84 | 66.3 | 132.9 | 265.5 |

**Effective diameter**

$$d = d_0 + 2 \cdot a$$

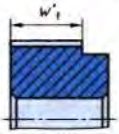
[1] Form SE for ≤ 20 grooves
[2] Form N for > 20 grooves

| Code | Pulley groove dimensions: Groove width $w_r$ Form SE[1] | Form N[2] | Groove height $h_g$ Form SE[1] | Form N[2] | 2 $a$ |
|---|---|---|---|---|---|
| T2.5 | 1.75 | 1.83 | 0.75 | 1 | 0.6 |
| T5 | 2.96 | 3.32 | 1.25 | 1.95 | 1 |
| T10 | 6.02 | 6.57 | 2.6 | 3.4 | 2 |

**Pully dimensions**




with pulley flange

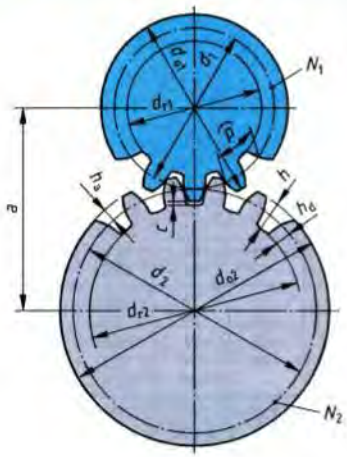



without pulley flange

| Letter symbols | Belt width w | Pulley width with flange $w_f$ | without flange $w'_f$ |
|---|---|---|---|
| T2.5 | 4 | 5.5 | 8 |
| | 6 | 7.5 | 10 |
| | 10 | 11.5 | 14 |
| T5 | 6 | 7.5 | 10 |
| | 10 | 11.5 | 14 |
| | 16 | 17.5 | 20 |
| | 25 | 26.5 | 29 |
| T10 | 16 | 18 | 21 |
| | 25 | 27 | 30 |
| | 32 | 34 | 37 |
| | 50 | 52 | 55 |

# Straight-toothed spur gears

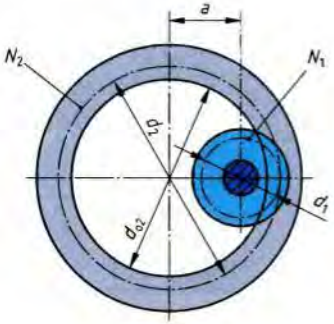
## Unmodified spur gears with straight teeth




| | | | | | |
|---|---|---|---|---|---|
| $m$ | module | $N, N_1, N_2$ | no. of teeth | | |
| $p$ | pitch | $d, d_1, d_2$ | pitch diameter | | |
| $c$ | clearance | | | | |
| $h$ | whole depth | $d_o, d_{o1}, d_{o2}$ | outside diameter | | |
| $h_a$ | addendum | | | | |
| $h_d$ | dedendum | $d_r, d_{r1}, d_{r2}$ | root diameter | | |
| $a$ | center distance | | | | |

**Example:**

External spur gear,
$m = 2$ mm; $N = 32$; $c = 0.167 \cdot m$; $d = ?$; $d_o = ?$; $h = ?$
$\boldsymbol{d} = m \cdot N = 2\text{ mm} \cdot 32 = \mathbf{64\text{ mm}}$
$\boldsymbol{d_o} = d + 2 \cdot m = 64\text{ mm} + 2 \cdot 2\text{ mm} = \mathbf{68\text{ mm}}$
$\boldsymbol{h} = 2 \cdot m + c = 2 \cdot 2\text{ mm} + 0.167 \cdot 2\text{ mm} = \mathbf{4.33\text{ mm}}$




### External teeth

| | |
|---|---|
| **Number of teeth** | $N = \frac{d}{m} = \frac{d_o - 2 \cdot m}{m}$ |
| **Outside diameter** | $d_o = d + 2 \cdot m = m \cdot (N + 2)$ |
| **Root diameter** | $d_r = d - 2 \cdot (m + c)$ |
| **Center distance** | $a = \frac{d_1 + d_2}{2} = \frac{m \cdot (N_1 + N_2)}{2}$ |

### External and internal teeth

| | |
|---|---|
| **Module** | $m = \frac{p}{\pi} = \frac{d}{N}$ |
| **Pitch** | $p = \pi \cdot m$ |
| **Pitch diameter** | $d = m \cdot N$ |
| **Clearance** | $c = 0.1 \cdot m$ to $0.3 \cdot m$<br>often $c = 0.167 \cdot m$ |
| **Addendum** | $h_a = m$ |
| **Dedendum** | $h_d = m + c$ |
| **Whole depth** | $h = 2 \cdot m + c$ |

### Internal teeth

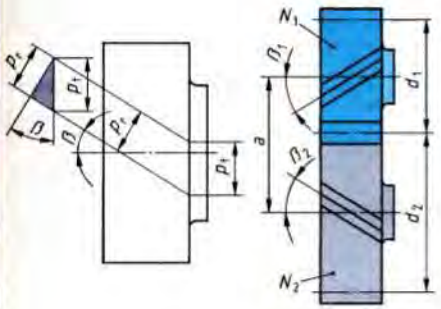
| | |
|---|---|
| **Number of teeth** | $N = \frac{d}{m} = \frac{d_o + 2 \cdot m}{m}$ |
| **Outside diameter** | $d_o = d + 2 \cdot m = m \cdot (N + 2)$ |
| **Root diameter** | $d_r = d - 2 \cdot (m + c)$ |
| **Center distance** | $a = \frac{d_2 - d_1}{2} = \frac{m \cdot (N_2 - N_1)}{2}$ |

**Example:**

Internal spur gear, $m = 1.5$ mm; $N = 80$;
$c = 0.167 \cdot m$; $d = ?$; $d_o = ?$; $h = ?$
$\boldsymbol{d} = m \cdot N = 1.5\text{ mm} \cdot 80 = \mathbf{120\text{ mm}}$
$\boldsymbol{d_o} = d - 2 \cdot m = 120\text{ mm} - 2 \cdot 1.5\text{ mm} = \mathbf{117\text{ mm}}$
$\boldsymbol{h} = 2 \cdot m + c = 2 \cdot 1.5\text{ mm} + 0.167 \cdot 1.5\text{ mm} = \mathbf{3.25\text{ mm}}$

# Helical gears, Module series for spur gears

## Unmodified helical gears




| | |
|---|---|
| $m_t$ | transverse module |
| $m_r$ | real pitch module |
| $p_t$ | transverse pitch |
| $p_r$ | real pitch |
| $\beta$ | helix angle (normally $\beta = 8°$ to $25°$) |
| $N$, $N_1$, $N_2$ | no. of teeth |
| $d$, $d_1$, $d_2$ | pitch diameter |
| $d_o$ | outside diameter |
| $a$ | center distance |

In helical gears the teeth run in a screw-like pattern on the cylindrical wheel body. The tools for manufacturing spur gears and helical gears conform to the real pitch module.

In the case of parallel shafts the two gears have the same helix angle, but opposite direction of rotation, i. e., one gear has a right-hand helix and the other a left-hand helix ($\beta_1 = -\beta_2$).

**Transverse module**

$$m_t = \frac{m_r}{\cos\beta} = \frac{p_t}{\pi}$$

**Transverse pitch**

$$p_t = \frac{p_r}{\cos\beta} = \frac{\pi \cdot m_r}{\cos\beta}$$

**Pitch diameter**

$$d = m_t \cdot N = \frac{N \cdot m_r}{\cos\beta}$$

**Number of teeth**

$$N = \frac{d}{m_t} = \frac{\pi \cdot d}{p_t}$$

**Real pitch module**

$$m_r = \frac{p_r}{\pi} = m_t \cdot \cos\beta$$

**Real pitch**

$$p_r = \pi \cdot m_r = p_t \cdot \cos\beta$$

**Outside diameter**

$$d_o = d + 2 \cdot m_r$$

**Center distance**

$$a = \frac{d_1 + d_2}{2}$$

**Example:**

Helical gear, $N = 32$; $m_r = 1.5$ mm;
$\beta = 19.5°$; $c = 0.167 \cdot m$; $m_t = ?$; $d_o = ?$; $d = ?$; $h = ?$

$$m_t = \frac{m_r}{\cos\beta} = \frac{1.5\text{ mm}}{\cos 19.5°} = \mathbf{1.591\,mm}$$

$d_o = d + 2 \cdot m_r = 50.9\text{ mm} + 2 \cdot 1.5\text{ mm} = \mathbf{53.9\,mm}$

$d = m_t \cdot N = 1.591\text{ mm} \cdot 32 = \mathbf{50.9\,mm}$

$h = 2 \cdot m_r + c = 2 \cdot 1.5\text{ mm} + 0.167 \cdot 1.5\text{ mm} = \mathbf{3.25\,mm}$

Calculations of whole depth, addendum, dedendum, clearance and root diameter are the same as those for spur gears with straight teeth (page 256). In the formulae the module $m$ is replaced by the real pitch module $m_r$.

### Module series for spur gears (Series I)

cf. DIN 780-1 (1977-05)

| Module | 0.2 | 0.25 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 | 1.0 | 1.25 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Pitch | 0.628 | 0.785 | 0.943 | 1.257 | 1.571 | 1.885 | 2.199 | 2.513 | 2.827 | 3.142 | 3.927 |
| Module | 1.5 | 2.0 | 2.5 | 3.0 | 4.0 | 5.0 | 6.0 | 8.0 | 10.0 | 12.0 | 16.0 |
| Pitch | 4.712 | 6.283 | 7.854 | 9.425 | 12.566 | 15.708 | 18.850 | 25.132 | 31.416 | 37.699 | 50.265 |

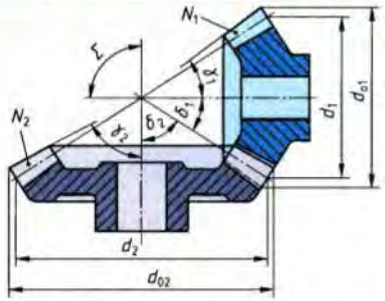
**Classification of a tool set of 8 module side milling cutters (up to $m = 9$ mm)[1]**

| Cutter no. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| No. of teeth | 12–13 | 14–16 | 17–20 | 21–25 | 26–34 | 35–54 | 55–134 | 135 to toothed rack |

[1] The manufacture of gears with side milling cutters is not an involute process. Only an approximate involute form of the tooth flank is produced. Therefore this manufacturing process is only suitable for secondary gears. For gears with $m > 9$ mm a tool set with 15 module side milling cutters is used.

# Bevel gears, Worm drive

## Unmodified bevel gears with straight teeth




| | | | |
|---|---|---|---|
| $m$ | module | $N, N_1, N_2$ | no. of teeth |
| $d, d_1, d_2$ | pitch diameter | $\delta, \delta_1, \delta_2$ | pitch angle |
| $d_o, d_{o1}, d_{o2}$ | outside diameter | $\gamma_1, \gamma_2$ | tip angle |
| $\Sigma$ | shaft angle (normally 90°) | | |

Pitch and whole depth narrow to the cone point, so that at every point of the tooth width a bevel gear has another module, outside diameter, etc. The outermost module corresponds to the standard module.

| | |
|---|---|
| **Pitch diameter** | $d = m \cdot N$ |
| **Outside diameter** | $d_o = d + 2 \cdot m \cdot \cos\delta$ |
| **Tip angle gear 1** | $\tan\gamma_1 = \dfrac{N_1 + 2 \cdot \cos\delta_1}{N_2 - 2 \cdot \sin\delta_1}$ |
| **Tip angle gear 2** | $\tan\gamma_2 = \dfrac{N_2 + 2 \cdot \cos\delta_2}{N_1 - 2 \cdot \sin\delta_2}$ |
| **Pitch angle gear 1** | $\tan\delta_1 = \dfrac{d_1}{d_2} = \dfrac{N_1}{N_2} = \dfrac{1}{i}$ |
| **Pitch angle gear 2** | $\tan\delta_2 = \dfrac{d_2}{d_1} = \dfrac{N_2}{N_1} = i$ |
| **Shaft angle** | $\Sigma = \delta_1 + \delta_2$ |

In addition to the dimensions given on the outside edges, the dimensions in the centers and inner edges of gear teeth are also important for manufacturing.

**Example:**

Bevel gear drive, $m$ = 2 mm; $N_1$ = 30; $N_2$ = 120; $\Sigma$ = 90°. Calculate the dimensions for turning the driving bevel gear.

$\tan\delta_1 = \dfrac{N_1}{N_2} = \dfrac{30}{120} = 0.2500$; $\delta_1 = 14.04°$

$d_1 = m \cdot N_1 = 2\text{ mm} \cdot 30 = 60\text{ mm}$

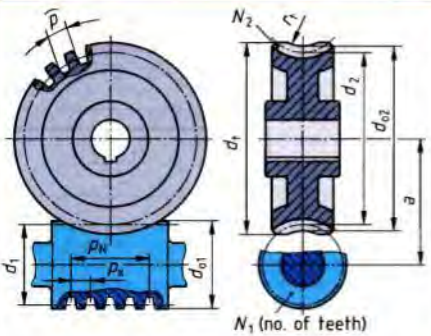
$d_{o1} = d_1 + 2 \cdot m \cdot \cos\delta_1$
$= 60\text{ mm} + 2 \cdot 2\text{ mm} \cdot \cos 14.04° = 63.88\text{ mm}$

$\tan\gamma_1 = \dfrac{N_1 + 2 \cdot \cos\delta_1}{N_2 - 2 \cdot \sin\delta_1} = \dfrac{30 + 2 \cdot \cos 14.04°}{120 - 2 \cdot \sin 14.04°} = 0.267$

$\gamma_1 = 14.95°$

Whole depth, addendum, clearance, etc. are calculated like spur gears with straight teeth (page 256).

## Worm drive




| | | | |
|---|---|---|---|
| $m$ | module | $N_1, N_2$ | no. of teeth |
| $d, d_1, d_2$ | pitch diameter | $p_n$ | lead |
| $d_o, d_{o1}, d_{o2}$ | outside diameter | $p_x, p$ | (axial ) pitch |
| $r_t$ | throat radius | $d_t$ | tip ∅ |

**Worm**

| | |
|---|---|
| **Pitch diameter** | $d_1$ = nominal size |
| **Axial pitch – worm** | $p_x = \pi \cdot m$ |
| **Outside diameter** | $d_{o1} = d_1 + 2 \cdot m$ |
| **Lead** | $p_n = p_x \cdot N_1 = \pi \cdot m \cdot N_1$ |

**Worm gear**

| | |
|---|---|
| **Pitch diameter** | $d_2 = m \cdot N_2$ |
| **Pitch** | $p = \pi \cdot m$ |
| **Outside diameter** | $d_{o2} = d_2 + 2 \cdot m$ |
| **Tip diameter** | $d_t \approx d_{o2} + m$ |
| **Throat radius** | $r_t = \dfrac{d_1}{2} - m$ |

**Example:**

Worm drive $m$ = 2.5 mm; $N_1$ = 2; $d_1$ = 40 mm; $N_2$ = 40; $d_{o1}$ = ?; $d_2$ = ?; $d_t$ = ?; $r_t$ = ?; $a$ = ?

$d_{o1} = d_1 + 2 \cdot m = 40\text{ mm} + 2 \cdot 2.5\text{ mm} = 45\text{ mm}$

$d_2 = m \cdot N_2 = 2.5\text{ mm} \cdot 40 = 100\text{ mm}$

$d_{o2} = d_2 + 2 \cdot m = 100\text{ mm} + 2 \cdot 2.5\text{ mm} = 105\text{ mm}$

$d_t \approx d_{o2} + m = 105\text{ mm} + 2.5\text{ mm} = 107.5\text{ mm}$

$r_t = \dfrac{d_1}{2} - m = \dfrac{40\text{ mm}}{2} - 2.5\text{ mm} = 17.5\text{ mm}$

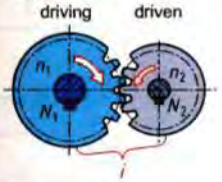
$a = \dfrac{d_1 + d_2}{2} = \dfrac{40\text{ mm} + 100\text{ mm}}{2} = 70\text{ mm}$

Clearance, whole depth, addendum, dedendum and center distance like spur gears (page 256).

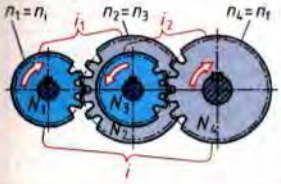
# Transmission ratios

## Gear drives

**Single gear ratio**




**Multiple gear ratio**




$N_1, N_3, N_5 \ldots$ no. of teeth } driving gears
$n_1, n_3, n_5 \ldots$ speeds
$N_2, N_4, N_6 \ldots$ no. of teeth } driven gears
$n_2, n_4, n_6 \ldots$ speeds
$n_i$ initial speed
$n_f$ final speed
$i$ total gear ratio
$i_1, i_2, i_3 \ldots$ individual gear ratios

**Example:**

$i = 0.4$; $n_1 = 180/\text{min}$; $N_2 = 24$; $n_2 = ?$; $N_1 = ?$

$$n_2 = \frac{n_1}{i} = \frac{180/\text{min}}{0.4} = \mathbf{450/min}$$

$$N_1 = \frac{n_2 \cdot N_2}{n_1} = \frac{450/\text{min} \cdot 24}{180/\text{min}} = \mathbf{60}$$

Torque for gears, page 37

**Drive formula**

$$n_1 \cdot N_1 = n_2 \cdot N_2$$

**Gear ratio**

$$i = \frac{N_2}{N_1} = \frac{n_1}{n_2} = \frac{n_i}{n_f}$$

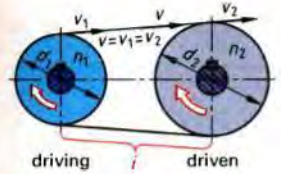
**Total gear ratio**

$$i = \frac{N_2 \cdot N_4 \cdot N_6 \ldots}{N_1 \cdot N_3 \cdot N_5 \ldots}$$

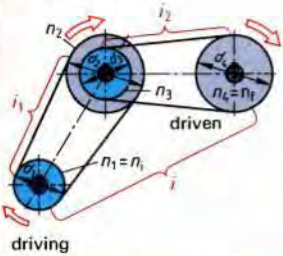
$$i = i_1 \cdot i_2 \cdot i_3 \ldots$$

## Belt drives

**Single gear ratio**




**Multiple gear ratio**




$d_1, d_3, d_5 \ldots$ diameters[1] } driving pulleys
$n_1, n_3, n_5 \ldots$ speeds
$d_2, d_4, d_6 \ldots$ diameters[1] } driven pulleys
$n_2, n_4, n_6 \ldots$ speeds
$n_i$ initial speed
$n_f$ final speed
$i$ total gear ratio
$i_1, i_2, i_3 \ldots$ individual gear ratios
$v, v_1, v_2$ circumferential velocity

**Example:**

$n_1 = 600/\text{min}$; $n_2 = 400/\text{min}$;
$d_1 = 240$ mm; $i = ?$; $d_2 = ?$

$$i = \frac{n_1}{n_2} = \frac{600/\text{min}}{400/\text{min}} = \frac{1.5}{1} = \mathbf{1.5}$$

$$d_2 = \frac{n_1 \cdot d_1}{n_2} = \frac{600/\text{min} \cdot 240\ \text{mm}}{400/\text{min}} = \mathbf{360\ mm}$$

[1] For V-belts (page 254) calculate with the effective diameter $d_e$; for positive drive belts (page 255) calculate with the number of teeth on the pulley.

**Velocity**

$$v = v_1 = v_2$$

**Drive formula**

$$n_1 \cdot d_1 = n_2 \cdot d_2$$

**Gear ratio**

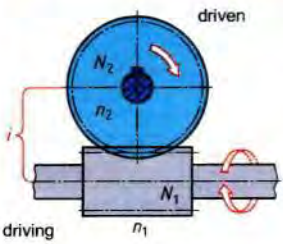
$$i = \frac{d_2}{d_1} = \frac{n_1}{n_2} = \frac{n_i}{n_f}$$

**Total gear ratio**

$$i = \frac{d_2 \cdot d_4 \cdot d_6 \ldots}{d_1 \cdot d_3 \cdot d_5 \ldots}$$

$$i = i_1 \cdot i_2 \cdot i_3 \ldots$$

## Worm drives




$N_1$ no. of teeth (no. of threads) of the worm
$n_1$ speed of the worm
$N_2$ no. of teeth of the worm gear
$n_2$ speed of the worm gear
$i$ gear ratio

**Example:**

$i = 25$; $n_1 = 1500/\text{min}$; $N_1 = 3$; $n_2 = ?$

$$n_2 = \frac{n_1}{i} = \frac{1500/\text{min}}{25} = \mathbf{60/min}$$

**Drive formula**

$$n_1 \cdot N_1 = n_2 \cdot N_2$$

**Gear ratio**

$$i = \frac{n_1}{n_2} = \frac{N_2}{N_1}$$

# Speed graph

The speed $n$ of a machine tool from the workpiece or tool diameter $d$ and the selected cutting speed $v_c$ can be determined

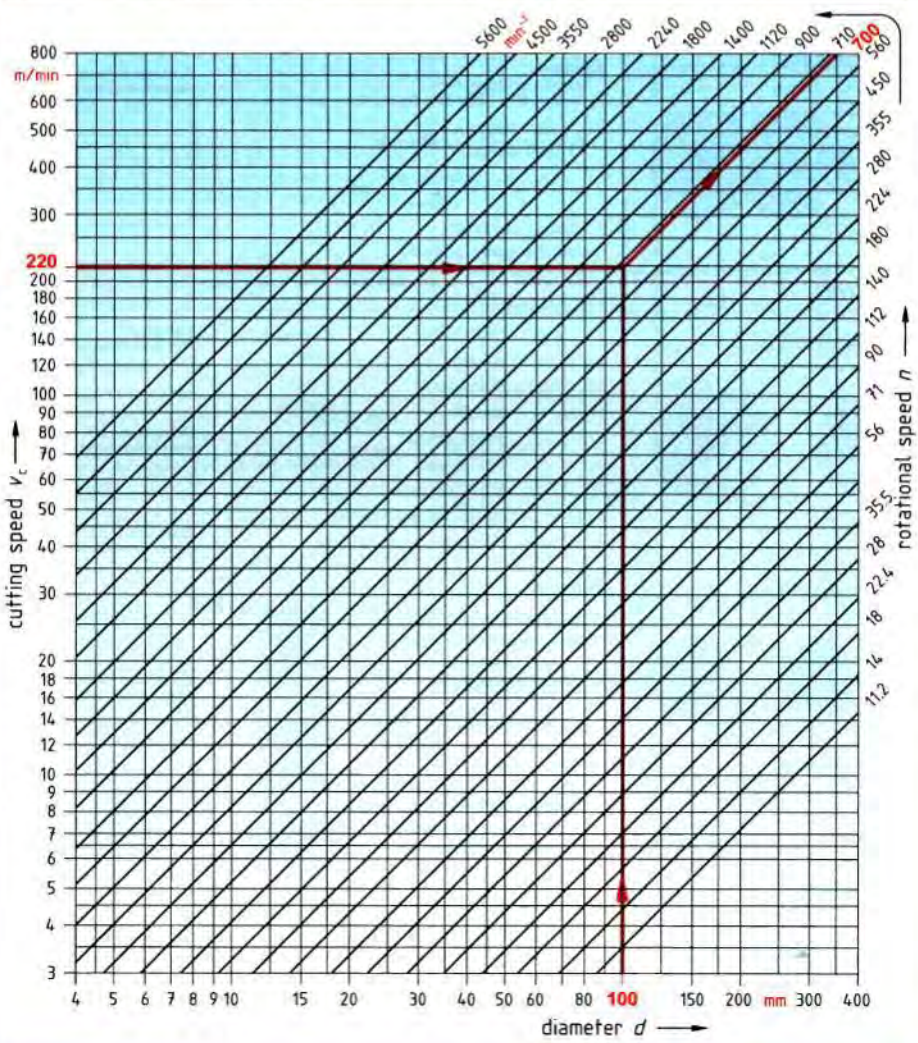
- on a computer/calculator using the formula, or
- graphically using the speed graph.

Speed graphs have the speeds under load which can be set on the machine. These are stepped geometrically. For infinitely variable drives the calculated speed can be set precisely.

**Speed**

$$n = \frac{v_c}{\pi \cdot d}$$

**Speed graph with logarithmically scaled coordinates**




**Example:** $d = 100$ mm; $v_c = 220 \frac{\text{m}}{\text{min}}$; $n = ?$

Calculation: $n = \frac{v_c}{\pi \cdot d} = \frac{220 \frac{\text{m}}{\text{min}}}{\pi \cdot 0.1\,\text{m}} = 700.3 \frac{1}{\text{min}}$; read from the speed graph above: $n \approx 700 \frac{1}{\text{min}}$

# Plain bearings, Overview

## Plain bearings[1] (Selection by type of lubrication)

### Hydrodynamic plain bearings



**Suitable for**

- low-wear continuous operation
- high speeds
- high impact loads

**Areas of application**

- main and big end bearings
- gearboxes
- electric motors
- turbines, compressors
- lifting equipm., agricul. machinery

### Hydrostatic plain bearings



**Suitable for**

- wear-free continuous operation
- low friction losses
- low speeds possible

**Areas of application**

- precision bearings
- space telescopes and antennae
- machine tools
- axial bearings for high forces

### Dry-running plain bearings



**Suitable for**

- maintenance free or low maintenance operation
- with or without lubrication

**Areas of application**

- construction equipment
- armatures and devices
- packaging machines
- jet engines
- household appliances

[1] Other plain bearings: air or gas and water lubricated plain bearings, magnetic bearings

## Properties of plain bearing materials

| Designation, Material number | Elongation limit $R_{p\,0.2}$ N/mm² | Specific bearing load $p_L$[1] N/mm² | Shaft min. hardness | Sliding properties | Sliding speed | Emergency-running behavior | Properties, application |
|---|---|---|---|---|---|---|---|
| **Lead and tin casting alloys** | | | | | | | cf. DIN ISO 4381 (2001-02) |
| G-PbSb15Sn10[2] 2.3391 | 43 | 7 | 160 HB | ◕ | ◐ | ◕ | Medium loading; all purpose plain bearing |
| G-SnSb12Cu6Pb 2.3790 | 61 | 10 | 160 HB | ● | ● | ◕ | Good impact loading; turbines, compressors, electric machines |
| **Cast copper alloys and copper wrought alloys** | | | | | | | cf. DIN ISO 4382-1 and -2 (1992-11) |
| CuSn8Pb2-C 2.1810 | 130 | 21 | 280 HB | ◕ | ◕ | ◐ | Low to moderate loading, sufficient lubrication |
| CuZn31Si1 2.1831 | 250 | 58 | 55 HRC | | | | High loading, high vertical and horizontal impact loading |
| CuPb10Sn10-C[2] 2.1816 | 80 | 18 | 250 HB | ◕ | ◕ | ◐ | High surface pressures; vehicle bearings, bearings in hot-rolling mills |
| CuPb20Sn5-C 2.1818 | 60 | 11 | 150 HB | ● | ● | ● | Suitable for water lubrication, resistant to sulfuric acid |
| **Thermoplastics** | | | | | | | cf. DIN ISO 6691 (2001-05) |
| PA 6 (Polyamide) | – | 12 | 50 HRC | ● | ○ | ● | Impact and wear resistant; bearings in farm machinery |
| POM (Polyoxymethylene | – | 18 | 50 HRC | | | | Harder and capable of higher compressive loads than PA; bearings in precision mechanics, suitable for dry-running |

[1] Bearing force based on the projected bearing surface

[2] Composite material according to DIN ISO 4383 for thin-walled plain bearings

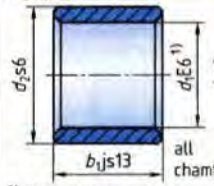
● very good ◕ good ◐ normal ◴ limited ○ poor

# Plain bearing bushings

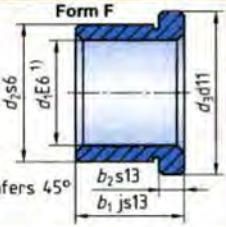
## Bushings made of copper alloys

cf. DIN ISO 4379 (1995-10)

Form C




Form F




1) Force fitting produces tolerance class H8

| Recommended tolerance classes for mounting dimensions | |
|---|---|
| Location hole | H7 |
| Shaft | e7 or g7 (depending on application) |

| $d_1$ | Form C $d_2$ | | | Form F Series 1 $d_2$ | $d_3$ | $b_2$ | Form F Series 2 $d_2$ | $d_3$ | $b_2$ | Lengths $b_1$ | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10 | 12 | 14 | 16 | 12 | 14 | 1 | 16 | 20 | 3 | – | 10 | – |
| 12 | 14 | 16 | 18 | 14 | 16 | 1 | 18 | 22 | 3 | 10 | 15 | 20 |
| 15 | 17 | 19 | 21 | 17 | 19 | 1 | 21 | 27 | 3 | 10 | 15 | 20 |
| 18 | 20 | 22 | 24 | 20 | 22 | 1 | 24 | 30 | 3 | 12 | 20 | 30 |
| 20 | 23 | 24 | 26 | 23 | 26 | 1.5 | 26 | 32 | 3 | 15 | 20 | 30 |
| 22 | 25 | 26 | 28 | 25 | 28 | 1.5 | 28 | 34 | 3 | 15 | 20 | 30 |
| 25 | 28 | 30 | 32 | 28 | 31 | 1.5 | 32 | 38 | 4 | 20 | 30 | 40 |
| 30 | 34 | 36 | 38 | 34 | 38 | 2 | 38 | 44 | 4 | 20 | 30 | 40 |
| 35 | 39 | 41 | 45 | 39 | 43 | 2 | 45 | 50 | 5 | 30 | 40 | 50 |
| 40 | 44 | 48 | 50 | 44 | 48 | 2 | 50 | 58 | 5 | 30 | 40 | 60 |

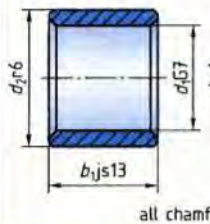
Diameter range $d_1$: 6–200

⇒ **Bushing ISO 4379 – F22 x 25 x 30 – CuSn8P:** Form F, $d_1$ = 22 mm, $d_2$ = 25 mm, $b_1$ = 30 mm, of CuSn8P

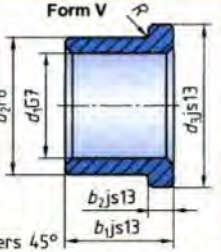
## Bushings made of sintered metal

cf. DIN 1850-3 (1998-07)

Form J




Form V




| Recommended tolerance classes for mounting dimensions | |
|---|---|
| Location hole | H7 |
| Shaft | – |

| $d_1$ | Form J $d_2$ | | Form V $d_2$ | $d_3$ | $b_2$ | $R_{max}$ | Lengths $b_1$ | | |
|---|---|---|---|---|---|---|---|---|---|
| 10 | 16 | 14 | 16 | 22 | 2 | 0.6 | 8 | 10 | 16 |
| 12 | 18 | 16 | 18 | 24 | 3 | 0.6 | 8 | 12 | 20 |
| 15 | 21 | 19 | 21 | 27 | 3 | 0.6 | 10 | 15 | 25 |
| 18 | 24 | 22 | 24 | 30 | 3 | 0.6 | 12 | 18 | 30 |
| 20 | 26 | 25 | 26 | 32 | 3 | 0.6 | 15 | 20 | 25 |
| 22 | 28 | 27 | 28 | 34 | 3 | 0.6 | 15 | 20 | 25 |
| 25 | 32 | 30 | 32 | 39 | 3.5 | 0.8 | 20 | 25 | 30 |
| 30 | 38 | 35 | 38 | 46 | 4 | 0.8 | 20 | 25 | 30 |
| 35 | 45 | 41 | 45 | 55 | 5 | 0.8 | 25 | 35 | 40 |
| 40 | 50 | 46 | 50 | 60 | 5 | 0.8 | 30 | 40 | 50 |

Diameter range $d_1$: 1–60

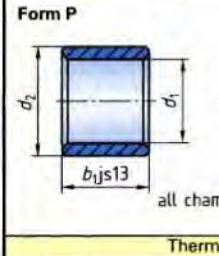
⇒ **Bushing DIN 1850 – V18 x 24 x 18 – Sint-B50:** $d_1$ = 18 mm, $d_2$ = 24 mm, $b_1$ = 18 mm, sintered bronze Sint-B50

## Bushings made of thermosets and thermoplastics

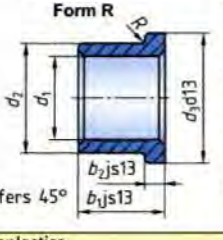
cf. DIN 1850-5 and -6 (1998-07)

Thermoset plastics

Form P




Form R

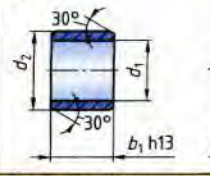



| $d_1$ | $d_2$ | $d_3$ | $b_2$ | $R_{max}$ | Lengths $b_1$ | | |
|---|---|---|---|---|---|---|---|
| 10 | 16 | 20 | 3 | 0.3 | 6 | 10 | – |
| 12 | 18 | 22 | 3 | 0.5 | 10 | 15 | 20 |
| 15 | 21 | 27 | 3 | 0.5 | 10 | 15 | 20 |
| 18 | 24 | 30 | 3 | 0.5 | 12 | 20 | 30 |
| 20 | 26 | 32 | 3 | 0.5 | 15 | 20 | 30 |
| 22 | 28 | 34 | 3 | 0.5 | 15 | 20 | 30 |
| 25 | 32 | 38 | 4 | 0.5 | 20 | 30 | 40 |
| 30 | 38 | 44 | 4 | 0.5 | 20 | 30 | 40 |
| 35 | 45 | 50 | 5 | 0.8 | 30 | 40 | 50 |

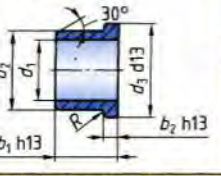
Diameter range $d_1$ for thermosets: 3–250, for thermoplastics: 6–200

Thermoplastics

Form S




Form T




| Recommended tolerance classes for mounting dimensions | Thermosets | Thermoplastics |
|---|---|---|
| Location hole | H7 | H7 |
| Shaft | h7 | h9 |

**Limit deviations $d_2$ and $d_1$ of tolerance classes A and B for bushings made of thermoplastics**

| | $d_2$ from 10 to 14 | 15 to 18 | 20 to 25 | 28 to 32 | 35 to 40 | 42 to 55 | Fabrication method | Tolerance class resulting after force fitting $d_1$ |
|---|---|---|---|---|---|---|---|---|
| A | +0.21 +0.07 | +0.2 0 | +0.4 +0.1 | +0.6 +0.2 | +0.69 +0.23 | +0.90 +0.30 | injection molded | D12 |
| B | Tolerance class zb11 | | | | | | machined | C11 |

**Additional codes for bushings made of thermoset plastics**

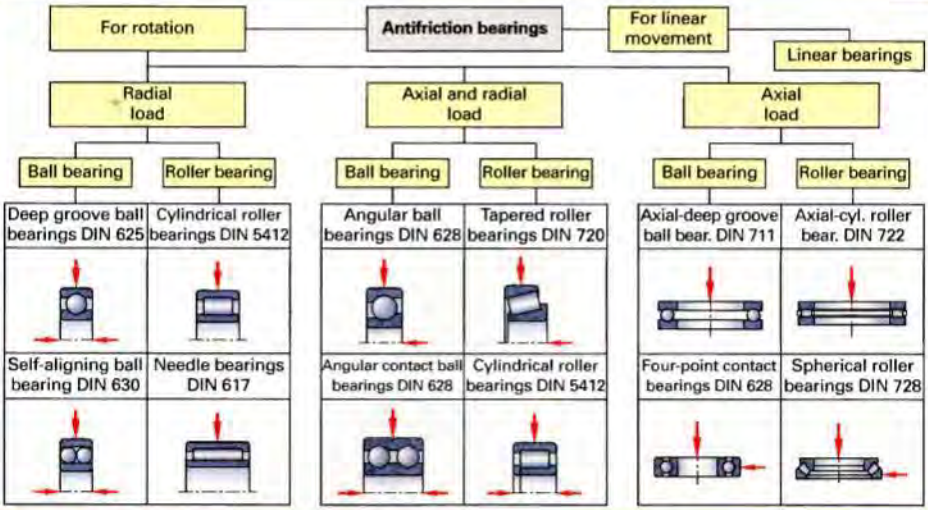
| | | | |
|---|---|---|---|
| W | Circular grooves on outer diameter $d_2$ | Y | Assembly bevel 15° (inst. of 45°) |
| | | Z | Undercut instead of radius $R$ |

⇒ **Bushing DIN 1850 – S20 A20 – PA 6:** Form S; $d_1$ = 20 mm, tolerance cl. A, $b_1$ = 20 mm, polyamide 6

Other stand. designs: Wrapped bushings DIN 1494, internal tension bushings DIN 1498, external tension bushings DIN 1499

# Antifriction bearings, Overview

## Roller bearings (selection)




## Properties of roller bearings

| Bearing design[1] | Inside Ø *d* | Radial loading | Axial loading | High speed | High loads | Quiet running | Application |
|---|---|---|---|---|---|---|---|
| **Ball bearings** | | | | | | | |
| Deep groove ball bearings | 1.5–600 | ◕ | ◐ | ● | ◐ | ● | Universal bearings in machine and automotive manufacturing |
| Self-aligning ball bearings | 5–120 | ◕ | ◴ | ◕ | ◴ | ◴ | Compensation with misalignment |
| Angular contact ball bearings single-row | 10–170 | ◕ | ◕ | ●[2] | ◕[3] | ◕ | Only used in pairs, large forces, automotive manufacturing |
| Angular contact ball bearings double-row | 10–110 | ◕ | ◕ | ◐ | ◕ | ◴ | Large forces, automotive manufacturing, with limited space requirements |
| Axial deep groove ball bearings | 8–360 | ○ | ◕ | ◐ | ◐ | ◴ | Acceptance of very high axial forces, drill spindles, tail stock centers |
| Four-point contact bearings | 20–240 | ◴ | ◕ | ◴ | ◐ | ◴ | Very tight spaces, spindle bearing layouts, gear and roller bearing assemblies |
| **Roller bearings** | | | | | | | |
| Cylindrical roller bearings (form N) | 17–240 | ● | ○ | ● | ◕ | ◐ | Acceptance of very large radial forces, roller bearing assemblies, transmissions |
| Cylindrical roller bearings (form NUP) | 15–240 | ● | ◐ | ◕ | ◕ | ◴ | Like Form N, with flanged wheel additional acceptance of axial forces |
| Needle bearings | 90–360 | ● | ○ | ◴ | ● | ◐ | High carrying capacity with tight mounting space |
| Tapered roller bearings | 15–360 | ● | ● | ◐[2] | ●[3] | ◴ | Usually mounted in pairs, wheel bearings in automobiles, spindle bearings |
| Axial cylindrical roller bearings | 15–600 | ○ | ● | ◴ | ◕ | ○ | Stiff bearing requiring minimal axial space, high friction |
| Spherical roller bearings | 60–1060 | ◴ | ● | ◴ | ◕ | ○ | Angular displacement thrust bearings, thrust bearings in cranes |

[1] For all radial bearings the prefix "radial" is omitted.
[2] Reduced suitability with paired mounting
[3] Mounted in pairs

**Suitability levels:**
● very good ◕ good ◐ normal
◴ limited ○ not suitable

# Antifriction bearings, Designation

## Designation of antifriction bearings

cf. DIN 623-1 (1993-05)

**Example:** Tapered roller bearings DIN 720 – S 30208 P2

Name | Standard | Prefix symbol | Basic numbers | Suffix symbol

### Prefix symbols

| | |
|---|---|
| K | cage with roller elements |
| L | free ring |
| R | ring with roller set |
| S | stainless steel |

### Suffix symbols (selection)

| | |
|---|---|
| K | bearing with tapered bore |
| Z | bearing with shield on one side |
| 2Z | bearing with shield on both sides |
| E | reinforced design |
| RS | bearing with seal on one side |
| 2RS | bearing with seal on both sides |
| P2 | highest precision: dimensional, form and running |

**Example of basic numbers:** 3 0 2 08

Bearing series 302 | Width series 0 | Diameter series 2 | Bearing type 3 | Dimension series 02 | Bore code 08

| Bearing type | Design |
|---|---|
| 0 | Angular contact ball bear., double row |
| 1 | Self-aligning ball bearing |
| 2 | Barrel and spherical roller bearings |
| 3 | Tapered roller bearings |
| 4 | Deep groove ball bear., double row |
| 5 | Axial deep groove ball bearings |
| 6 | Deep groove ball bear., single row |
| 7 | Angular contact ball bear., single row |
| 8 | Axial cylindrical roller bearings |
| NA | Needle bearings |
| QJ | Four-point contact bearing |
| N, NJ, NJP, NN, NNU, NU, NUP | Cylindrical roller bearings |

| Bore-code | Bore ∅ *d* | Bore code | Bore ∅ *d* |
|---|---|---|---|
| 00 | 10 | 12 | 60 |
| 01 | 12 | 13 | 65 |
| 02 | 15 | 14 | 70 |
| 03 | 17 | 15 | 75 |
| 04 | 20 | 16 | 80 |
| 05 | 25 | 17 | 85 |
| 06 | 30 | 18 | 90 |
| 07 | 35 | 19 | 95 |
| 08 | 40 | 20 | 100 |
| 09 | 45 | 21 | 105 |
| 10 | 50 | 22 | 110 |
| 11 | 55 | 23 | 115 |

## Dimension series (selection)

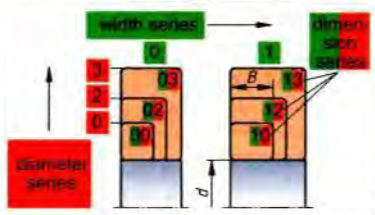
cf. DIN 616 (1994-06)

**Explanation**

The dimension plans in DIN 616 contain diameter series in which each nominal diameter of a bearing bore *d* (= shaft diameter) is assigned a number of:

- outside diameters and
- width series (for radial bearings) or
- height series (for axial bearings).

**Structure of the dimension series**




**Example: Tapered roller bearings**[1)]

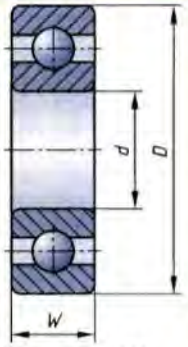
| Dimension series 02 | | | |
|---|---|---|---|
| Bore code | Bore ∅ *d* | *D* | *B* |
| 07 | 35 | 72 | 17 |
| 08 | 40 | 80 | 18 |
| 09 | 45 | 85 | 19 |
| 10 | 50 | 90 | 20 |

[1)] other dimensions, see page 267

# Ball bearings

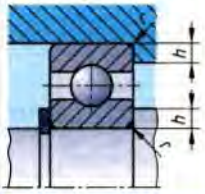
## Deep groove ball bearings (selection)

cf. DIN 625-1 (1989-04)




*d* from 1.5 to 600 mm

**Mounting dimensions according to DIN 5418:**

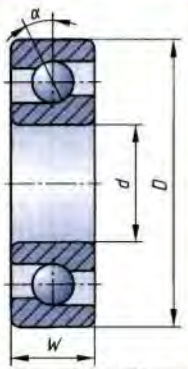



| *d* | Bearing series 60 | | | | | Bearing series 62 | | | | | Bearing series 63 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *D* | *W* | *r* max | *h* min | Basic number | *D* | *W* | *r* max | *h* min | Basic number | *D* | *W* | *r* max | *h* min | Basic number |
| 10 | 26 | 8 | 0.3 | 1 | 6000 | 30 | 9 | 0.6 | 2.1 | 6200 | 35 | 11 | 0.6 | 2.1 | 6300 |
| 12 | 28 | 8 | 0.3 | 1 | 6001 | 32 | 10 | 0.6 | 2.1 | 6201 | 37 | 12 | 1 | 2.8 | 6301 |
| 15 | 32 | 9 | 0.3 | 1 | 6002 | 35 | 11 | 0.6 | 2.1 | 6202 | 42 | 13 | 1 | 2.8 | 6302 |
| 17 | 35 | 10 | 0.3 | 1 | 6003 | 40 | 12 | 0.6 | 2.1 | 6203 | 47 | 14 | 1 | 2.8 | 6303 |
| 20 | 42 | 12 | 0.6 | 1.6 | 6004 | 47 | 14 | 1 | 2 | 6204 | 52 | 15 | 1 | 3.5 | 6304 |
| 25 | 47 | 12 | 0.6 | 1.6 | 6005 | 52 | 15 | 1 | 2 | 6205 | 62 | 17 | 1 | 3.5 | 6305 |
| 30 | 55 | 13 | 1 | 2.3 | 6006 | 62 | 16 | 1 | 2 | 6206 | 72 | 19 | 1 | 3.5 | 6306 |
| 35 | 62 | 14 | 1 | 2.3 | 6007 | 72 | 17 | 1 | 2 | 6207 | 80 | 21 | 1.5 | 4.5 | 6307 |
| 40 | 68 | 15 | 1 | 2.3 | 6008 | 80 | 18 | 1 | 3.5 | 6208 | 90 | 23 | 1.5 | 4.5 | 6308 |
| 45 | 75 | 16 | 1 | 2.3 | 6009 | 85 | 19 | 1 | 3.5 | 6209 | 100 | 25 | 1.5 | 4.5 | 6309 |
| 50 | 80 | 16 | 1 | 2.3 | 6010 | 90 | 20 | 1 | 3.5 | 6210 | 110 | 27 | 2 | 5.5 | 6310 |
| 55 | 90 | 18 | 1 | 3 | 6011 | 100 | 21 | 1.5 | 4.5 | 6211 | 120 | 29 | 2 | 5.5 | 6311 |
| 60 | 95 | 18 | 1 | 3 | 6012 | 110 | 22 | 1.5 | 4.5 | 6212 | 130 | 31 | 2.1 | 6 | 6312 |
| 65 | 100 | 18 | 1 | 3 | 6013 | 120 | 23 | 1.5 | 4.5 | 6213 | 140 | 33 | 2.1 | 6 | 6313 |
| 70 | 110 | 20 | 1 | 3 | 6014 | 125 | 24 | 1.5 | 4.5 | 6214 | 150 | 35 | 2.1 | 6 | 6314 |
| 75 | 115 | 20 | 1 | 3 | 6015 | 130 | 25 | 2 | 5.5 | 6215 | 160 | 37 | 2.1 | 6 | 6315 |
| 80 | 125 | 22 | 1 | 3 | 6016 | 140 | 26 | 2 | 5.5 | 6216 | 170 | 39 | 2.5 | 7 | 6316 |
| 85 | 130 | 22 | 1.5 | 3.5 | 6017 | 150 | 28 | 2.1 | 6 | 6217 | 180 | 41 | 2.5 | 7 | 6317 |
| 90 | 140 | 24 | 1.5 | 3.5 | 6018 | 160 | 30 | 2.1 | 6 | 6218 | 190 | 43 | 2.5 | 7 | 6318 |
| 95 | 145 | 24 | 1.5 | 3.5 | 6019 | 170 | 32 | 2.1 | 6 | 6219 | 200 | 45 | 2.5 | 7 | 6319 |
| 100 | 150 | 24 | 1.5 | 3.5 | 6020 | 180 | 34 | 2.1 | 6 | 6220 | 215 | 47 | 2.5 | 7 | 6320 |

⇒ **Deep groove ball bearing DIN 625 – 6208 – 2Z – P2:** Deep groove ball bearing (bearing type 6), width series 0[1], diameter series 2, bore code 08 ($d$ = 8 · 5 mm = 40 mm), design with 2 shields, bearing with highest precision (tolerance class 2)

## Angular contact ball bearings (selection)

cf. DIN 628-1 (1993-12)




*d* from 10 to 170 mm

**Mounting dimensions according to DIN 5418:**




| *d* | Bearing series 72 | | | | | Bearing series 73 | | | | | Bearing ser. 33 (double row) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *D* | *W* | *r* max | *h* min | Basic number[2] | *D* | *W* | *r* max | *h* min | Basic number[2] | *D* | *W* | *r* max | *h* min | Basic number[3] |
| 15 | 35 | 11 | 0.6 | 2.1 | 7202B | 42 | 13 | 1 | 2.8 | 7302B | 42 | 19 | 1 | 2.8 | 3302 |
| 17 | 40 | 12 | 0.6 | 2.1 | 7203B | 47 | 14 | 1 | 2.8 | 7303B | 47 | 22.2 | 1 | 2.8 | 3303 |
| 20 | 47 | 14 | 1 | 2.8 | 7204B | 52 | 15 | 1 | 3.5 | 7304B | 52 | 22.2 | 1 | 3.5 | 3304 |
| 25 | 52 | 15 | 1 | 2.8 | 7205B | 62 | 17 | 1 | 3.5 | 7305B | 62 | 25.4 | 1 | 3.5 | 3305 |
| 30 | 62 | 16 | 1 | 2.8 | 7206B | 72 | 19 | 1 | 3.5 | 7306B | 72 | 30.2 | 1 | 3.5 | 3306 |
| 35 | 72 | 17 | 1 | 3.5 | 7207B | 80 | 21 | 1.5 | 4.5 | 7307B | 80 | 34.9 | 1.5 | 4.5 | 3307 |
| 40 | 80 | 18 | 1 | 3.5 | 7208B | 90 | 23 | 1.5 | 4.5 | 7308B | 90 | 36.5 | 1.5 | 4.5 | 3308 |
| 45 | 85 | 19 | 1 | 3.5 | 7209B | 100 | 25 | 1.5 | 4.5 | 7309B | 100 | 39.7 | 1.5 | 4.5 | 3309 |
| 50 | 90 | 20 | 1 | 3.5 | 7210B | 110 | 27 | 2 | 5.5 | 7310B | 110 | 44.4 | 2 | 5.5 | 3310 |
| 55 | 100 | 21 | 1.5 | 4.5 | 7211B | 120 | 29 | 2 | 5.5 | 7311B | 120 | 49.2 | 2 | 5.5 | 3311 |
| 60 | 110 | 22 | 1.5 | 4.5 | 7212B | 130 | 31 | 2.1 | 6 | 7312B | 130 | 54 | 2.1 | 6 | 3312 |
| 65 | 120 | 23 | 1.5 | 4.5 | 7213B | 140 | 33 | 2.1 | 6 | 7313B | 140 | 58.7 | 2.1 | 6 | 3313 |
| 70 | 125 | 24 | 1.5 | 4.5 | 7214B | 150 | 35 | 2.1 | 6 | 7314B | 150 | 63.5 | 2.1 | 6 | 3314 |
| 75 | 130 | 25 | 1.5 | 4.5 | 7215B | 160 | 37 | 2.1 | 6 | 7315B | 160 | 68.3 | 2.1 | 6 | 3315 |
| 80 | 140 | 26 | 2 | 5.5 | 7216B | 170 | 39 | 2.1 | 6 | 7316B | 170 | 68.3 | 2.1 | 6 | 3316 |
| 85 | 150 | 28 | 2 | 5.5 | 7217B | 180 | 41 | 2.5 | 7 | 7317B | 180 | 73 | 2.5 | 7 | 3317 |
| 90 | 160 | 30 | 2 | 5.5 | 7218B | 190 | 43 | 2.5 | 7 | 7318B | 190 | 73 | 2.5 | 7 | 3318 |
| 95 | 170 | 32 | 2.1 | 6 | 7219B | 200 | 45 | 2.5 | 7 | 7319B | 200 | 77.8 | 2.5 | 7 | 3319 |
| 100 | 180 | 34 | 2.1 | 6 | 7220B | 215 | 47 | 2.5 | 7 | 7320B | 215 | 82.6 | 2.5 | 7 | 3320 |

⇒ **Angular contact ball bearing DIN 628 – 7309B:** Angular contact ball bearing (Bearing type 7), width series 0[1], diameter series 3, bore code 09 (bore diameter $d$ = 9 · 5 mm = 45 mm), contact angle $\alpha$ = 40° (B)

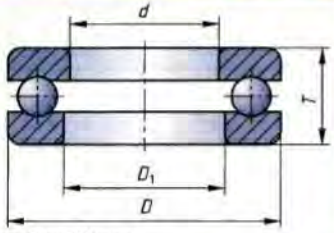
[1] In the designations for deep groove and angular contact ball bearings the 0 for the width series is sometimes omitted according to DIN 623-1.

[2] Contact angle $\alpha$ = 40° [3] Contact angle not standardized

# Ball bearings, Roller bearings

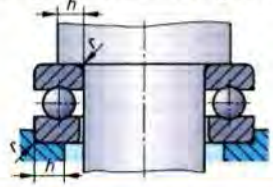
## Axial deep groove ball bearings (selection)

cf. DIN 711 (1988-02)




*d* from 8 to 360 mm

**Mounting dimensions according to DIN 5418:**



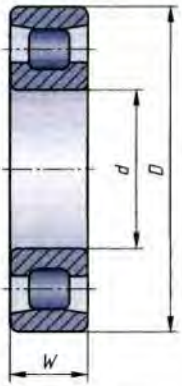

| *d* | $D_1$ | Bearing series 512 | | | | | Bearing series 513 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *D* | *T* | *r* max | *h* min | Basic number | *D* | *T* | *r* max | *h* min | Basic number |
| 25 | 27 | 47 | 15 | 0.6 | 6 | 51205 | 52 | 18 | 1 | 7 | 51305 |
| 30 | 32 | 52 | 16 | 0.6 | 6 | 51206 | 60 | 21 | 1 | 8 | 51306 |
| 35 | 37 | 62 | 18 | 1 | 7 | 51207 | 68 | 24 | 1 | 9 | 51307 |
| 40 | 42 | 68 | 19 | 1 | 7 | 51208 | 78 | 26 | 1 | 10 | 51308 |
| 45 | 47 | 73 | 20 | 1 | 7 | 51209 | 85 | 28 | 1 | 10 | 51309 |
| 50 | 52 | 78 | 22 | 1 | 7 | 51210 | 95 | 31 | 1 | 12 | 51310 |
| 55 | 57 | 90 | 25 | 1 | 9 | 51211 | 105 | 35 | 1 | 13 | 51311 |
| 60 | 62 | 95 | 26 | 1 | 9 | 51212 | 110 | 35 | 1 | 13 | 51312 |
| 65 | 67 | 100 | 27 | 1 | 9 | 51213 | 115 | 36 | 1 | 13 | 51313 |
| 70 | 72 | 105 | 27 | 1 | 9 | 51214 | 125 | 40 | 1 | 14 | 51314 |
| 75 | 77 | 110 | 27 | 1 | 9 | 51215 | 135 | 44 | 1.5 | 15 | 51315 |
| 80 | 82 | 115 | 28 | 1 | 9 | 51216 | 140 | 44 | 1.5 | 15 | 51316 |

⇒ **Axial deep groove ball bearing DIN 711 – 51210:** Axial-deep groove ball bearing of the bearing series 512 with bearing type 5, width series 1, diameter series 2 and bore code 10

## Cylindrical roller bearings (selection)

cf. DIN 5412-1 (2005-08)

Form N




Form NU



Form NJ



Form NUP

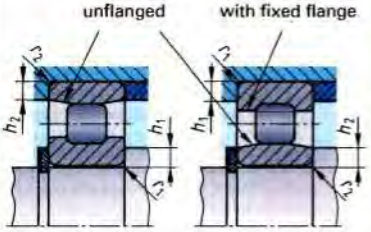


*d* from 15 to 500 mm

**Mounting dimensions according to DIN 5418:**

Form N — unflanged

Form NU — with fixed flange




| *d* | Bearing series N2, NU2, NJ2, NUP2 | | | | | | Bearing series N3, NU3, NJ3, NUP3 | | | | | | Bore code |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *D* | *W* | $r_1$ max | $h_1$ min | $r_2$ max | $h_2$ min | *D* | *W* | $r_1$ max | $h_1$ min | $r_2$ max | $h_2$ min | |
| 17 | 40 | 12 | 0.6 | 2.1 | 0.3 | 1.2 | 47 | 14 | 1 | 2.8 | 1 | 2.8 | 03 |
| 20 | 47 | 14 | 1 | 2.8 | 0.6 | 2.1 | 52 | 15 | 1.1 | 3.5 | 1 | 2.8 | 04 |
| 25 | 52 | 15 | 1 | 2.8 | 0.6 | 2.1 | 62 | 17 | 1.1 | 3.5 | 1 | 2.8 | 05 |
| 30 | 62 | 16 | 1 | 2.8 | 0.6 | 2.1 | 72 | 19 | 1.1 | 3.5 | 1 | 2.8 | 06 |
| 35 | 72 | 17 | 1 | 3.5 | 0.6 | 2.1 | 80 | 21 | 1.5 | 4.5 | 1 | 2.8 | 07 |
| 40 | 80 | 18 | 1 | 3.5 | 1 | 3.5 | 90 | 23 | 1.5 | 4.5 | 2 | 5.5 | 08 |
| 45 | 85 | 19 | 1 | 3.5 | 1 | 3.5 | 100 | 25 | 1.5 | 4.5 | 2 | 5.5 | 09 |
| 50 | 90 | 20 | 1 | 3.5 | 1 | 3.5 | 110 | 27 | 2 | 5.5 | 2 | 5.5 | 10 |
| 55 | 100 | 21 | 1.5 | 4.5 | 1 | 3.5 | 120 | 29 | 2 | 5.5 | 2 | 5.5 | 11 |
| 60 | 110 | 22 | 1.5 | 4.5 | 1.5 | 4.5 | 130 | 31 | 2.1 | 6 | 2 | 5.5 | 12 |
| 65 | 120 | 23 | 1.5 | 4.5 | 1.5 | 4.5 | 140 | 33 | 2.1 | 6 | 2 | 5.5 | 13 |
| 70 | 125 | 24 | 1.5 | 4.5 | 1.5 | 4.5 | 150 | 35 | 2.1 | 6 | 2 | 5.5 | 14 |
| 75 | 130 | 25 | 1.5 | 4.5 | 1.5 | 4.5 | 160 | 37 | 2.1 | 6 | 2 | 5.5 | 15 |
| 80 | 140 | 26 | 2 | 5.5 | 2 | 5.5 | 170 | 39 | 2.1 | 6 | 2 | 5.5 | 16 |
| 85 | 150 | 28 | 2 | 5.5 | 2 | 5.5 | 180 | 41 | 3 | 7 | 3 | 7 | 17 |
| 90 | 160 | 30 | 2 | 5.5 | 2 | 5.5 | 190 | 43 | 3 | 7 | 3 | 7 | 18 |
| 95 | 170 | 32 | 2.1 | 6 | 2.1 | 6 | 200 | 45 | 3 | 7 | 3 | 7 | 19 |
| 100 | 180 | 34 | 2.1 | 6 | 2.1 | 6 | 215 | 47 | 3 | 7 | 3 | 7 | 20 |
| 105 | – | – | – | – | – | – | 225 | 49 | 3 | 7 | 3 | 7 | 21 |
| 110 | 200 | 38 | 2.1 | 6 | 2.1 | 6 | 240 | 50 | 3 | 7 | 3 | 7 | 22 |
| 120 | 215 | 40 | 2.1 | 6 | 2.1 | 6 | 260 | 55 | 3 | 7 | 3 | 7 | 24 |

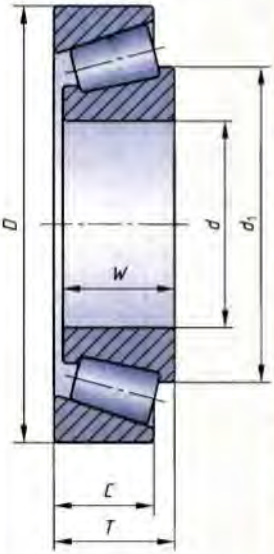
⇒ **Cylindrical roller bearing DIN 5412 – NUP 312 E:** Cylindrical roller bearing of bearing series NUP3 with bearing type NUP, width series 0, diameter series 3 and bore code 12, reinforced design

The normal design of the dimension series 02, 22, 03 and 23 were deleted from the standard with no replacement and then replaced with the reinforced design (suffix symbol E).

# Roller bearings

## Tapered roller bearings (selection)

cf. DIN 720 (1979-02) and DIN 5418 (1993-02)



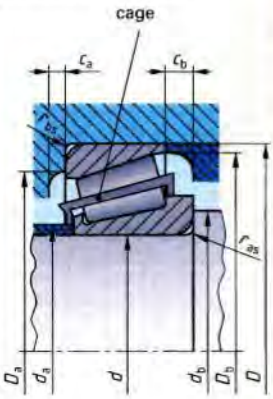

**Bearing series 302**

| Dimensions | | | | | | Mounting dimension | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| d | D | W | C | T | $d_1$ | $d_a$ max | $d_b$ min | $D_a$ min | $D_a$ max | $D_b$ min | $c_a$ min | $c_b$ min | $r_{as}$ max | $r_{bs}$ max | Basic no. |
| 20 | 47 | 14 | 12 | 15.25 | 33.2 | 27 | 26 | 40 | 41 | 43 | 2 | 3 | 1 | 1 | 30204 |
| 25 | 52 | 15 | 13 | 16.25 | 37.4 | 31 | 31 | 44 | 46 | 48 | 2 | 2 | 1 | 1 | 30205 |
| 30 | 62 | 16 | 14 | 17.25 | 44.6 | 37 | 36 | 53 | 56 | 57 | 2 | 3 | 1 | 1 | 30206 |
| 35 | 72 | 17 | 15 | 18.15 | 51.8 | 44 | 42 | 62 | 65 | 67 | 3 | 3 | 1.5 | 1.5 | 30207 |
| 40 | 80 | 18 | 16 | 19.75 | 57.5 | 49 | 47 | 69 | 73 | 74 | 3 | 3.5 | 1.5 | 1.5 | 30208 |
| 45 | 85 | 19 | 16 | 20.75 | 63 | 54 | 52 | 74 | 78 | 80 | 3 | 4.5 | 1.5 | 1.5 | 30209 |
| 50 | 90 | 20 | 17 | 21.75 | 67.9 | 58 | 57 | 79 | 83 | 85 | 3 | 4.5 | 1.5 | 1.5 | 30210 |
| 55 | 100 | 21 | 18 | 22.75 | 74.6 | 64 | 64 | 88 | 91 | 94 | 4 | 4.5 | 2 | 1.5 | 30211 |
| 60 | 110 | 22 | 19 | 23.75 | 81.5 | 70 | 69 | 96 | 101 | 103 | 4 | 4.5 | 2 | 1.5 | 30212 |
| 65 | 120 | 23 | 20 | 24.75 | 89 | 77 | 74 | 106 | 111 | 113 | 4 | 4.5 | 2 | 1.5 | 30213 |
| 70 | 125 | 24 | 21 | 26.25 | 93.9 | 81 | 79 | 110 | 116 | 118 | 4 | 5 | 2 | 1.5 | 30214 |
| 75 | 130 | 25 | 22 | 27.25 | 99.2 | 86 | 84 | 115 | 121 | 124 | 4 | 5 | 2 | 1.5 | 30215 |
| 80 | 140 | 26 | 22 | 28.25 | 105 | 91 | 90 | 124 | 130 | 132 | 4 | 6 | 2.5 | 2 | 30216 |
| 85 | 150 | 28 | 24 | 30.5 | 112 | 97 | 95 | 132 | 140 | 141 | 5 | 6.5 | 2.5 | 2 | 30217 |
| 90 | 160 | 30 | 26 | 32.5 | 118 | 103 | 100 | 140 | 150 | 150 | 5 | 6.5 | 2.5 | 2 | 30218 |
| 95 | 170 | 32 | 27 | 34.5 | 126 | 110 | 107 | 149 | 158 | 159 | 5 | 7.5 | 3 | 2.5 | 30219 |
| 100 | 180 | 34 | 29 | 37 | 133 | 116 | 112 | 157 | 168 | 168 | 5 | 8 | 3 | 2.5 | 30220 |
| 105 | 190 | 36 | 30 | 39 | 141 | 122 | 117 | 165 | 178 | 177 | 6 | 9 | 3 | 2.5 | 30221 |
| 110 | 200 | 38 | 32 | 41 | 148 | 129 | 122 | 174 | 188 | 187 | 6 | 9 | 3 | 2.5 | 30222 |
| 120 | 215 | 40 | 34 | 43.5 | 161 | 140 | 132 | 187 | 203 | 201 | 6 | 9.5 | 3 | 2.5 | 30224 |

**Bearing series 303**

| Dimensions | | | | | | Mounting dimension | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| d | D | W | C | T | $d_1$ | $d_a$ max | $d_b$ min | $D_a$ min | $D_a$ max | $D_b$ min | $c_a$ min | $c_b$ min | $r_{as}$ max | $r_{bs}$ max | Basic no. |
| 20 | 52 | 15 | 13 | 16.25 | 34.3 | 28 | 27 | 44 | 45 | 47 | 2 | 3 | 1.5 | 1.5 | 30304 |
| 25 | 62 | 17 | 15 | 18.25 | 41.5 | 34 | 32 | 54 | 55 | 57 | 2 | 3 | 1.5 | 1.5 | 30305 |
| 30 | 72 | 19 | 16 | 20.75 | 44.8 | 40 | 37 | 62 | 65 | 66 | 3 | 4.5 | 1.5 | 1.5 | 30306 |
| 35 | 80 | 21 | 18 | 22.75 | 54.5 | 45 | 44 | 70 | 71 | 74 | 3 | 4.5 | 2 | 1.5 | 30307 |
| 40 | 90 | 23 | 20 | 25.25 | 62.5 | 52 | 49 | 77 | 81 | 82 | 3 | 5 | 2 | 1.5 | 30308 |
| 45 | 100 | 25 | 22 | 27.25 | 70.1 | 59 | 54 | 86 | 91 | 92 | 3 | 5 | 2 | 1.5 | 30309 |
| 50 | 110 | 27 | 23 | 29.25 | 77.2 | 65 | 60 | 95 | 100 | 102 | 4 | 6 | 2.5 | 2 | 30310 |
| 55 | 120 | 29 | 25 | 31.5 | 84 | 71 | 65 | 104 | 110 | 111 | 4 | 6.5 | 2.5 | 2 | 30311 |
| 60 | 130 | 31 | 26 | 33.5 | 91.9 | 77 | 72 | 112 | 118 | 120 | 5 | 7.5 | 3 | 2.5 | 30312 |
| 65 | 140 | 33 | 28 | 36 | 98.6 | 83 | 77 | 122 | 128 | 130 | 5 | 8 | 3 | 2.5 | 30313 |
| 70 | 150 | 35 | 30 | 38 | 105 | 89 | 82 | 120 | 138 | 140 | 5 | 8 | 3 | 2.5 | 30314 |
| 75 | 160 | 37 | 31 | 40 | 112 | 95 | 87 | 139 | 148 | 149 | 5 | 9 | 3 | 2.5 | 30315 |
| 80 | 170 | 39 | 33 | 42.5 | 120 | 102 | 92 | 148 | 158 | 159 | 5 | 9.5 | 3 | 2.5 | 30316 |
| 85 | 180 | 41 | 34 | 44.5 | 126 | 107 | 99 | 156 | 166 | 167 | 6 | 10.5 | 4 | 3 | 30317 |
| 90 | 190 | 43 | 36 | 46.5 | 132 | 113 | 104 | 165 | 176 | 176 | 6 | 10.5 | 4 | 3 | 30318 |
| 95 | 200 | 45 | 38 | 49.5 | 139 | 118 | 109 | 172 | 186 | 184 | 6 | 11.5 | 4 | 3 | 30319 |
| 100 | 215 | 47 | 39 | 51.5 | 148 | 127 | 114 | 184 | 201 | 197 | 6 | 12.5 | 4 | 3 | 30320 |
| 105 | 225 | 49 | 41 | 53.5 | 155 | 132 | 119 | 193 | 211 | 206 | 7 | 12.5 | 4 | 3 | 30321 |
| 110 | 240 | 50 | 42 | 54.5 | 165 | 141 | 124 | 206 | 226 | 220 | 8 | 12.5 | 4 | 3 | 30322 |
| 120 | 260 | 55 | 46 | 59.5 | 178 | 152 | 134 | 221 | 246 | 237 | 8 | 13.5 | 4 | 3 | 30324 |

**Mounting dimensions according to DIN 5418:**




In the case of tapered roller bearings the cage projects beyond the lateral face of the outer ring.

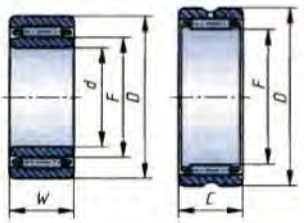
The mounting dimensions of DIN 5418 must be maintained so that the cage does not rub against other parts.

⇒ **Tapered roller bearing DIN 720 – 30212:** Tapered roller bearing of bearing series 302 with bearing type 3, width series 0, diameter series 2, bore code 12

# Needle bearings, Lock nuts, Lock washers

## Needle bearings (selection)

cf. DIN 617 (1993-04)




**Mounting dimensions according to DIN 5418:**



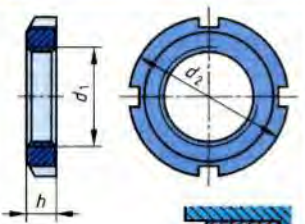

| d | D | F | r max | h min | Bearing series NA49 W | Bearing series NA49 Basic number | Bearing series NA69 W | Bearing series NA69 Basic number |
|---|---|---|---|---|---|---|---|---|
| 20 | 37 | 25 | 0.3 | 1 | 17 | NA4904 | 30 | NA6904 |
| 25 | 42 | 28 | 0.3 | 1 | 17 | NA4905 | 30 | NA6905 |
| 30 | 47 | 30 | 0.3 | 1 | 17 | NA4906 | 30 | NA6906 |
| 35 | 55 | 42 | 0.6 | 1.6 | 20 | NA4907 | 36 | NA6907 |
| 40 | 62 | 48 | 0.6 | 1.6 | 22 | NA4908 | 40 | NA6908 |
| 45 | 68 | 52 | 0.6 | 1.6 | 22 | NA4909 | 40 | NA6909 |
| 50 | 72 | 58 | 0.6 | 1.6 | 22 | NA4910 | 40 | NA6910 |
| 55 | 80 | 63 | 1 | 2.3 | 25 | NA4911 | 45 | NA6911 |
| 60 | 85 | 68 | 1 | 2.3 | 25 | NA4912 | 45 | NA6912 |
| 65 | 90 | 72 | 1 | 2.3 | 25 | NA4913 | 45 | NA6913 |
| 70 | 100 | 80 | 1 | 2.3 | 30 | NA4914 | 54 | NA6914 |
| 75 | 105 | 85 | 1 | 2.3 | 30 | NA4915 | 54 | NA6915 |

⇒ **Needle bearing DIN 617 – NA4909:** Needle bearing of bearing series NA49 with bearing type NA, width series 4, diameter series 9, bore code 09

NA6907 and up: double row

## Lock nuts for antifriction bearings (selection)

cf. DIN 981 (1993-02)




Mounting example:



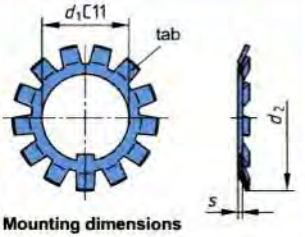
$d_1$ from M10 to M200

| $d_1$ | $d_2$ | h | Code | $d_1$ | $d_2$ | h | Code |
|---|---|---|---|---|---|---|---|
| M10 × 0.75 | 18 | 4 | KM0 | M60 × 2 | 80 | 11 | KM12 |
| M12 × 1 | 22 | 4 | KM1 | M65 × 2 | 85 | 12 | KM13 |
| M15 × 1 | 25 | 5 | KM2 | M70 × 2 | 92 | 12 | KM14 |
| M17 × 1 | 28 | 5 | KM3 | M75 × 2 | 98 | 13 | KM15 |
| M20 × 1 | 32 | 6 | KM4 | M80 × 2 | 105 | 15 | KM16 |
| M25 × 1.5 | 38 | 7 | KM5 | M85 × 2 | 110 | 16 | KM17 |
| M30 × 1.5 | 45 | 7 | KM6 | M90 × 2 | 120 | 16 | KM18 |
| M35 × 1.5 | 52 | 8 | KM7 | M95 × 2 | 125 | 17 | KM19 |
| M40 × 1.5 | 58 | 9 | KM8 | M100 × 2 | 130 | 18 | KM20 |
| M45 × 1.5 | 65 | 10 | KM9 | M105 × 2 | 140 | 18 | KM21 |
| M50 × 1.5 | 70 | 11 | KM10 | M110 × 2 | 145 | 19 | KM22 |
| M55 × 2 | 75 | 11 | KM11 | M115 × 2 | 150 | 19 | KM23 |

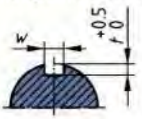
⇒ **Lock nut DIN 981 – KM6:** Lock nut of $d_1$ = M30 x 1.5

## Lock washers (selection)

cf. DIN 5406 (1993-02)




**Mounting dimensions**




$d_1$ from 10 to 200 mm

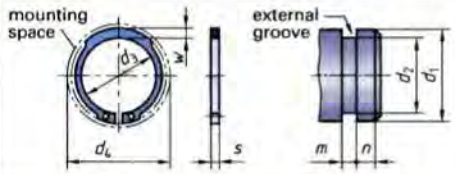
| $d_1$ | $d_2$ | s | w H11 | t | Code | $d_1$ | $d_2$ | s | w H11 | t | Code |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 10 | 21 | 1 | 4 | 2 | MB0 | 60 | 86 | 1.5 | 9 | 4 | MB12 |
| 12 | 25 | 1 | 4 | 2 | MB1 | 65 | 92 | 1.5 | 9 | 4 | MB13 |
| 15 | 28 | 1 | 5 | 2 | MB2 | 70 | 98 | 1.5 | 9 | 5 | MB14 |
| 17 | 32 | 1 | 5 | 2 | MB3 | 75 | 104 | 1.5 | 9 | 5 | MB15 |
| 20 | 36 | 1 | 5 | 2 | MB4 | 80 | 112 | 1.7 | 11 | 5 | MB16 |
| 25 | 42 | 1.2 | 6 | 3 | MB5 | 85 | 119 | 1.7 | 11 | 5 | MB17 |
| 30 | 49 | 1.2 | 6 | 4 | MB6 | 90 | 126 | 1.7 | 11 | 5 | MB18 |
| 35 | 57 | 1.2 | 7 | 4 | MB7 | 95 | 133 | 1.7 | 11 | 5 | MB19 |
| 40 | 62 | 1.2 | 7 | 4 | MB8 | 100 | 142 | 1.7 | 14 | 6 | MB20 |
| 45 | 69 | 1.2 | 7 | 4 | MB9 | 105 | 145 | 1.7 | 14 | 6 | MB21 |
| 50 | 74 | 1.2 | 7 | 4 | MB10 | 110 | 154 | 1.7 | 14 | 6 | MB22 |
| 55 | 81 | 1.5 | 9 | 4 | MB11 | 115 | 159 | 2 | 14 | 6 | MB23 |

⇒ **Lock washer DIN 5406 – MB6:** Lock washer of $d_1$ = 30 mm

# Internal and external retaining rings, Circlips

## Retaining rings in standard design[1] (selection)

### For shafts (external) — cf. DIN 471 (1981-09)



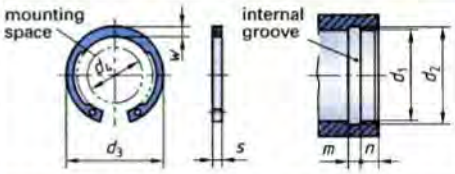

| Nominal size $d_1$ mm | Ring $s$ | Ring $d_3$ | Ring $d_4$ | Ring $w$ ≈ | Slot $d_2$ | Slot $m$ H13 | Slot $n$ min |
|---|---|---|---|---|---|---|---|
| 10 | 1 | 9.3 | 17 | 1.8 | 9.6 | 1.1 | 0.6 |
| 12 | 1 | 11 | 19 | 1.8 | 11.5 | 1.1 | 0.8 |
| 15 | 1 | 13.8 | 22.6 | 2.2 | 14.3 | 1.1 | 1.1 |
| 18 | 1.2 | 16.5 | 26.2 | 2.4 | 17 | 1.3 | 1.5 |
| 20 | 1.2 | 18.5 | 28.4 | 2.6 | 19 | 1.3 | 1.5 |
| 22 | 1.2 | 20.5 | 30.8 | 2.8 | 21 | 1.3 | 1.5 |
| 25 | 1.2 | 23.2 | 34.2 | 3 | 23.9 | 1.3 | 1.7 |
| 28 | 1.5 | 25.9 | 37.9 | 3.2 | 26.6 | 1.6 | 2.1 |
| 30 | 1.5 | 27.9 | 40.5 | 3.5 | 28.6 | 1.6 | 2.1 |
| 32 | 1.5 | 29.6 | 43 | 3.6 | 30.3 | 1.6 | 2.6 |
| 35 | 1.5 | 32.2 | 46.8 | 3.9 | 33 | 1.6 | 3 |
| 38 | 1.75 | 35.2 | 50.2 | 4.2 | 36 | 1.85 | 3 |
| 40 | 1.75 | 36.5 | 52.6 | 4.4 | 37.5 | 1.85 | 3.8 |
| 42 | 1.75 | 38.5 | 55.7 | 4.5 | 39.5 | 1.85 | 3.8 |
| 45 | 1.75 | 41.5 | 59.1 | 4.7 | 42.5 | 1.85 | 3.8 |
| 48 | 1.75 | 44.5 | 62.5 | 5 | 45.5 | 1.85 | 3.8 |
| 50 | 2.0 | 45.8 | 64.5 | 5.1 | 47.0 | 2.15 | 4.5 |
| 60 | 2.0 | 55.8 | 75.6 | 5.8 | 57.0 | 2.15 | 4.5 |
| 65 | 2.5 | 60.8 | 81.4 | 6.3 | 62.0 | 2.65 | 4.5 |
| 70 | 2.5 | 65.5 | 87 | 6.6 | 67.0 | 2.65 | 4.5 |
| 75 | 2.5 | 70.5 | 92.7 | 7.0 | 72.0 | 2.65 | 4.5 |
| 80 | 2.5 | 74.5 | 98.1 | 7.4 | 76.5 | 2.65 | 5.3 |
| 90 | 3.0 | 84.5 | 108.5 | 8.2 | 86.5 | 3.15 | 5.3 |
| 100 | 3.0 | 94.5 | 120.2 | 9 | 96.5 | 3.15 | 5.3 |

⇒ **Retaining ring DIN 471 – 40 x 1.75:** $d_1$ = 40 mm, $s$ = 1.75 mm

**Tolerance classes for $d_2$**

| $d_1$ in mm | 3–10 | 12–22 | 24–100 |
|---|---|---|---|
| $d_2$ | h10 | h11 | h12 |

### For bores (internal) — cf. DIN 472 (1981-09)




| Nominal size $d_1$ mm | Ring $s$ | Ring $d_3$ | Ring $d_4$ | Ring $w$ ≈ | Slot $d_2$ | Slot $m$ H13 | Slot $n$ min |
|---|---|---|---|---|---|---|---|
| 10 | 1 | 10.8 | 3.3 | 1.4 | 10.4 | 1.1 | 0.6 |
| 12 | 1 | 13 | 4.9 | 1.7 | 12.5 | 1.1 | 0.8 |
| 15 | 1 | 16.2 | 7.2 | 2 | 15.7 | 1.1 | 1.1 |
| 18 | 1 | 19.5 | 9.4 | 2.2 | 19 | 1.1 | 1.5 |
| 20 | 1 | 21.5 | 11.2 | 2.3 | 21 | 1.1 | 1.5 |
| 22 | 1 | 23.5 | 13.2 | 2.5 | 23 | 1.1 | 1.5 |
| 25 | 1.2 | 26.9 | 15.5 | 2.7 | 26.2 | 1.3 | 1.8 |
| 28 | 1.2 | 30.1 | 17.9 | 2.9 | 29.4 | 1.3 | 2.1 |
| 30 | 1.2 | 32.1 | 19.9 | 3 | 31.4 | 1.3 | 2.1 |
| 32 | 1.2 | 34.4 | 20.6 | 3.2 | 33.7 | 1.3 | 2.6 |
| 35 | 1.5 | 37.8 | 23.6 | 3.4 | 37 | 1.6 | 3 |
| 38 | 1.5 | 40.8 | 26.4 | 3.7 | 40 | 1.6 | 3 |
| 40 | 1.75 | 43.5 | 27.8 | 3.9 | 42.5 | 1.85 | 3.8 |
| 42 | 1.75 | 45.5 | 29.6 | 4.1 | 44.5 | 1.85 | 3.8 |
| 45 | 1.75 | 48.5 | 32 | 4.3 | 47.5 | 1.85 | 3.8 |
| 48 | 1.75 | 51.5 | 34.5 | 4.5 | 50.5 | 1.85 | 3.8 |
| 50 | 2.0 | 54.2 | 36.3 | 4.6 | 53.0 | 2.15 | 4.5 |
| 60 | 2.0 | 64.2 | 44.7 | 5.4 | 63.0 | 2.15 | 4.5 |
| 65 | 2.5 | 69.2 | 49.0 | 5.8 | 68.0 | 2.65 | 4.5 |
| 72 | 2.5 | 76.5 | 55.6 | 6.4 | 75.0 | 2.65 | 4.5 |
| 75 | 2.5 | 79.5 | 58.6 | 6.6 | 78.0 | 2.65 | 4.5 |
| 80 | 2.5 | 85.5 | 62.1 | 7.0 | 83.5 | 2.65 | 5.3 |
| 90 | 3.0 | 95.5 | 71.9 | 7.6 | 93.5 | 3.15 | 5.3 |
| 100 | 3.0 | 105.5 | 80.6 | 8.4 | 103.5 | 3.15 | 5.3 |

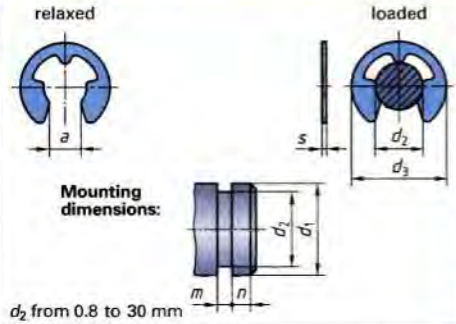
⇒ **Retaining ring DIN 472 – 80 x 2.5:** $d_1$ = 80 mm, $s$ = 2.5 mm

**Tolerance classes for $d_2$**

| $d_1$ in mm | 8–22 | 24–100 | 100–300 |
|---|---|---|---|
| $d_2$ | H11 | H12 | H13 |

[1] Standard design: $d_1$ from 3–300 mm; heavy duty design: $d_1$ from 15–100 mm

## Circlips (selection) — cf. DIN 6799 (1981-09)




$d_2$ from 0.8 to 30 mm

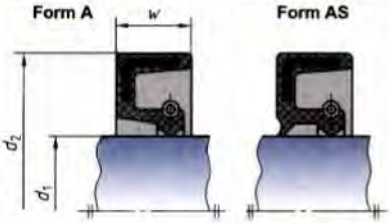
| Circlips $d_2$ h11 | Circlips $d_3$ loaded | Circlips $a$ | Circlips $s$ | Shaft $d_1$ from–to | Shaft $m$ | | Shaft $n$ min |
|---|---|---|---|---|---|---|---|
| 6 | 12.3 | 5.26 | 0.7 | 7– 9 | 0.74 | + 0.05 | 1.2 |
| 7 | 14.3 | 5.84 | 0.9 | 8–11 | 0.94 | 0 | 1.5 |
| 8 | 16.3 | 6.52 | 1 | 9–12 | 1.05 | | 1.8 |
| 9 | 18.8 | 7.63 | 1.1 | 10–14 | 1.15 | | 2 |
| 10 | 20.4 | 8.32 | 1.2 | 11–15 | 1.25 | | 2 |
| 12 | 23.4 | 10.45 | 1.3 | 13–18 | 1.35 | + 0.08 0 | 2.5 |
| 15 | 29.4 | 12.61 | 1.5 | 16–24 | 1.55 | | 3 |
| 19 | 37.6 | 15.92 | 1.75 | 20–31 | 1.80 | | 3.5 |
| 24 | 44.6 | 21.88 | 2 | 25–38 | 2.05 | | 4 |

⇒ **Circlip DIN 6799 – 15:** $d_2$ = 15 mm

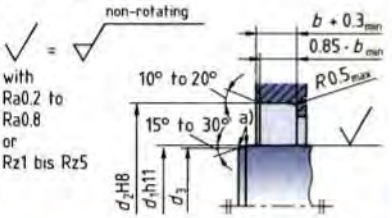
# Sealing elements

## Radial seals (selection)

cf. DIN 3760 (1996-09)




**Mounting dimensions:**




a) = edges rounded

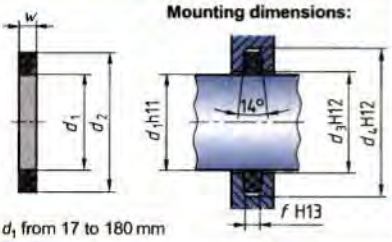
$d_1$ from 6 to 500 mm

| $d_1$ | $d_2$ | | $w$ | $d_3$ | $d_1$ | $d_2$ | | $w$ | $d_3$ | $d_1$ | $d_2$ | | $w$ | $d_3$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10 | 22 | 26 | 7 | 8.5 | 28 | 40 | 52 | 7 | 25.5 | 50 | 65 | 72 | 8 | 46.5 |
| | 25 | – | | | | 47 | – | | | | 68 | – | | |
| 12 | 22 | 30 | 7 | 10 | 30 | 40 | 47 | 8 | 27.5 | 55 | 70 | 80 | 8 | 51 |
| | 25 | – | | | | 42 | 52 | | | | 72 | – | | |
| 14 | 24 | 30 | 7 | 12 | 32 | 45 | 52 | 8 | 29 | 60 | 75 | 85 | 8 | 56 |
| 15 | 26 | 35 | 7 | 13 | | 47 | – | | | | 80 | – | | |
| | 30 | – | | | 35 | 47 | 52 | 8 | 32 | 65 | 85 | 90 | 10 | 61 |
| 16 | 30 | 35 | 7 | 14 | | 50 | 55 | 8 | 35 | 70 | 90 | 95 | 10 | 66 |
| 18 | 30 | 35 | 7 | 16 | 38 | 55 | 62 | | | 75 | 95 | 100 | 10 | 70.5 |
| 20 | 30 | 40 | 7 | 18 | 40 | 52 | 62 | 8 | 37 | 80 | 100 | 110 | 10 | 75.5 |
| | 35 | – | | | | 55 | – | 8 | 38.5 | 85 | 110 | 120 | 12 | 80.5 |
| 22 | 35 | 47 | 7 | 19.5 | 42 | 55 | 62 | | | 90 | 110 | 120 | 12 | 85.5 |
| | 40 | – | | | 45 | 60 | 65 | 8 | 41.5 | 95 | 120 | 125 | 12 | 90.5 |
| 25 | 35 | 47 | 7 | 22.5 | | 62 | – | 8 | 44.5 | 100 | 120 | 130 | 12 | 94.5 |
| | 40 | 52 | | | 48 | 62 | – | | | | 125 | – | | |

⇒ **RWDR DIN 3760 – A25 x 40 x 7 – NB:** Radial seal (RWDR) of form A with $d_1$ = 25 mm, $d_2$ = 40 mm and $w$ = 7 mm, elastomer part of Nitrile-Butadiene rubber (NBR)

## Felt rings (selection)

cf. DIN 5419 (1959-09)



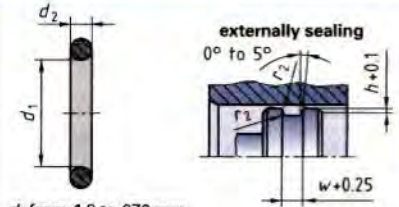

$d_1$ from 17 to 180 mm

| Dimensions | | | Mounting dim. | | | Dimensions | | | Mounting dim. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $d_1$ | $d_2$ | $w$ | $d_3$ | $d_4$ | $f$ | $d_1$ | $d_2$ | $w$ | $d_3$ | $d_4$ | $f$ |
| 20 | 30 | 4 | 21 | 31 | 3 | 60 | 76 | 6.5 | 61.5 | 77 | 5 |
| 25 | 37 | 5 | 26 | 38 | 4 | 65 | 81 | 6.5 | 66.5 | 82 | 5 |
| 30 | 42 | 5 | 31 | 43 | 4 | 70 | 88 | 7.5 | 71.5 | 89 | 6 |
| 35 | 47 | 5 | 36 | 48 | 4 | 75 | 93 | 7.5 | 76.5 | 94 | 6 |
| 40 | 52 | 5 | 41 | 53 | 4 | 80 | 99 | 7.5 | 81.5 | 99 | 6 |
| 45 | 57 | 5 | 46 | 58 | 4 | 85 | 103 | 7.5 | 86.5 | 104 | 6 |
| 50 | 66 | 6.5 | 51 | 67 | 5 | 90 | 110 | 9.5 | 92 | 111 | 7 |
| 55 | 71 | 6.5 | 56 | 72 | 5 | 100 | 124 | 10 | 102 | 125 | 8 |

⇒ **Felt ring DIN 5419 M5-40:** Felt ring of $d_1$ = 40 mm, felt hardn. M5

## O-rings

DIN 3771 (withdrawn)



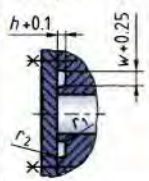

$d_1$ from 1.8 to 670 mm,
$d_2$ from 1.8 to 7 mm

| $d_1$ | $d_2$ | | $d_1$ | $d_2$ | | $d_1$ | $d_2$ | | $d_1$ | $d_2$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | | | 18 | | | 56 | | | 85 | | |
| 6 | | | 20 | | | 58 | | | 90 | | |
| 8 | 1.8 | | 25 | 2.65 | 3.55 | 60 | | | 95 | | |
| 9 | | | 28 | | | 63 | | | 100 | | |
| 10 | | | 30 | | | 67 | 3.55 | 5.3 | 103 | 3.55 | 5.3 |
| 14 | | | 40 | | | 69 | | | 106 | | |
| 15 | | | 45 | | | 71 | | | 109 | | |
| 16 | 1.8 | 2.65 | 50 | 3.55 | 5.3 | 75 | | | 112 | | |
| 17 | | | 53 | | | 80 | | | 115 | | |

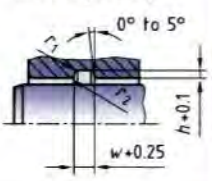
**Mounting dimensions for static loading**

| $d_2$ | $r_1$ | $r_2$ | internally & extern. sealing | | | axially sealing | |
|---|---|---|---|---|---|---|---|
| | | | $w$ | internal | external | $w$ | $h$ |
| | | | | $h$ | | | |
| 1.8 | 0.3 | 0.2 | 2.4 | 1.4 | 1.3 | 2.6 | 1.3 |
| 2.65 | | | 3.6 | 2.1 | 1.95 | 3.8 | 2 |
| 3.55 | 0.6 | 0.2 | 4.8 | 2.85 | 2.65 | 5 | 2.75 |
| 5.3 | | | 7.1 | 4.3 | 4.15 | 7.3 | 4.25 |

**axially sealing**




**internally sealing**



# Lubricating oils

## Designation of lubricating oils

cf. DIN 51502 (1990-08)

**Designation using code letters**

PGLP 220

- Code letters for lubricating oils
- Additional code letters
- ISO viscosity grade

**Designation using symbols**

| CL 100 |
|---|
| Mineral oil based lubricating oil |

| PGLP |
|---|
| 220 |
| Silicon based lubricating oil |

⇒ **Lubricating oil DIN 51517 – CL 100:** Circulating mineral oil based lubricating oil (C), increased corrosion and aging resistance (L), ISO viscosity grade VG 100 (100)

⇒ **Lubricating oil DIN 51517 – PGLP 220:** Polyglycol oil (PG), increased corrosion and aging resistance (L), increased wear protection (P), ISO viscosity grade VG 220 (220)

## Types of lubrication oils

cf. DIN 51502 (1990-08)

| Code letters | Type of lubricant and properties | Standard | Application |
|---|---|---|---|
| **Mineral oils** | | | |
| AN | Normal lubricating oils without additives | DIN 51501 | Once-through and circulating lubrication at oil temperatures up to 50 °C |
| B | Bitumen containing lubricating oils with high adhesion | DIN 51513 | Manual, continuous flow and oil bath lubrications, mainly for open lubrication points |
| C | Circulating lubricating oil, without additives | DIN 51517 | Plain bearings, antifriction bearings, gears |
| CG | Sliding track oil with active ingredients for reducing wear | DIN 8659 T2 | In mixed friction operations for slideways and guideways, and for worm gears |
| **Synthetic liquids** | | | |
| E | Ester oils with especially low change in viscosity | – | Bearings with widely varying temperatures |
| PG | Polyglycol oils with high aging resistance | – | Bearings with frequent mixed friction conditions |
| SI | Silicon oils with high aging resistance | – | Bearings with very high and low temperatures, very water repellant |

## Additional code letters

cf. DIN 51502 (1990-08)

| Additional code letters | Application and explanation |
|---|---|
| E | For lubricants that are mixed with water, e.g. cooling lubricant SE |
| F | For lubricants with solid lubricant additive, e.g. graphite, molybdenum sulfide |
| L | For lubricants with active ingredients to improve corrosion protection and/or aging resistance |
| P | For lubricants with active ingredients for reducing friction and wear in mixed friction areas and/or to increase the load capacity |

## ISO viscosity grade for liquid industrial lubricants

cf. DIN 51519 (1998-08)

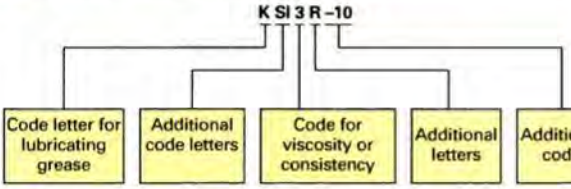
| Viscosity grade | Kinetic viscosity in mm²/s at | | | Viscosity grade | Kinetic viscosity in mm²/s at | | | Viscosity grade | Kinetic viscosity in mm²/s at | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 20 °C | 40 °C | 50 °C | | 20 °C | 40 °C | 50 °C | | 20 °C | 40 °C | 50 °C |
| ISO VG 2 | 3.3 | 2.2 | 1.3 | ISO VG 22 | – | 22 | 15 | ISO VG 220 | – | 220 | 130 |
| ISO VG 3 | 5 | 3.2 | 2.7 | ISO VG 32 | – | 32 | 20 | ISO VG 320 | – | 320 | 180 |
| ISO VG 5 | 8 | 4.6 | 3.7 | ISO VG 46 | – | 46 | 30 | ISO VG 460 | – | 460 | 250 |
| ISO VG 7 | 13 | 6.8 | 5.2 | ISO VG 68 | – | 68 | 40 | ISO VG 680 | – | 680 | 360 |
| ISO VG 10 | 21 | 10 | 7 | ISO VG 100 | – | 100 | 60 | ISO VG 1000 | – | 1000 | 510 |
| ISO VG 15 | 34 | 15 | 11 | ISO VG 150 | – | 150 | 90 | ISO VG 1500 | – | 1500 | 740 |

# Lubricating grease, Solid lubricants

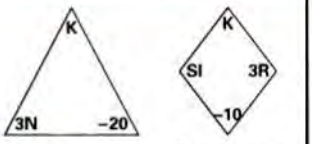
cf. DIN 51502 (1990-08)

## Designation of lubricating greases

**Designation by code letters**




**Designation by symbols**




Mineral oil based lubricating grease

Silicon based lubricating grease

⇒ **Lubricating grease DIN 51517 – K3N –20:** Lubricating grease for antifriction and plain bearings (K) based on mineral oil (NLGI grade 3) (3), upper working temperature +140 °C (N), lower working temperature –20 °C (–20)

⇒ **Lubricating grease DIN 51517 – KSI3R –10:** Silicon based lubricating grease for antifriction and plain bearings (K) (SI), NLGI-grade 3 (3), upper working temperature +180 °C (R), lower working temperature –10 °C (–10)

## Lubricating greases

| Code letters | Application/additives | Code letters | Application |
|---|---|---|---|
| K | General: antifriction bearings, plain bearing, sliding surfaces | G | Closed gears |
| KP | Like K, but with additives for reducing friction | OG | Open gears (adhesive lubricant without bitumen) |
| KF | Like K, but with solid lubricant additives | M | For plain bearings and seals (low requirements) |

## Consistency[1] classification for lubricating greases

| NLGI-grade[3] | Worked penetration[2] | NLGI-grade[3] | Worked penetration[2] | NLGI-grade[3] | Worked penetration[2] |
|---|---|---|---|---|---|
| 000 | 445–475 (very soft) | 1 | 310–340 | 4 | 175–205 |
| 00 | 400–430 | 2 | 265–295 | 5 | 130–160 |
| 0 | 355–385 | 3 | 220–250 | 6 | 85–115 (very firm) |

[1] Code for the viscoelasticity
[2] Measure of the penetration depth of a standardized test ball in the kneaded (worked) grease
[3] National Lubrication Grease Institute (NLGI)

## Additional letters for lubricating greases

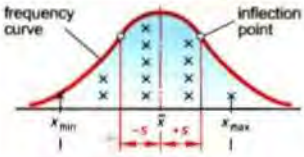
| Addit. letter[1] | Upper working temperature °C | Grade [2] | Addit. letter[1] | Upper working temperature °C | Grade [2] | Addit. letter[1] | Upper working temperature °C | Grade [2] |
|---|---|---|---|---|---|---|---|---|
| C | +60 | 0 or 1 | G | +100 | 0 or 1 | N | +140 | as per agreement |
| D | +60 | 2 or 3 | H | +100 | 2 or 3 | P | +160 | |
| | | | | | | R | +180 | |
| E | +80 | 0 or 1 | K | +120 | 0 or 1 | S | +200 | |
| F | +80 | 2 or 3 | M | +120 | 2 or 3 | T | +220 | |
| | | | | | | U | +220 | |

[1] The number value for the lower working temperature can be appended to the additional code letters; e.g. –20 for –20 °C
[2] Grades for behavior when subjected to water, cf. DIN 51807-1:
0: no change; 1: small change; 2: moderate change; 3: large change

## Solid lubricants

| Lubricant | Code | Working temperature | Application |
|---|---|---|---|
| Graphite | C | –18 to +450 °C | As powder or paste and as an additive to lubricating oils and lubricating greases, not in oxygen, nitrogen and vacuums |
| Molybdenum | $MoS_2$ | –180 to +400 °C | As mineral oil-free paste, sliding lacquer or additive to lubricating oils sulfide and lubricating greases, suitable for very high surface pressures |
| Polytetra-fluorethylene | PTFE | –250 to +260 °C | As powder in sliding lacquer and synthetic lubricating greases and as bearing material, very low coefficient of sliding friction $\mu = 0.04$ to 0.09 |

# 6 Production Engineering

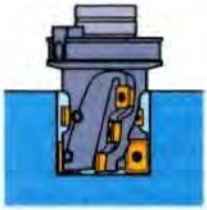




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**Material overhead**
in percent of material direct costs, e.g. purchasing costs, warehousing costs, etc.


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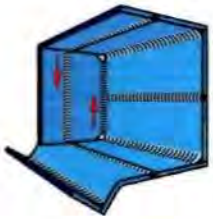


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Wear safety glasses



Wear hard hat


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# Standards ISO 9000, 9001, 9004

Standards of the ISO-9000 family should help organizations of all types and sizes to implement quality management systems, to work with existing quality management systems, and to facilitate mutual understanding in national and international trade.

## Quality management standards

cf. DIN EN ISO 9000 (2005-12), 9001, 9004 (2000-12)

| Standard | Explanation, contents |
|---|---|
| **DIN EN ISO 9000** | **Fundamentals of quality management systems** |
| | **Principle of quality management**<br>• customer focus<br>• leadership<br>• involvement of people<br>• process approach<br>• system approach to management<br>• continuous improvement<br>• factual approach to decision making<br>• mutually beneficial supplier relationships<br>**Fundamentals of quality management systems (QM systems)**<br>• reasons for QM systems<br>• requirements of QM systems and products<br>• progressive implementation of QM systems<br>• process oriented evaluation<br>• quality policies and goals<br>• role of top management in the QM system<br>• documentation; advantages and types<br>• evaluation of QM systems<br>• continuous improvement<br>• role of statistical methods<br>• QM systems as part of the total management system<br>• requirements of QM systems and comparative evaluation of organizations based on criteria of excellence models |
| | **Terminology for quality management systems** |
| | For a selection of definitions and explanations of terms, see page 275. |
| **DIN EN ISO 9001[1]** | **Requirements of a quality management system** |
| | This international standard applies to organizations in any industry or business sector regardless of products offered. It establishes requirements for a QM system, based on fundamentals outlined in ISO 9000, if an organization:<br>• must demonstrate capability to offer products which fulfill both customer and regulatory requirements,<br>• strives to improve customer satisfaction, including the process of continuous improvement of the system.<br>Specified requirements can be used for:<br>• internal applications by organizations<br>• certification purposes<br>• contract purposes<br>The standard is based on **a process oriented evaluation**, i.e. every activity or sequence of activities which uses resources to convert input into results is regarded as a process.<br>**Requirements**<br>The organization must:<br>• recognize all necessary processes for the QM system and their use in the organization,<br>• establish the flows and interdependencies of these processes,<br>• establish criteria and methods for ensuring implementation and control of these processes,<br>• ensure availability of resources and information for these processes,<br>• monitor, measure and analyze these processes,<br>• take necessary actions for continuous improvement of these processes,<br>• fulfill documentation requirements for the QM system, and<br>• observe regulations for document control. |
| | [1] This standard also replaces previous standards 9002 and 9003. |
| **DIN EN ISO 9004** | **Guideline for assessing the overall performance, effectiveness and efficiency of quality management systems** |
| | The goal of this standard is to improve the organization and to improve the satisfaction of customers and other relevant parties.<br>It is not intended for certification or contract purposes. |

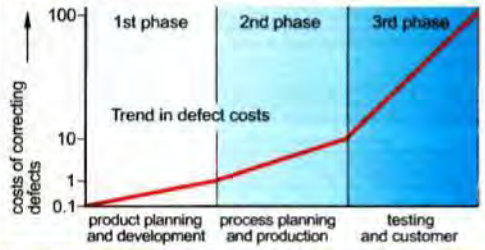
## Terminology

| Terms (selection) | Definitions & explanations cf. DIN EN ISO 9000 (2005-12) |
|---|---|
| **Quality-related terms** | |
| **Quality** | Extent to which the characteristics of a product fulfill the requirements for that product. |
| **Requirement** | Specified or mandatory demands for characteristics of a unit, e.g. nominal values, tolerances, functional capability or safety. |
| **Customer satisfaction** | Customer's perception of degree to which its requirements have been fulfilled. |
| **Capability** | Suitability of an organization, system or process to provide a product that fulfills that product's quality requirements. |
| **Characteristic and conformity related terms** | |
| **Quality characteristic** | Identifying attribute of a product or process, which is utilized in assessing quality based on the specified quality requirements.<br>• Quantitative (variable) characteristics:<br>discrete characteristics (whole numbers), i.e. number of holes, piece count<br>continuous characteristics (measured values), e.g. length, position, mass<br>• Qualitative characteristics:<br>ordinal characteristics (with ranking), e.g. light blue – blue – dark blue<br>nominal characteristics (without ranking), e.g. good – bad, blue – yellow<br>Identifying attribute of a product, a process or system relating to a requirement. |
| **Conformity** | Fulfilling a specified requirement, e.g. a dimensional tolerance. |
| **Defect** | Not fulfilling a specified requirement, e.g. not conforming to a required dimensional tolerance or surface quality. |
| **Rework** | Action taken on a defective product so that it fulfills requirements. |
| **Process and product related terms** | |
| **Process** | Mutually interactive resources and activities which convert inputs into results. Some examples of resources are personnel, finances, facilities and manufacturing methods. |
| **Method** | Defined manner in which an activity or process is performed. In written form also referred to as process instructions. |
| **Product** | Result of a process, e.g. part, assembly, service, processed item, knowledge, concept, document, contract, pollutant. |
| **Terms related to organization** | |
| **Organization** | Group of persons and facilities with a matrix of responsibilities, authorities and relationships. |
| **Customer** | Organization or person which receives a product from a supplier. |
| **Supplier** | Organization or person which provides a product to a customer. |
| **Terms relating to management** | |
| **Quality management system** | Organization and organizational structures, methods and processes of an operation required to put a quality management into practice. |
| **Quality management** | All coordinated activities for managing and controlling the quality-related aspects of an organization by:<br>• establishing a quality policy<br>• setting quality goals<br>• quality planning<br>• quality control<br>• quality assurance<br>• quality improvement |
| **Quality planning** | Activities directed toward establishing quality goals and required implementation processes, as well as associated resources for attaining quality goals. |
| **Quality control** | Work activities and techniques to continually fulfill requirements despite unavoidable variations in quality. Consists primarily of process monitoring and elimination of weak points. |
| **Quality assurance** | Performing and generating required documentation for all activities relating to the QM system, with the goal of creating an atmosphere of trust, both in-house and with the customer, that quality requirements will be fulfilled. |
| **Quality improvement** | Actions taken throughout the organization to increase product quality. |
| **Quality manual** | Document describing the quality policy, quality goals and quality management system of an organization. |

# Quality planning, Quality control, Quality testing

## Quality planning

**Rule-of-ten (for costs)**

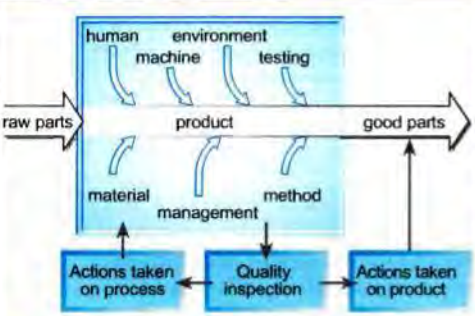



Costs required to eliminate defects or costs resulting from defects increase by about a factor of 10 from phase to phase in the product life cycle.

**Example:** A tolerance error on a single part can be corrected during the design phase with negligible increase of costs. If the defect is first noticed in production, much larger costs result. If the defect leads to problems in assembly or has an adverse impact on the functionality of the finished product or even leads to a recall, enormous costs are incurred.

## Quality control

**Quality control circle**




**Factors causing variance in quality**

| Factor | Examples |
|---|---|
| **Human** | qualification, motivation, degree of utilization |
| **Machine** | machine rigidity, positioning accuracy, wear condition |
| **Material** | deviations, material properties, material variations |
| **Method** | work steps, production process, test conditions |
| **Surroundings (environment)** | temperature, vibrations, light, noise, dust |
| **Management** | poor quality goals or policies |
| **Measurability** | measurement inaccuracy |

## Quality testing

cf. DIN 55350-17 (1988-08)

| Concepts | Explanations |
|---|---|
| **Quality testing** | Determine to what extent a unit meets specified quality requirements. |
| **Test plan Test instructions** | Define and describe the type and scope of testing, e.g. measuring and monitoring devices, frequency of testing, test personnel, testing location. |
| **Complete testing** | Testing of a unit for all specified quality characteristics, e.g. complete inspection of a single workpiece regarding all requirements. |
| **100% testing** | Testing of all units within a test lot, e.g. visual inspection of all delivered parts. |
| **Statistical testing (sampling test)** | Quality testing with the aid of statistical methods, e.g. evaluation of a large quantity of parts by analyzing a number of sampled parts. |
| **Test lot (sampling test)** | All of the units being tested, e.g. a production of 5000 identical workpieces. |
| **Sample** | One or more units which are taken from the population or a subset of the population, e.g. 50 parts from a daily production of 400 parts. |

## Probability (Probability of defect)

Probability of a defective part within a defined total number of parts.

$P$ probability in %
$n$ number of defective parts
$m$ total number of parts

**Example:**

In a crate there are $m = 400$ parts, where $n = 10$ parts have a dimensional defect. What is the probability $P$ of obtaining a defective part when taking one part out of the crate?

**Probability** $P = \frac{n}{m} \cdot 100\% = \frac{10}{400} \cdot 100\% = \mathbf{2.5\%}$

**Probability**

$$P = \frac{n}{m} \cdot 100\%$$

# Statistical analysis

## Statistical analysis of continuous characteristics

vgl. DIN 53804-1 (2002-04)

**Presentation of test data**

### Raw data list

Raw data is the documentation of all observed values from the test lot or sample in the sequence in which they occur.

**Example**

Sample size: 40 parts

Test characteristic: part diameter $d = 8 \pm 0.05$ mm

Measured part diameter $d$ in mm

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Parts 1–10 | 7.98 | 7.96 | 7.99 | 8.01 | 8.02 | 7.96 | 8.03 | 7.99 | 7.99 | 8.01 |
| Parts 11–20 | 7.96 | 7.99 | 8.00 | 8.02 | 8.02 | 7.99 | 8.02 | 8.00 | 8.01 | 8.01 |
| Parts 21–30 | 7.99 | 8.05 | 8.03 | 8.00 | 8.03 | 7.99 | 7.98 | 7.99 | 8.01 | 8.02 |
| Parts 31–40 | 8.02 | 8.01 | 8.05 | 7.94 | 7.98 | 8.00 | 8.01 | 8.01 | 8.02 | 8.00 |

### Tally sheet

The tally sheet provides a clear presentation of the observed values and assignment into classes (ranges) of a specific class interval size.

- $n$ number of individual values
- $k$ number of classes
- $i$ class interval
- $R$ range (page 278)
- $n_j$ absolute frequency
- $h_j$ relative frequency in %

| Class no. | Measured value ≥ | Measured value < | Tally sheet | $n_j$ | $h_j$ in % |
|---|---|---|---|---|---|
| 1 | 7.94 | 7.96 | I | 1 | 2.5 |
| 2 | 7.96 | 7.98 | III | 3 | 7.5 |
| 3 | 7.98 | 8.00 | 𝍸 𝍸 I | 11 | 27.5 |
| 4 | 8.00 | 8.02 | 𝍸 𝍸 III | 13 | 32.5 |
| 5 | 8.02 | 8.04 | 𝍸 𝍸 | 10 | 25 |
| 6 | 8.04 | 8.06 | II | 2 | 5 |
| | | | $\Sigma =$ | 40 | 100 |

$c = \sqrt{n} = \sqrt{40} = 6.3 \approx 6$

$i = \frac{R}{c} = \frac{0.11 \text{ mm}}{6} = 0.018 \text{ mm} \approx 0.02 \text{ mm}$

**Number of classes**

$$k \approx \sqrt{n}$$

**Class interval size**

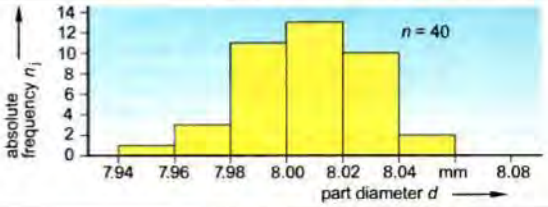
$$i \approx \frac{R}{k}$$

**Relative frequency**

$$h_j = \frac{n_j}{n} \cdot 100\%$$

### Histogram

A histogram is a bar graph for visualizing the distribution of individual test data.




### Cumulative frequency curve in probability system

The cumulative frequency curve in the probability system is a simple and clear graphical method used to check for the existence of a normal distribution (page 278).

**If the cumulative relative frequency in the probability system approximates a straight line, then a normal distribution of the individual values can be assumed,** i. e. a further evaluation can be conducted per DIN 53804-1 (page 278).

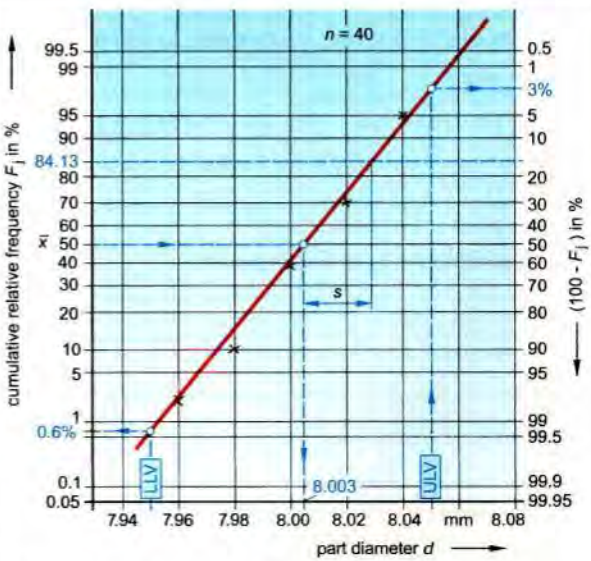
In this case specific values can additionally be determined from the samples.

**Example of problem solving using the graph:**

Arithmetic mean $\bar{x}$ (for $F_j = 50\%$) and standard deviation $s$ (as difference 68.26% ÷ 2 between $F_j = 50\%$ and 84.13%):

$\bar{x} \approx 8.003$ mm; $s \approx 0.02$ mm

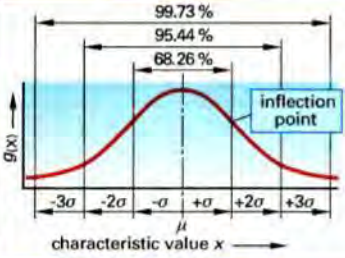
The probability model of the example shows that in the entire lot approximately 0.6% of parts can be expected to be too thin and 3% too thick.




LLV lower limit value; ULV upper limit value

# Normal distribution

## Gaussian distribution




Continuous data values often exhibit a characteristic in their distribution which is approximated mathematically by the **Gaussian normal distribution** model. For an infinite number of individual values the probability density of a normal distribution yields the typical **bell curve**. This symmetrical and continuous distribution curve is clearly described by the following parameters:

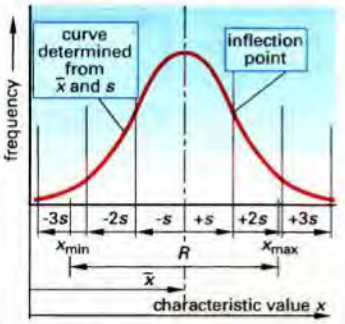
The **mean** $\mu$ lies on the curve maximum and identifies the position of the distribution.

The **standard deviation** $\sigma$ is a measure of the variations, i.e. how values deviate from the mean.

[1] Carl Friedrich Gauß (1777–1855), German mathematician

## Normal distribution in sampling

cf. DIN 53804-1 (2002-04) or DGQ 16-31 (1990)




| | |
|---|---|
| $n$ | number of individual values (sample size) |
| $x_i$ | value of measurable properties, e.g. individual value |
| $x_{max}$ | largest measurement value |
| $x_{min}$ | smallest measurement value |
| $\bar{x}$ | arithmetic mean |
| $\tilde{x}$ | median value[1], middle value of measured values arranged in order of magnitude |
| $s$ | standard deviation |
| $R$ | range |
| $D$ | mode (measurement value occurring most frequently in a test series) |
| $g_{(x)}$ | probability density |

**Arithmetic mean**[2]

$$\bar{x} = \frac{x_1 + x_2 + \ldots + x_n}{n}$$

**Standard deviation**[2]

$$s = \sqrt{\frac{\sum(x_i - \bar{x})^2}{n-1}}$$

**Range**

$$R = x_{max} - x_{min}$$

**When evaluating several samples:**

| | | | |
|---|---|---|---|
| $m$ | number of samples | $\bar{R}$ | mean of multiple sample ranges |
| $\bar{\bar{x}}$ | mean of multiple sample means | $\bar{s}$ | mean of standard deviations |

**Mean of sample ranges**

$$\bar{R} = \frac{R_1 + R_2 + \ldots + R_m}{m}$$

**Example:** Evaluation of sample values from page 277:

$\bar{x}$ = **8.00225 mm** $R$ = **0.11 mm** $\tilde{x}$ = **8.005 mm** $s$ = **0.02348 mm** $D$ = **7.99 mm**

**Mean of sample means**

$$\bar{\bar{x}} = \frac{\bar{x}_1 + \bar{x}_2 + \ldots + \bar{x}_m}{m}$$

[1] Median value for
odd number of individual values:
e.g. $x_1; x_2; x_3; x_4; x_5$:
$\tilde{x} = x_3$

even number of individual values:
e.g. $x_1; x_2; x_3; x_4; x_5; x_6$:
$\tilde{x} = (x_3 + x_4)/2$

**Mean of standard deviations**

$$\bar{s} = \frac{s_1 + s_2 + \ldots + s_m}{m}$$

[2] Many pocket calculators have special functions for calculating the mean and standard deviation.
Repeated occurrences of identical measurement values can be represented by a suitable factor.

## Normal distribution in an inspection lot

Parameters of the population are estimated using a sampling method based on characteristic values from the sample (confirmatory statistics). To differentiate sampling characteristics clearly from parameters of the population, other designations are used. These estimated values are distinguished from the calculated process values for a 100% inspection (descriptive statistics) by adding a ^ mark.

## Characteristic values and designations in quality testing

| **Sampling test (confirmatory statistics)** | | **100% inspection (descriptive statistics)** |
|---|---|---|
| **Sample** | **Population** | |
| Number of measured values $n$ | Number of measured values $m \cdot n$ | Number of measured values $N$ |
| Arithmetic mean $\bar{x}$ | Estimated process mean $\hat{\mu}$ | Process mean $\mu$ |
| Standard deviation $s$ | Estimated process standard deviation $\hat{\sigma}$ (calculator $\sigma_{n-1}$) | Process standard deviation $\sigma$ (calculator $\sigma_n$) |

# Statistical process control

## Quality control charts

### Process control charts

Process control charts are used for monitoring a process for changes compared to a target value or a previous process value. The intervention and warning limits are determined by the process estimated value of a population or a preliminary run.

### Acceptance control charts

Acceptance control charts are used to monitor a process in reference to set specification limits (limit values). Control limits are calculated as tolerance limits for the location of the process mean and a tolerance range for process variance.

## Process control charts for quantitative characteristics (Shewhart-control charts)[1)]

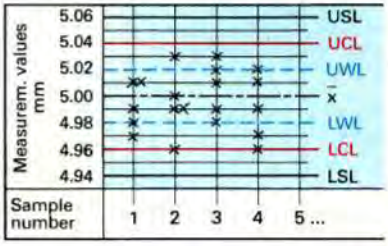
### Raw data chart

The raw data chart is a documentation of all measurement values by entering directly on the chart. It assumes an approximate normal distribution process and is relatively complex because of the number of entries.

### Control limits

| | |
|---|---|
| $\bar{x}$ | characteristic mean (mean of the characteristic, target value, ideal value) |
| UWL | upper warning limit |
| LWL | lower warning limit |
| UCL | upper control limit |
| LCL | lower control limit |
| USL | upper specification limit |
| LSL | lower specification limit |

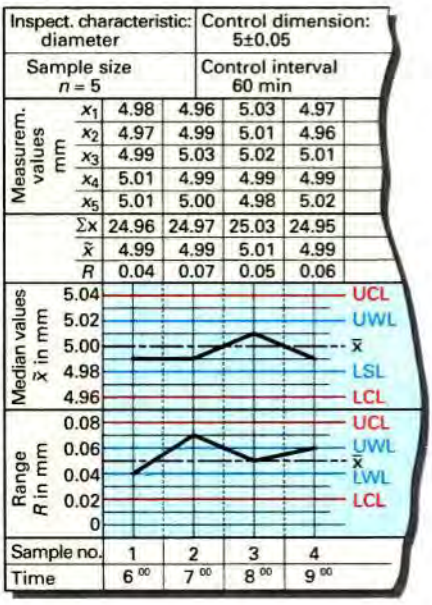
**Example:** 5 individual values for each sample




### Median value range chart ($\tilde{x}$-R-chart)

These charts are used to clearly represent production dispersion without requiring much calculation. They are suitable for manual control chart management.

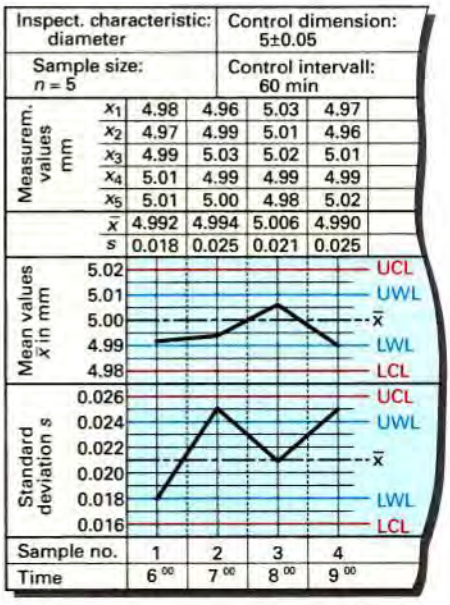
**Example:**




### Mean standard deviation chart ($\bar{x}$-s-chart)

These charts are used to show the trend of the mean and exhibit greater sensitivity than $\tilde{x}$-R-charts. They require computer-aided control chart management.

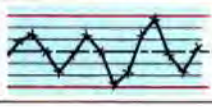
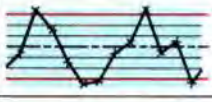
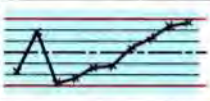
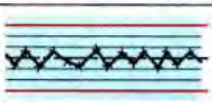
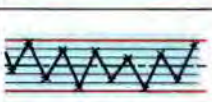
**Example:**




[1)] Walter Andrew Shewhart (1891–1967), American scientist

# Process trend, Acceptance sampling and plan

## Process trends

| Process trend (e.g. from an $\bar{x}$ trace) | Designation/observations | Possible causes → Actions |
|---|---|---|
|  | **Natural run**<br>2/3 of all values lie in the range ± standard deviation *s* and all values lie within the control limits. | The process is under control and can continue without interruption. |
|  | **Exceeding the control limits**<br>The values are outside of the control limits. | Over-adjusted machine, different material, damaged or worn equipment<br>→ Stop process and 100% inspect parts since the last sampling |
|  | **RUN (sequential)**<br>7 or more sequential values lie on one side of the mean line. | Tool wear, other material charge, new tool, new personnel<br>→ Tightened observation of the process |
|  | **Trend**<br>7 or more sequential values show an increasing or decreasing trend. | Wear on tool, equipment or measuring devices, operator fatigue<br>→ Stop process to determine reasons for adjustment |
|  | **Middle Third**<br>At least 15 consecutive values lie within ± standard deviation *s*. | Improved production, better supervision, corrected test results<br>→ Determine how the process was improved or check the test results |
|  | **Cyclical**<br>The values cross the mean line periodically . | Different measuring devices, systematic spread of the data<br>→ Examine manufacturing process for influences |

## Acceptance sampling (attribute sampling)

cf. DIN ISO 2859-1 (2004-01)

An attribute inspection is an acceptance sampling inspection in which the acceptability of the inspection lot is determined based on defective units or defects in individual sampling.

The **percentage of nonconforming units or the number of defects per hundred units of the lot** identifies the **quality level**. The acceptable quality level is the quality level defined for continuously presented lots; it is a quality level that is specified by the customer in most cases. The associated sampling instructions are summarized in control tables.

**Acceptance sampling plan for single sampling inspection as the normal inspection (excerpt from a control table)**

| Lot size | Acceptable quality level AQL (preferred values) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0.04 | 0.065 | 0.10 | 0.15 | 0.25 | 0.40 | 0.65 | 1.0 | 1.5 | 2.5 |
| 2– 8 | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ |
| 9– 15 | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | 8 0 | 5 0 |
| 16– 25 | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | 13 0 | 8 0 | 5 0 |
| 26– 50 | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | 20 0 | 13 0 | 8 0 | 5 0 |
| 51– 90 | ↓ | ↓ | ↓ | ↓ | 50 0 | 32 0 | 20 0 | 13 0 | 8 0 | 20 1 |
| 91– 150 | ↓ | ↓ | ↓ | 80 0 | 50 0 | 32 0 | 20 0 | 13 0 | 32 1 | 20 1 |
| 151– 280 | ↓ | ↓ | 125 0 | 80 0 | 50 0 | 32 0 | 20 0 | 50 1 | 32 1 | 32 2 |
| 281– 500 | ↓ | 200 0 | 125 0 | 80 0 | 50 0 | 32 0 | 80 1 | 50 1 | 50 2 | 50 3 |
| 501–1200 | 315 0 | 200 0 | 125 0 | 80 0 | 50 0 | 125 1 | 80 1 | 80 2 | 80 3 | 80 5 |

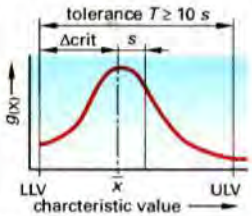
**Explanation:** ↓ / 50 2 — Use first sampling instruction of this column. If the sample size is greater than or equal to the batch size: Carry out a 100% inspection.

- Second number: Acceptance number = number of the accepted delivered defective units
- First number: Sample size = number of units to be tested

# Process and machine capability, Quality control charts

## Capability, Quality control charts

During an evaluation of the quality-related capability of a process through **capability characteristics** (capability indices), differentiation must be made between **short-term capability (machine capability)** and **long-term capability (process capability)**.




**Machine capability** is an evaluation of the machine, i.e. whether there is sufficient probability that it can produce within specified limits given its normal fluctuations.

If $C_m \geq 1.67$ and $C_{mk} \geq 1.67$, this means that 99.99994 % (range ± 5 $s$) of the quality characteristics lie within the limits and the mean $\bar{x}$ lies at least an amount of 5 $s$ away from the tolerance limits.

LLV lower limit value
ULV upper limit value
$\bar{x}$ arithmetic mean
$s$ standard deviation
Δcrit smallest interval between mean and a tolerance limit
$C_m$, $C_{mk}$ machine capability index

**Process capability** is an assessment of the manufacturing process, i.e. whether there is sufficient probability that it can fulfill specified requirements given its normal fluctuations.

$\hat{\sigma}$ estimated standard deviation
$C_p$, $C_{pk}$ process capability index

**Example:**

Examination of machine capability for production dimension 80 ± 0.05;

Values from preliminary run: $s = 0.009$ mm; $\bar{x} = 79.997$ mm

$$C_m = \frac{T}{6 \cdot s} = \frac{0{,}1\text{mm}}{6 \cdot 0.009\text{ mm}} = \mathbf{1.852};\quad C_{mk} = \frac{\Delta\text{crit}}{3 \cdot s} = \frac{0.047\text{ mm}}{3 \cdot 0.009\text{ mm}} = \mathbf{1.74}$$

The machine capability is below requirements.

**Machine capability index**

$$C_m = \frac{T}{6 \cdot s}$$

$$C_{mk} = \frac{\Delta\text{krit}}{3 \cdot s}$$

Requirement[1] e.g. **$C_m \geq 1.67$ and $C_{mk} \geq 1.67$.**

**Process capability index**

$$C_p = \frac{T}{6 \cdot \hat{\sigma}}$$

$$C_{pk} = \frac{\Delta\text{crit}}{3 \cdot \hat{\sigma}}$$

Requirement[1] e.g. **$C_p \geq 1.33$ and $C_{pk} \geq 1.33$**

[1] Customer or contract specific requirements; in large scale production, e.g. automotive industry, tendency to higher requirements, e.g. $C_m \geq 2.0$.

## Quality control charts for qualitative characteristics

cf. DGQ 16-33 (1990); DGQ 11-19 (1994)

### Defect chart

Defect charts record the defective units, the defect types and their frequency in a sampling.

**Example of reading from the graph for F3:**

$n = 9 \cdot 50 = 450$

$$\text{defects in \%} = \frac{\sum i_j}{n} \cdot 100\% = \frac{3}{450} \cdot 100\% = \mathbf{0.66\ \%}$$

**Example:**

| Part: **Cover** | Sample size $n$ = 50 | | | | | | | | | Test interval: 60 min | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Defect type | | Frequency of defect $i_j$ | | | | | | | | $\sum i_j$ | % | Perc. of total |
| Paint damage | F1 | | 1 | | | | | 1 | | 2 | 0.44 | |
| Dents | F2 | 1 | 2 | | 2 | 1 | 2 | 2 | 2 | 14 | 3.11 | |
| Corrosion | F3 | | 1 | | | 1 | | | 1 | 3 | 0.66 | |
| Burr | F4 | 1 | | | | | | | | 1 | 0.22 | |
| Crackings | F5 | | 1 | | | | | | | 1 | 0.22 | |
| Angle error | F6 | 2 | | 3 | 1 | | 3 | 1 | | 12 | 2.66 | |
| Bent | F7 | | | | | 1 | | | 2 | 1 | 0.22 | |
| Threads missing | F8 | | 1 | | | | | | | 1 | 0.22 | |
| Defects per sample | | 4 | 6 | 3 | 3 | 3 | 5 | 4 | 3 | 4 | 35 | |
| Sample no. | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | | |

### Pareto[1] diagram

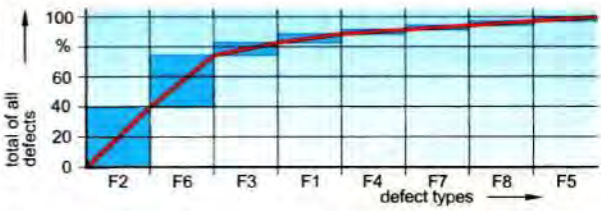
The Pareto diagram classifies criteria (e.g. defects) according to type and frequency and is therefore an important aid in analyzing criteria and establishing priorities.

**Example for F2:**

Percentage of total defects

$$= \frac{14}{35} \cdot 100\% = 40\%$$

**Example:**

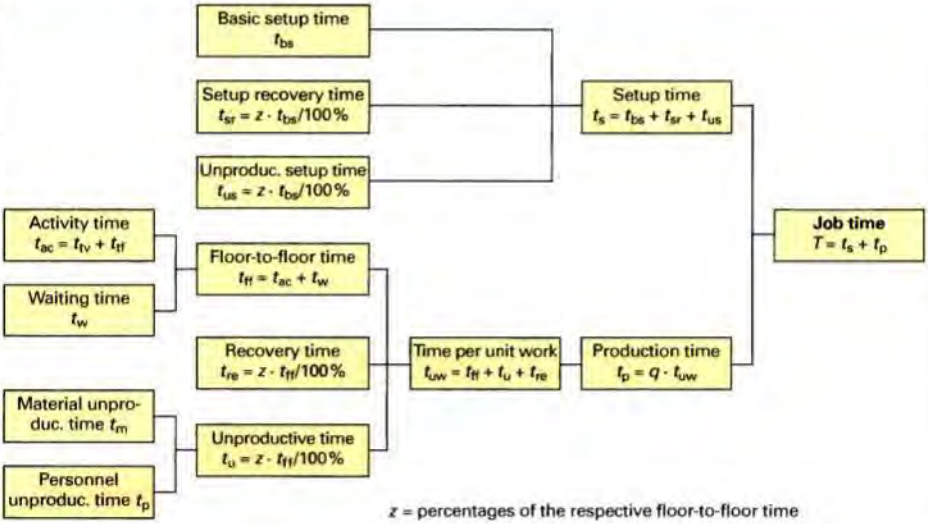



**Example of graphic representation:** Dents (F2) and angle error (F6) together make up approx. 74 % of the total errors.

[1] Pareto – Italian sociologist

# Job time[1)]

## Structure of types of time for workers




| Symbol | Designation | Explanation with examples |
|---|---|---|
| $T$ | Job time | Time allowed for manufacturing a lot size |
| $t_s$ | Setup time | Setup for an entire job<br>• basic setup time $t_{bs}$ → turn on machine<br>• setup recovery time $t_{sr}$ → recovery time after strenuous changeover<br>• setup unproductive time $t_{us}$ → repair of brief machine malfunction |
| $t_p$ | Production time | Time allowed for production of a lot size (without setup) |
| $t_{re}$ | Recovery time | Personnel break time to reduce work-related fatigue |
| $t_u$ | Unproductive time | • job-related interruption time $t_m$ → unforeseen tool sharpening<br>• personnel interruption time $t_p$ → checking work times, taking care of needs |
| $t_{ac}$ | Activity time | Times in which the actual job is processed<br>• variable times $t_{tv}$ → assembly or deburring work<br>• fixed times $t_{tf}$ → cycle of a CNC program |
| $t_w$ | Waiting time | Waiting for the next workpiece in the continuous flow production |
| $q$ | Job volume | Number of units to be produced for a job (lot size) |

**Example: Turning three shafts on a lathe**

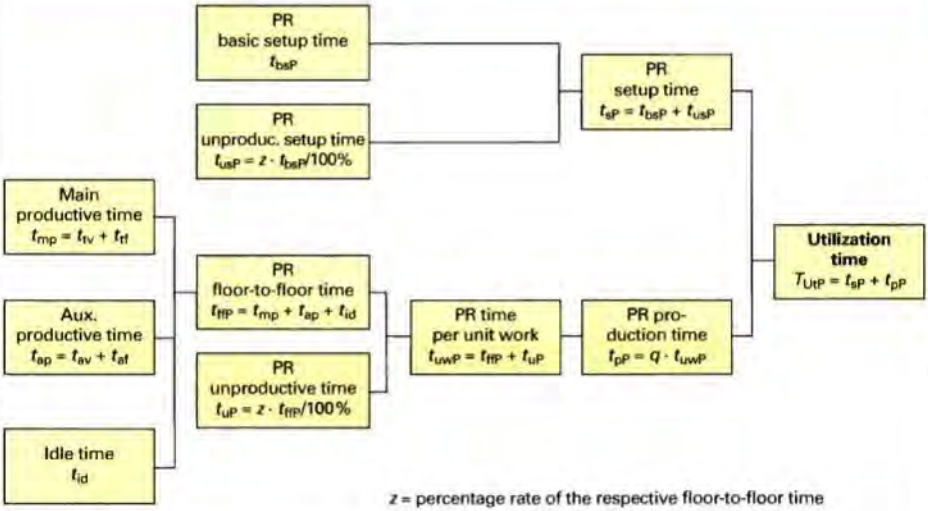
| **Setup times:** | | min | **Production times:** | | min |
|---|---|---|---|---|---|
| Setup job | | = 4.50 | Activity time | $t_{ac}$ | = 14.70 |
| Setup of machine | | = 10.00 | Waiting time | $t_w$ | = 3.75 |
| Setup of tool | | = 12.50 | Floor-to-floor time | $t_{ff} = t_{ac} + t_w$ | = 18.45 |
| Basic setup time | $t_{bs}$ | = 27.00 | Recovery time | $t_{re}$ compens. for in $t_w$ | – |
| Setup recovery time | $t_{sr}$ = 4 % of $t_{bs}$ | = 1.08 | Unproductive time | $t_u$ = 8 % of $t_{ff}$ | = 1.48 |
| Unproduc. setup time | $t_{us}$ = 14 % of $t_{bs}$ | = 3.78 | Time per unit work | $t_{uw} = t_{ff} + t_{re} + t_u$ | = 19.93 |
| **Setup time** | $t_s = t_{bs} + t_{sr} + t_{us}$ | **= 31.86** | **Production time** | $t_p = q \cdot t_{uw}$ | **= 59.79** |

Job time $T = t_s + t_p \approx 32$ min + 60 min = **92 min** (= 1.53 hr)

[1)] According to REFA (Verband für Arbeitsgestaltung, Betriebsorganisation und Unternehmensentwicklung e.V.) International Association for Work Design, Industrial Organization and Corporate Development

# Utilization time[1)]

## Structure of the types of times for production resources (PR)




| Symbol | Designation | Explanation with examples |
|---|---|---|
| $T_{UtP}$ | Utilization time | Time allowed for utilization of a production resource for manufacturing a lot size |
| $t_{sP}$ | Production resource setup time | Setup of production resource for completing an entire job<br>• PR basic setup time $t_{bsP}$ → clamping equipment on a machine<br>• unproductive setup time $t_{usP}$ → optimization of CNC program |
| $t_{pP}$ | Production resource production time | Time allowed for the production time of a lot size (without setup) |
| $t_{uP}$ | Production resource interruption time | Time in which the production resource is not utilized or additionally utilized; power outage, un-planned repair work, etc. |
| $t_{mp}$ | Main productive time | Times in which the work object is processed according to plan<br>• variable times $t_{tv}$ → manual drilling<br>• fixed times $t_{tf}$ → cycle of CNC program |
| $t_{ap}$ | Auxiliary productive time | Production resources are prep., loaded or emptied for the main productive time<br>• variable times $t_{av}$ → manual clamping<br>• fixed times $t_{af}$ → automatic workpiece change |
| $t_{id}$ | Idle time | Process or recovery related down time, e.g. filling of a magazine |
| $q$ | Job volume | Number of units to be produced for a job (lot size) |

**Example: Milling a contact surface on 20 base plates using a vertical milling machine**

| **Setup times:** | | min | **Production times:** | | min |
|---|---|---|---|---|---|
| Read the job order and drawing | = | 4.54 | Milling ≙ main productive time $t_{mp}$ | = | 3.52 |
| Set up and store the surface cutter | = | 3.65 | Clamp workpiece ≙ aux. productive time $t_{ap}$ | = | 4.00 |
| Clamp and unclamp the cutter | = | 3.10 | Transport workpiece ≙ idle time $t_{id}$ | = | 1.20 |
| Set up the machine | = | 2.84 | Prod. res. floor-to-floor time $t_{ffP} = t_{mp} + t_{ap} + t_{id}$ | = | 8.72 |
| Production resources basic setup time $t_{bsP}$ | = | 14.13 | Prod. res. unproductive time $t_{uP}$ = 10% of $t_{ffP}$ | = | 0.87 |
| Prod. res. unproductive s. time $t_{usP}$ = 10% of $t_{bsP}$ | = | 1.41 | Prod. resource time per unit $t_{uwP} = t_{ffP} + t_{uP}$ | = | 9.59 |
| **Production resources setup time $t_{sP} = t_{bsP} + t_{usP}$** | = | **15.54** | **Production resource prod. time $t_{pP} = q \cdot t_{uwP}$** | = | **191.80** |

**Utilization time $T_{UtP} = t_{sP} + t_{pP}$** ≈ 16 min + 192 min = **208 min** (= 3.47 hr)

[1)] According to REFA (Verband für Arbeitsgestaltung, Betriebsorganisation und Unternehmensentwicklung e.V.) International Association for Work Design, Industrial Organization and Corporate Development

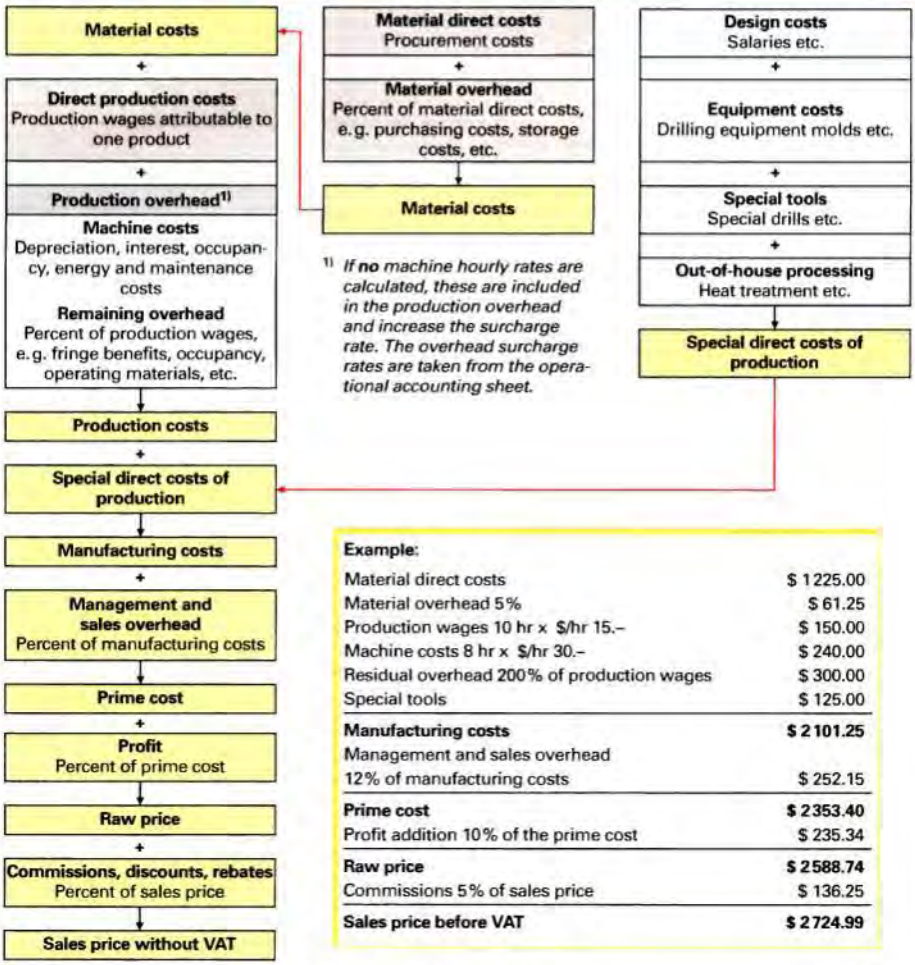
# Cost accounting

## Simple calculation (numerical example)

| | Direct costs[1] directly attributable to a specific product | | Overhead [1] Not directly attributable to a specific product | | Surcharge in percent of wage costs |
|---|---|---|---|---|---|
| Types of costs[1] | Material costs | $ 80 000.00 | Depreciation | $ 50 000.00 | $\frac{\$\ 220\,000.00 \cdot 100\%}{\$\ 120\,000.00} = 183.33\%$ |
| | Labor costs | $ 120 000.00 | Salaries (incl. management salaries) | $ 80 000.00 | A surcharge rounded off to 185% is applied to each wage hour to cover overhead costs. |
| | | | Interest | $ 40 000.00 | |
| | | | Other costs | $ 50 000.00 | |
| | | | Σ Overhead | $ 220 000.00 | |

| Cost calculation | | | |
|---|---|---|---|
| Wage hours = 10000 hrs | Labor costs/hr = $/hr 12.00 | Material costs of order | $ 124.75 |
| Rate per hour = $/hr 12.00 + 185% = $/hr 34.20 (for independent contractor invoices; management salaries = profit) | | Working time 5 hr x $/hr 34.20 | $ 171.00 |
| [1] Costs must be determined periodically for every operation. | | Price without VAT | $ 295.75 |

## Expanded calculation (schematic)




**Example:**

| | |
|---|---|
| Material direct costs | $ 1225.00 |
| Material overhead 5% | $ 61.25 |
| Production wages 10 hr x $/hr 15.– | $ 150.00 |
| Machine costs 8 hr x $/hr 30.– | $ 240.00 |
| Residual overhead 200% of production wages | $ 300.00 |
| Special tools | $ 125.00 |
| **Manufacturing costs** | **$ 2101.25** |
| Management and sales overhead 12% of manufacturing costs | $ 252.15 |
| **Prime cost** | **$ 2353.40** |
| Profit addition 10% of the prime cost | $ 235.34 |
| **Raw price** | **$ 2588.74** |
| Commissions 5% of sales price | $ 136.25 |
| **Sales price before VAT** | **$ 2724.99** |

# Machine hourly rate calculation

## Machine hourly rate calculation

Average production overhead does not take into consideration various machine costs attributable to a specific product. This type of cost accounting would be misleading.
If machine costs are taken out of production overhead and converted to hours the machine was utilized, this yields the **machine hourly rate**.

**Compilation of machine costs**

Machine costs are:

- **Calculated depreciation**
  Linear loss of value over the service life of the machine relative to replacement cost
- **Calculated interest**
  Average interest for capital invested for the machine
- **Occupancy costs**
  Costs incurred by floor and traffic space of the machine
- **Energy costs**
  Costs incurred by electricity, natural gas, steam or gasoline consumption
- **Maintenance costs**
  Costs for repairs and regular service
- **Other types of costs**
  Costs for tool wear, insurance premiums, disposal of coolants and lubricants etc.

## Machine running time, Machine hourly rates

according to VDI Directive 3258

$T_{RT}$ machine running time in hours/period
$T_T$ total theoretical machine time in hours/period
$T_{ST}$ down times, e.g. work free days, work interruptions etc., usually in % of $T_T$
$T_{SM}$ times for service and maintenance, usually in % of $T_T$

$C_M$ sum of machine costs per period (usually per year)
$C_{Mhr}$ machine costs per hour; machine hourly rate
$C_f$ machine fixed costs per year; e.g. depreciation
$C_v/hr$ machine variable costs per hour; e.g. electrical consumption

**Machine running time**

$$T_{RT} = T_T - T_{ST} - T_{SM}$$

**Machine hourly rates**

$$C_{Mhr} = \frac{C_f}{T_{RT}} + C_v/hr$$

## Calculation of machine hourly rate (example)

**Tool machine:**

Procurement value $ 160 000.00
Power consumption 8 kW
Occupancy costs $/m² 10.00 × month
Additional maintenance $/hr 5.00

Service life 10 years
Cost per kWh $ 0.15
Space req. 15 m²
Normal utilization
$T_{RT}$ = 1200 hr/year (100%)

Assumed interest rate 8%
Base charge $/month 20.00
Maintenance $/year 8 000.00
Actual utilization 80%

What would be the machine hourly rate for normal utilization and 80% utilization?

| Type of cost | Calculation | Fixed costs $/year | Variable costs $/hr |
|---|---|---|---|
| Calculated depreciation | $\frac{\text{procurement value}}{\text{service life in years}} = \frac{\$\ 160\,000.00}{10\ \text{years}}$ | $ 16 000.00 | |
| Calculated interest | $\frac{1/2\ \text{procurement value in \$} \times \text{interest}}{100\%} = \frac{\$\ 80\,000.- \times 8\%}{100\ \%}$ | $ 6 400.00 | |
| Maintenance costs | maintenance factor × depreciation – e.g. 0.5 × $ 16 000.00 maintenance is dependent upon utilization. | $ 8 000.00 | $ 5.00 |
| Energy costs | base charge for power supply $/month 20.00 x 12 mon. power consumption × energy costs 8 kW × $/kWh 0.15 | $ 240.00 | $ 1.20 |
| Proportional occupancy costs | space cost rate x space requirement = $/m² 10.00 × month × 15 m² × 12 months | $ 1 800.00 | |
| | **Total machine costs (CM)** | **$ 32 440.00** | **$ 6.20** |

**Machine hourly rate ($C_{Mhr}$) at 100% utilization** = $\frac{C_f}{T_{RT}} + C_v/hr = \frac{\$\ 32\,440.00}{1200\ hr} + \$/hr\ 6.20 =$ **$/hr 33.23**

**Machine hourly rate ($C_{Mhr}$) at 80% utilization** = $\frac{C_f}{0.8 \cdot T_{RT}} + C_v/hr = \frac{\$\ 32\,440.00}{0.8 \cdot 1\,200\ hr} + \$/hr\ 6.20 =$ **$/hr 40.00**

The machine hourly rate does not include costs for operator.

# Direct costing[1)]

## Marginal costing (with numerical example)

Marginal costing takes the market price of a product into consideration. The market price must at least cover variable costs (lower price limit). The remainder is the contribution margin. Contribution margins of all products carry the costs of operational readiness.

| | | | |
|---|---|---|---|
| *R/piece* | market price; revenue per piece | $C_f$ | fixed costs |
| *R* | revenue (sales) of product | $C_v$ | variable costs |
| *CM* | contribution margin of product | *P* | profit or gain |
| *CM/piece* | contribution margin per piece | *Bp* | breakeven point |

**Contribution margin**

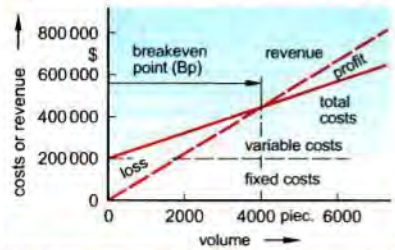
$$\frac{CM}{\text{piece}} = \frac{R}{\text{piece}} - \frac{C_v}{\text{piece}}$$

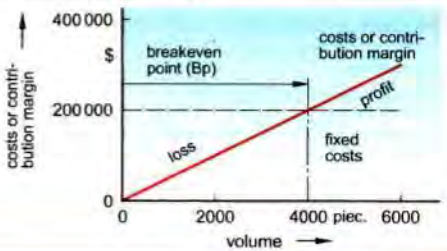
$$CM = \frac{CM}{\text{piece}} \cdot \text{volume}$$

**Profit**

$$P = CM - C_f$$

| | Variable costs ($C_v$)[2)] depends on production volume | | Fixed costs ($C_f$) independent of production volume | | Contribution margin (CM) |
|---|---|---|---|---|---|
| Types of costs | Material costs | \$/piece 30.00 | Depreciation | \$ 50 000.00 | Revenue of \$/piece 110.00 must cover all variable costs first. The remainder is used to cover total fixed costs and includes profit. |
| | Labor costs | \$/piece 20.00 | Wages | \$ 80 000.00 | |
| | Energy costs | \$/piece 10.00 | Interest | \$ 40 000.00 | |
| | | | Others $C_f$ | \$ 30 000.00 | |
| | Σ Variable costs | \$/piece 60.00 | Σ Fixed costs | \$ 200 000.00 | |
| Cost calculation | No. of pieces produced | 5 000 pieces | Contribution margin | \$ 110.00 – \$ 60.00 = \$/piece 50.00 | **Breakeven point** $Bp = \frac{C_f}{CM/\text{piece}}$ |
| | Total contribution margin 5 000 pieces · \$/piece 50.00 = \$ 250 000.00 | | | | |
| | Σ Fixed costs \$ 200 000.00 | | | | |
| | Profit \$ 50 000.00 | | | | |
| | Breakeven point $Bp = \frac{C_f}{CM/\text{piece}} = \frac{\text{\$ 200 000.00}}{\text{\$/piece 50.00}} = 4\,000$ pieces | | | | |




## Cost comparison method

In the cost comparison method, the machine or facility that incurs the lowest costs for a given production volume should be selected.

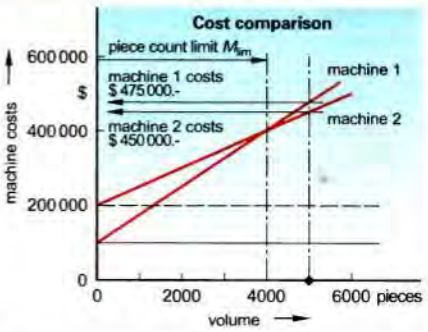
**Example** for 5 000 pieces

**Machine 1**: $C_{f1}$ = \$/year 100 000.–; $C_{v1}$ = \$/piece 75.00
\$/year 100 000.– + \$/piece 75 × 5 000 pieces = \$ 475 000
**Machine 2**: $C_{f2}$ = \$/year 200 000.00; $C_{v2}$ = \$/piece 50.00
\$/year 200 000.– + \$/piece 50.00 × 5000 pieces = \$ 450 000
**Machine 1 costs > machine 2 costs**

$$\text{Piece count limit } M_{lim} = \frac{C_{f2} - C_{f1}}{C_{v1}/\text{piece} - C_{v2}/\text{piece}}$$

$$M_{lim} = \frac{\text{\$ 200 000.00} - \text{\$ 100 000.00}}{\text{\$/piece 75.00} - \text{\$/piece 50.00}} = 4000 \text{ pieces}$$

**Machine 2 is more economical at volumes above 4000 pieces.**




1) Direct costing separates costs into fixed costs (costs of operating readiness) and variable costs (direct costs).
2) Variable costs are calculated for each job and compared to revenue.

# Turning, Thread cutting

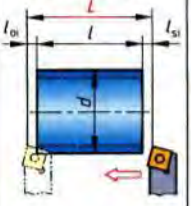
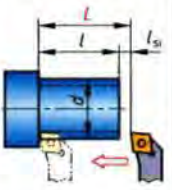
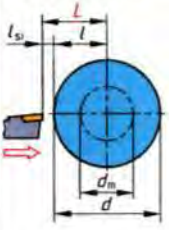
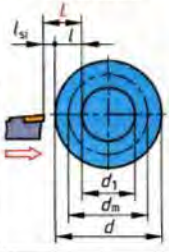
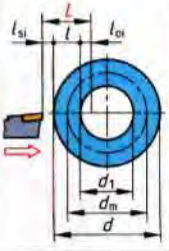
## Straight cylindrical turning and facing at constant rotational speed

$t_p$ productive time
$d$ outside diameter
$d_1$ inside diameter
$d_m$ mean diameter[1)]
$l$ workpiece length
$l_{si}$ starting idle
$l_{oi}$ overrun idle travel
$L$ travel
$f$ feed per revolution
$n$ rotational speed
$i$ number of cuts
$v_c$ cutting speed

**Productive time**

$$t_p = \frac{L \cdot i}{n \cdot f}$$

### Calculating travel $L$, mean diameter $d_m$ and rotational speed $n$

| Straight cylindrical turning | | Facing | | |
|---|---|---|---|---|
| without shoulder | with shoulder | Solid cylinder without shoulder | Solid cylinder with shoulder | Hollow cylinder |
|  |  |  |  |  |
| $L = l + l_{si} + l_{oi}$ | $L = l + l_{si}$ | $L = \frac{d}{2} + l_{si}$ | $L = \frac{d - d_1}{2} + l_{si}$ | $L = \frac{d - d_1}{2} + l_{si} + l_{oi}$ |
| $n = \frac{v_c}{\pi \cdot d}$ | | $d_m = \frac{d}{2}$; $n = \frac{v_c}{\pi \cdot d_m}$ | $d_m = \frac{d + d_1}{2}$; $n = \frac{v_c}{\pi \cdot d_m}$ | |

[1)] Use of mean diameter $d_m$ leads to higher cutting speeds. This ensures acceptable cutting conditions for small diameters (inside area).

**Example:**

Straight cylindrical turning without shoulder, $l$ = 1240 mm; $l_{si} = l_{oi}$ = 2 mm; $f$ = 0.6 mm; $v_c$ = 120 m/min; $i$ = 2; $d$ = 160 mm; $L$ = ?; $n$ = ? (for infinitely variable speed adjustment); $t_p$ = ?

$L = l + l_{si} + l_{oi}$ = 1240 mm + 2 mm + 2 mm = **1244 mm**

$$n = \frac{v_c}{\pi \cdot d} = \frac{120 \frac{\text{m}}{\text{min}}}{\pi \cdot 0.16\ \text{m}} \approx 239 \frac{1}{\text{min}}$$

$$t_p = \frac{L \cdot i}{n \cdot f} = \frac{1244\ \text{mm} \cdot 2}{239 \frac{1}{\text{min}} \cdot 0.6\ \text{mm}} \approx 17.4\ \text{min}$$

## Thread cutting

$t_p$ productive time
$L$ total travel of thread cutting tool
$l$ thread length
$l_{si}$ starting idle
$l_{oi}$ overrun idle travel
$i$ number of cuts
$P$ thread pitch
$n$ rotational speed
$s$ no. of starts
$h$ thread depth
$a_p$ cutting depth
$v_c$ cutting speed

**Productive time**

$$t_p = \frac{L \cdot i \cdot s}{P \cdot n}$$

**Number of cuts**

$$i = \frac{h}{a_p}$$

**Example:**

Threads M 24; $l$ = 76 mm; $l_{si} = l_{oi}$ = 2 mm; $f$ = 0.6 mm; $v_c$ = 6 m/min; $i$ = 2; $a_p$ = 0.15 mm; $h$ = 1.84 mm; $P$ = 3 mm; $s$ = 1; $L$ = ?; $n$ = ?; $i$ = ?; $t_p$ = ?

$L = l + l_{si} + l_{oi}$ = 76 mm + 2 mm + 2 mm = **80 mm**

$$n = \frac{v_c}{\pi \cdot d} = \frac{6 \frac{\text{m}}{\text{min}}}{\pi \cdot 0.024\ \text{m}} \approx 80 \frac{1}{\text{min}}$$

$$t_p = \frac{L \cdot i \cdot s}{P \cdot n} = \frac{80\ \text{mm} \cdot 13 \cdot 1}{3\ \text{mm} \cdot 80 \frac{1}{\text{min}}} = 4.3\ \text{min}$$

$$i = \frac{h}{a_p} = \frac{1.84\ \text{mm}}{0.15\ \text{mm}} = 12.2 \approx 13$$

# Turning

## Straight cylindrical turning and facing at constant cutting speed

If the rotational speed must be limited for safety reasons by inputting a rotational speed limit $n_{lim}$, a turning diameter of $d <$ transition diameter $d_t$ is turned at constant rotational speed (page 287).

| | | | |
|---|---|---|---|
| $d_t$ | transition diameter | $i$ | number of cuts |
| $v_c$ | cutting speed | $d$ | outside diameter |
| $n_{lim}$ | rotational speed limit | $d_1$ | inside diameter |
| $t_p$ | productive time | $a_p$ | cutting depth |
| $d_e$ | effective diameter | $l_{si}$ | starting idle |
| $L$ | travel | $l_{oi}$ | overrun idle travel |
| $f$ | feed | | |

**Transition diameter**

$$d_t = \frac{v_c}{\pi \cdot n_{lim}}$$

**Productive time**

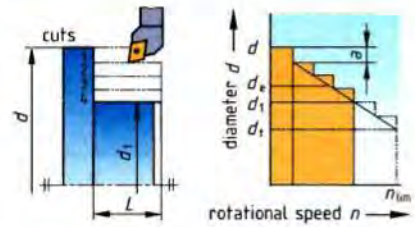
$$t_p = \frac{\pi \cdot d_e \cdot L \cdot i}{v_c \cdot f}$$

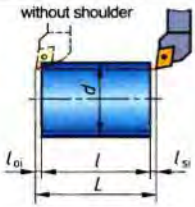
**Number of cuts for straight cylindrical turning**

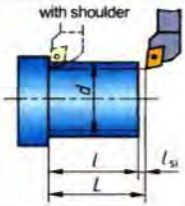
$$i = \frac{d - d_1}{2 \cdot a_p}$$

### Calculating travel $L$ and effective diameter $d_e$

#### Straight cylindrical turning



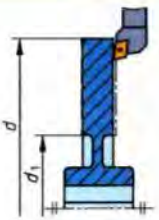



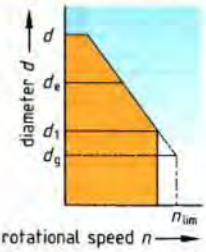

$L = l + l_{si} + l_{oi}$

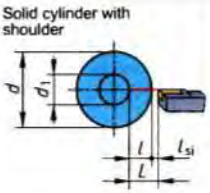
$d_e = d - a_p \cdot (i + 1)$

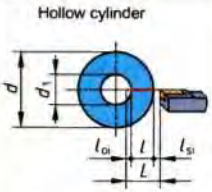
$L = l + l_{si}$

#### Facing



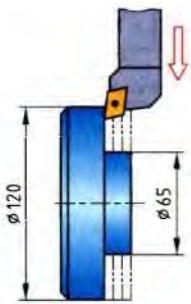

$L = \frac{d - d_1}{2} + l_{si}$

$d_e = \frac{d + d_1}{2} + l_{si}$

$L = \frac{d - d_1}{2} + l_{si} + l_{oi}$

$d_e = \frac{d + d_1}{2} + l_{si} - l_{oi}$

**Example:**




Facing; $l_{si} = 1.5$ mm; $v_c = 220$ m/min; $f = 0.2$ mm; $i = 2$; $n_{lim} = 3000$/min; $d_t = ?$; $L = ?$; $d_e = ?$; $t_p = ?$

$$d_t = \frac{v_c}{\pi \cdot n_{lim}} = \frac{220\,000 \frac{mm}{min}}{\pi \cdot 3000 \frac{1}{min}} = \mathbf{23.3\ mm}\ (d_1 > d_t)$$

$$L = \frac{d - d_1}{2} + l_{si} = \frac{120\ mm - 65\ mm}{2} + 1.5\ mm = \mathbf{29\ mm}$$

$$d_e = \frac{d + d_1}{2} + l_{si} = \frac{120\ mm + 65\ mm}{2} + 1.5\ mm = \mathbf{94\ mm}$$

$$t_p = \frac{\pi \cdot d_e \cdot L \cdot i}{v_c \cdot f} = \frac{\pi \cdot 94\ mm \cdot 29\ mm \cdot 2}{220\,000 \frac{mm}{min} \cdot 0.2\ mm} = \mathbf{0.39\ min}$$

# Drilling, Reaming, Counterboring, Planing, Shaping

## Drilling, reaming, countersinking

| Cut $l_c$ | |
|---|---|
| $\sigma$ | $l_c$ |
| 80° | $0.6 \cdot d$ |
| 118° | $0.3 \cdot d$ |
| 130° | $0.23 \cdot d$ |
| 140° | $0.18 \cdot d$ |

$t_p$ productive time
$d$ tool diameter
$l$ bore depth
$l_{si}$ starting idle
$l_{oi}$ overrun idle travel
$l_c$ lead
$L$ travel
$f$ feed per revolution
$n$ rotational speed
$v_c$ cutting speed
$i$ number of cuts
$\sigma$ drill point angle

**Productive time**

$$t_p = \frac{L \cdot i}{n \cdot f}$$

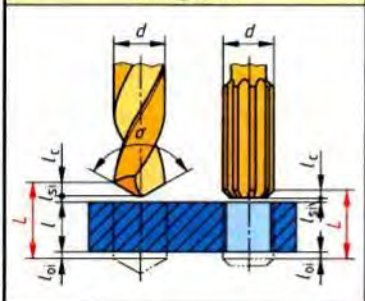
**Speed**

$$n = \frac{v_c}{\pi \cdot d}$$

**Calculating travel $L$**

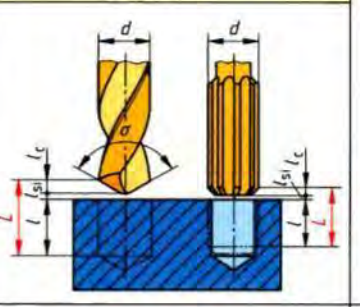
**for drilling and reaming**

Through hole



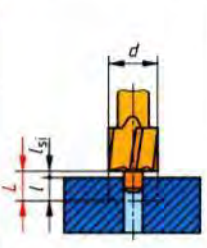

$$L = l + l_c + l_{si} + l_{oi}$$

Blind hole




$$L = l + l_c + l_{si}$$

**for counterboring**




$$L = l + l_{si}$$

**Example:**

Blind hole of $d = 30$ mm;
$l = 90$ mm; $f = 0.15$ mm;
$n = 450$/min; $i = 15$; $l_{si} = 1$ mm;
$\sigma = 130°$; $L = ?$; $t_p = ?$

$$L = l + l_c + l_{si} = 90\text{ mm} + 0.23 \cdot 30\text{ mm} + 1\text{ mm} = \mathbf{98\text{ mm}}$$

$$t_p = \frac{L \cdot i}{n \cdot f} = \frac{98\text{ mm} \cdot 15}{450\,\frac{1}{\text{min}} \cdot 0.15\text{ mm}} = \mathbf{21.78\text{ min}}$$

## Planing and shaping

$t_p$ productive time
$l$ workpiece length
$l_{si}$ starting idle
$l_{oi}$ overrun idle travel
$L$ stroke length
$w$ width of workpiece
$w_a$ approach width
$w_o$ overrun width
$n$ no. of double strokes per minute
$v_c$ cutting speed, approach speed
$v_r$ return speed
$W$ planing, shaping width
$f$ feed per double stroke
$i$ number of cuts

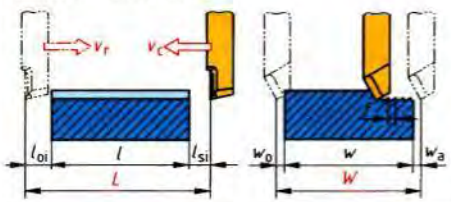
**Productive time**

$$t_p = \frac{W \cdot i}{n \cdot f}$$

$$t_p = \left(\frac{L}{v_c} + \frac{L}{v_r}\right) \cdot \frac{W \cdot i}{f}$$

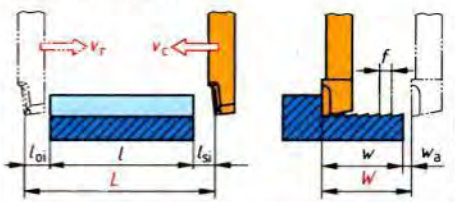
**Calculating stroke length $L$ and planing width $W$**

Workpieces without shoulder



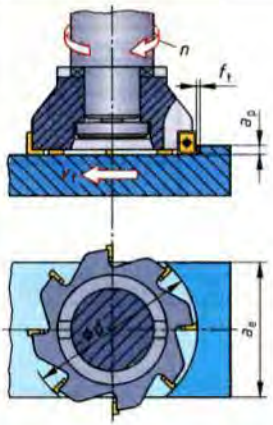

$$L = l + l_{si} + l_{oi} \qquad W = w + w_a + w_o$$

Workpieces with shoulder




$$L = l + l_{si} + l_{oi} \qquad W = w + w_a$$

# Milling




$t_p$ productive time
$l$ workpiece length
$a_p$ cutting depth
$a_e$ engagement (milling width)
$l_a$ approach
$l_{oi}$ overrun idle travel
$l_{st}$ starting travel
$L$ total travel
$d$ cutter diameter
$n$ rotational speed
$f$ feed per revolution
$f_t$ feed per tooth
$N$ number of teeth
$v_c$ cutting speed
$v_f$ feed rate
$i$ number of cuts

**Productive time**

$$t_p = \frac{L \cdot i}{n \cdot f} \qquad t_p = \frac{L \cdot i}{v_f}$$

**Feed per revolution of milling cutter**

$$f = f_t \cdot N$$

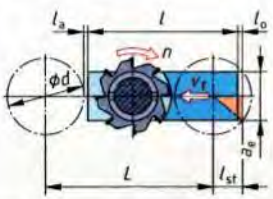
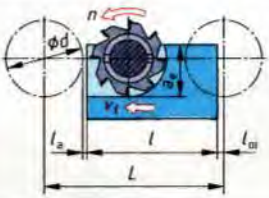
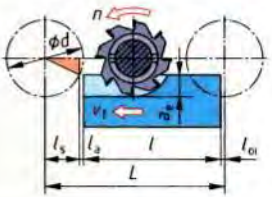
**Feed rate**

$$v_f = n \cdot f \qquad v_f = n \cdot f_t \cdot N$$

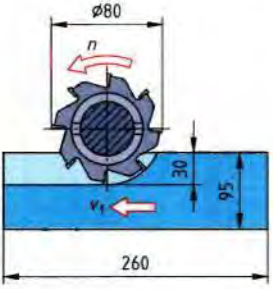
**Rotational speed**

$$n = \frac{v_c}{\pi \cdot d}$$

**Total travel $L$ and starting travel $l_{st}$ in relation to the milling process**

| Face milling | | | Peripheral face milling |
|---|---|---|---|
| centric | eccentric | | |
| | $a_e > 0.5 \cdot d$ | $a_e < 0.5 \cdot d$ | |
|  |  |  | |
| $L = l + 0.5 \cdot d + l_a + l_{oi} - l_{st}$ | $L = l + 0.5 \cdot d + l_a + l_{oi}$ | $L = l + l_a + l_{oi} + l_{st}$ | |
| $l_{st} = 0.5 \cdot \sqrt{d^2 - a_e^2}$ | | $l_{st} = \sqrt{a_e \cdot d - a_e^2}$ | |






**Example:**

Face milling (see left illustration): $N = 10$, $f_t = 0.08$ mm, $v_c = 30$ m/min, $l_a = l_{oi} = 1.5$ mm, $i = 1$ cut

**Sought after:** $n$; $v_f$; $L$; $t_p$

**Solution:**

$$n = \frac{v_c}{\pi \cdot d} = \frac{30 \frac{m}{min}}{\pi \cdot 0.08\ m} = \mathbf{119 \frac{1}{min}}$$

$$v_f = n \cdot f_t \cdot N = 119 \frac{1}{min} \cdot 0.08\ mm \cdot 10 = \mathbf{95.2 \frac{mm}{min}}$$

$$\frac{a_e}{d} = \frac{30\ mm}{80\ mm} = 0.375, \text{ it follows that } a_e < 0.5 \cdot d$$

$$L = l + l_a + l_{oi} + l_{st}$$

$$l_{st} = \sqrt{a_e \cdot d - a_e^2} = \sqrt{30mm \cdot 80\ mm - (30\ mm)^2} = \mathbf{38.7\ mm}$$

$$L = 260\ mm + 1.5\ mm + 1.5\ mm + 38.7\ mm = \mathbf{301.7\ mm}$$

$$t_p = \frac{L \cdot i}{v_f} = \frac{301.7\ mm \cdot 1}{95.2 \frac{mm}{min}} = \mathbf{3.2\ min}$$

# Grinding

## Straight cylindrical grinding

$t_p$ productive time
$L$ travel
$i$ number of cuts
$n$ workpiece rotational speed
$f$ workpiece feed per revolution
$v_f$ feed rate
$d_1$ initial diameter of workpiece
$d$ final diameter of workpiece
$a_p$ cutting depth
$l$ workpiece length
$w_g$ grinding wheel width
$l_{oi}$ overrun idle travel
$t$ grinding allowance

**Productive time**

$$t_p = \frac{L \cdot i}{n \cdot f}$$

**Workpiece rotational speed**

$$n = \frac{v_f}{\pi \cdot d_1}$$

**Number of cuts**

**for external straight grinding**

$$i = \frac{d_1 - d}{2 \cdot a_p} + 2^{1)}$$

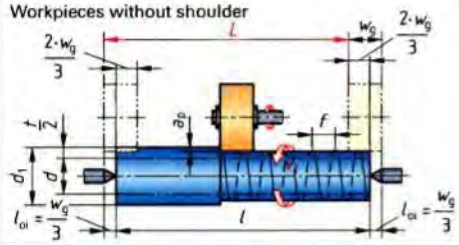
**for internal straight grinding**

$$i = \frac{d - d_1}{2 \cdot a_p} + 2^{1)}$$

1) 2 cuts to spark out, for lower tolerance grades additional cuts are necessary

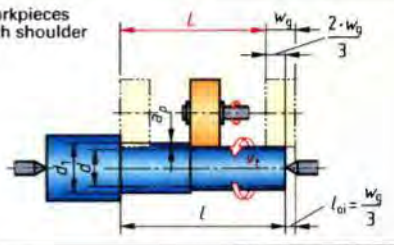
### Calculating travel $L$

Workpieces without shoulder




$$L = l - \frac{1}{3} \cdot w_g$$

Workpieces with shoulder




$$L = l - \frac{2}{3} \cdot w_g$$

Feed for roughing $f = {}^2/_3 \cdot w_g$ to ${}^3/_4 \cdot w_g$; feed for finishing $f = {}^1/_4 \cdot w_g$ to ${}^1/_2 \cdot w_g$

## Surface grinding

$t_p$ productive time
$l$ workpiece length
$l_i$ start. idle, overrun idle travel
$L$ travel
$w$ width of workpiece
$w_o$ overrun width
$W$ grinding width
$f$ transverse feed per stroke
$n$ no. of strokes per minute
$v_f$ feed rate
$i$ number of cuts
$t$ grinding allowance
$w_g$ grinding wheel width
$a_p$ cutting depth

**Number of cuts**

$$i = \frac{t}{a_p} + 2^{1)}$$

1) 2 cuts to spark out

**No. of strokes**

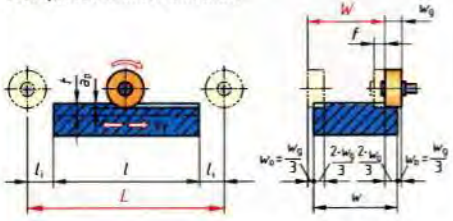
$$n = \frac{v_f}{L}$$

**Productive time**

$$t_p = \frac{i}{n} \cdot \left(\frac{W}{f} + 1\right)$$

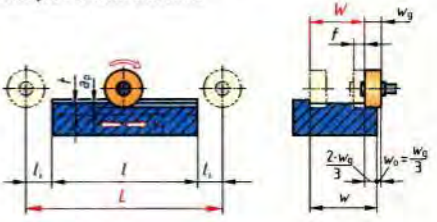
### Calculating travel $L$ and grinding width $W$

Workpieces without shoulder




$$L = l + 2 \cdot l_i \qquad l_i \approx 0.04 \cdot l \qquad W = w - \frac{1}{3} \cdot w_g$$

Workpieces with shoulder




$$L = l + 2 \cdot l_i \qquad l_i \approx 0.04 \cdot l \qquad W = w - \frac{2}{3} \cdot w_g$$

Transverse feed for roughing $f = {}^2/_3 \cdot w_g$ to ${}^4/_5 \cdot w_g$; feed for finishing $f = {}^1/_2 \cdot w_g$ to ${}^2/_3 \cdot w_g$

# Machining coolants for cutting metals

## Terminology and applications for machining coolants

cf. DIN 51385 (1991-06)

| Type of machining coolant | Effect | Group | Explanation | |
|---|---|---|---|---|
| | | | Composition | Applications |
| SESW machining coolants | increasing cooling effect ↑ / increasing lubricating effect ↓ | Solutions/ dispersions | Inorganic materials in water | Grinding |
| | | | Organic or synthetic materials in water | Machining at high cutting speed |
| SEMW machining coolants (oil in water) | | Emulsions | 2%–20% emulsive (soluble) machining coolant in water | Good cooling effect, but low lubrication, e.g. machining (turning, milling, drilling) of easy-to-machine materials, at high cutting speed; for high working temperatures; susceptible to bacterial or fungal attack |
| SN machining coolants insoluble in water | | Cutting oil | Mineral oils with polar additives (greases or synthetic esters) or EP additives[2] to increase lubricating performance | For lower cutting speed, higher surface quality, for difficult-to-machine materials; very good lubrication and corrosion protection |

[1] Machining coolants may be hazardous to health (page 198) and are therefore only used in small quantities.
[2] EP = Extreme Pressure; additives to increase acceptance of high surface pressure between chip and tool

## Guidelines for selecting coolants

| Manufacturing process | | Steel | Cast iron, malleable cast iron | Cu, Cu alloys | Al, Al alloys | Mg alloys |
|---|---|---|---|---|---|---|
| Turning | Roughing | emulsion, solution | dry | dry | emulsion, cutting oil | dry, cutting oil |
| | Finishing | emulsion, cutting oil | emulsion, cutting oil | dry, emulsion | dry, cutting oil | dry, cutting oil |
| Milling | | emulsion, solution, cutting oil | dry, emulsion | dry, emulsion, cutting oil | cutting oil, emulsion | dry, cutting oil |
| Drilling | | emulsion, cutting oil | dry, emulsion | dry, cutting oil, emulsion | cutting oil, emulsion | dry, cutting oil |
| Reaming | | cutting oil, emulsion | dry, cutting oil | dry, cutting oil | cutting oil | cutting oil |
| Sawing | | emulsion | dry, emulsion, | dry, cutting oil | cutting oil, emulsion | dry, cutting oil |
| Broaching | | cutting oil, emulsion | emulsion | cutting oil | cutting oil | cutting oil |
| Hobbing, gear shaping | | cutting oil | cutting oil, emulsion | – | – | – |
| Thread cutting | | cutting oil | cutting oil, emulsion | cutting oil | cutting oil | cutting oil, dry |
| Grinding | | emulsion, solution, cutting oil | solution, emulsion | emulsion, solution | emulsion | – |
| Honing, lapping | | cutting oil | cutting oil | – | – | – |

# Hard and dry machining, High-speed milling, MQCL

## **Hard turning** with cubic boron nitride (CBN)



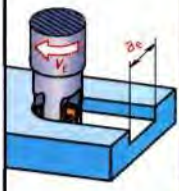
| Turning process | Material hardened steel HRC | Cutting speed $v_c$ m/min | Feed $f$ mm/revolution | Cutting depth $a_p$ mm |
|---|---|---|---|---|
| External turning | 45–58 | 60–220 | 0.05–0.3 | 0.05–0.5 |
| Internal turning | | 60–180 | 0.05–0.2 | 0.05–0.2 |
| External turning | > 58–65 | 50–190 | 0.05–0.25 | 0.05–0.4 |
| Internal turning | | 50–150 | 0.05–0.2 | 0.05–0.2 |

## **Hard milling** with coated solid carbide (VHM) tools



| Material hardened steel HRC | Cutting speed $v_c$ m/min | working engagement $a_{e\,max}$ mm | Feed per tooth $f_t$ in mm for lathe diameter $d$ in mm 2–8 | > 8–12 | > 12–20 |
|---|---|---|---|---|---|
| to 35 | 80–90 | $0.05 \cdot d$ | 0.04 | 0.05 | 0.06 |
| 36–45 | 60–70 | $0.05 \cdot d$ | | | |
| 46–54 | 50–60 | $0.05 \cdot d$ | 0.03 | 0.04 | 0.05 |

## **High-speed cutting (HSC)** with PCD



| Material group | Cutting speed $v_c$ m/min | Cutter diameter $d$ in mm 10 $a_e$ mm | 10 $f_t$ mm | 20 $a_e$ mm | 20 $f_t$ mm |
|---|---|---|---|---|---|
| Steel $R_m$ 850–1100 | 280–360 | 0.25 | 0.09–0.13 | 0.40 | 0.13–0.18 |
| > 1100–1400 | 210–270 | | | | |
| Hardened steel 48–55 HRC | 90–240 | 0.25 | 0.09–0.13 | 0.40 | 0.13–0.18 |
| > 55–67 HRC | 75–120 | 0.20 | | 0.35 | |
| EN-GJS > 180HB | 300–360 | 0.25 | 0.09–0.13 | 0.40 | 0.13–0.18 |
| Titanium alloy | 90–270 | 0.20–0.25 | 0.09–0.13 | 0.35–0.40 | 0.13–0.18 |
| Cu alloy | 90–140 | 0.20 | 0.09–0.13 | 0.35 | 0.13–0.18 |

## **Dry machining**

| Process | Cutting tool material and machining coolant for: Iron materials: Quenched and tempered steels | High-alloy steels | Cast iron | Al materials: Cast alloy | Wrought alloy |
|---|---|---|---|---|---|
| Drilling | TiN, dry | TiAlN[1], MQCL | TiN, dry | TiAlN, MQCL | TiAlN, MQCL |
| Reaming | PCD, MQCL | –[2] | PCD, MQCL | TiAlN, PCD, MQCL | TiAlN, MQCL |
| Milling | TiN, dry | TiAlN, MQCL | TiN, dry | TiAlN, dry | TiAlN, MQCL |
| Sawing | MQCL | MQCL | –[2] | TiAlN, MQCL | TiAlN, MQCL |

## **Minimum quantity of machining coolant (MQCL or MQL)**[3]

**Dependency of MQCL volume on machining method**

milling drilling grinding lapping turning reaming honing

Increasing lubrication requirement

**Suitability of minimum quantity lubrication for the material to be machined**

Cu alloys Al alloy castings Ferritic steel Mg alloys Al wrought alloys Pearlitic steel Cast iron materials Stainless steels

Increasing material suitability

[1] Titanium aluminum nitride (super hard coating) [2] Not normally done [3] Generally 0.01–3 l/hr

# Cutting tool materials

## Designation of hard cutting tool materials

cf. DIN ISO 513 (2005-11)

**Example:** Code letter (see the table below) — HC – K 20 — Application group

Cutting main group: P (blue) | M (yellow) | K (red) | N (green) | S (brown) | H (gray)

| Cutting tool material group | K[1] | Components | Properties | Applications |
|---|---|---|---|---|
|  Hard metals | Uncoated hard metal, main component is tungsten carbide (WC) | | High hot hardness up to 1000 °C, high wear resistance, high compression strength, vibration damping | Indexable inserts for drilling, turning and milling tools, also for solid hard metal tools |
| | HW | Grain size > 1 µm | | |
| | HF | Grain size < 1 µm | | |
| | HT | Uncoated hard metal of titanium carbide (TiC), titanium nitride (TiN) or of both, also called cermet. | Like HW, but with high cutting edge stability, chemical resistance | Indexable inserts for lathe and milling tools for finishing at high cutting speeds |
| | HC | HW and HT, but coated with titanium carbonitride (TiCN) | Increase of wear resistance without reducing toughness | Increasingly replacing the uncoated hard metals |
|  Cutting ceramics | CA | Cutting ceramics, primarily of aluminum oxide ($Al_2O_3$) | High hardness and hot hardness up to 1200 °C sensitive to severe temperature changes | Cutting of cast iron, usually without cooling lubricant |
| | CM | Mixed ceramics with aluminum oxide ($Al_2O_3$) base, as well as other oxides | Tougher than pure ceramics, better resistance to temperature variations | Precision hard turning of hardened steel, cutting at high cutting speed |
| | CN | Silicon nitride ceramics, primarily of silicon nitride ($Si_3N_4$) | High toughness, high cutting edge stability | Cutting of cast iron at high cutting speed |
| | CR | Cutting ceramics with aluminum oxide ($Al_2O_3$), as a main component, reinforced | Tougher than pure ceramics due to reinforcement, improved resistance against temperature variations | Hard turning of hardened steel, cutting at high cutting speed |
| | CC | Cutting ceramics such as CA, CM and CN, but coated with titanium carbonitride (TiCN) | Increase of wear resistance without reducing toughness | Increasingly replacing the uncoated cutting ceramics |
|  Boron nitride | Cubic crystalline boron nitride (BN), also designated CBN or PCB or "superhard cutting tool material" | | Very high hardness and hot hardness up to 2000 °C, high wear resistance, chemical resistance | Dressing of hard materials (HRC > 48) with high surface quality |
| | BL | With low boron nitride content | | |
| | BH | With high boron nitride content | | |
| | BC | BL and BH, but coated | | |
|  Diamond | Cutting tool material of carbon (C), also designated CBN, PCB or "superhard cutting tool material" | | High wear resistance, very brittle, temperature resistance up to 600 °C, reacts with alloying elements | Cutting of non-ferrous metals and Al alloys with high silicon content |
| | DP | Polycrystalline diamond (PCD) | | |
| | DM | Monocrystalline diamond | | |
|  Tool steel[2] | HS | High-performance high-speed steel with alloying elements tungsten (W), molybdenum (Mo), vanadium (V) and cobalt (Co), usually coated with titanium nitride (TiN) | High toughness, high bending strength, low hardness, temperature resistant up to 600 °C | For severe alternating cutting forces, machining of plastics, for the cutting of Al and Cu alloys |

[1] Code letters according to DIN ISO 513
[2] Tool steels are not included in DIN ISO 513 but in ISO 4957

# Cutting tool materials

## Classification and application of hard cutting tool materials

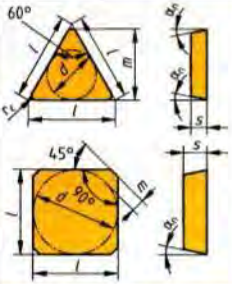
cf. DIN ISO 513 (2005-11)

| Code letter color code | Application group | | Workpiece – material | Cutting tool material properties[1] | | Possible cutting parameters[1] | |
|---|---|---|---|---|---|---|---|
| | | | | Wear resistance | Toughness | Cutting speed | Feed |
| **Steel** | | | | | | | |
| **P** blue | P01<br>P10<br>P20<br>P30<br>P40<br>P50 | P05<br>P15<br>P25<br>P35<br>P45 | All types of steels and cast steels, with the exception of stainless steel with austenitic structure |  |  |  |  |
| **Stainless steel** | | | | | | | |
| **M** yellow | M01<br>M10<br>M20<br>M30<br>M40 | M05<br>M15<br>M25<br>M35 | Austenitic and austenitic ferritic stainless steels and cast steels |  |  |  |  |
| **Cast iron** | | | | | | | |
| **K** red | K01<br>K10<br>K20<br>K30<br>K40 | K05<br>K15<br>K25<br>K35 | Cast iron with flake and spheroidal graphite malleable cast iron |  |  |  |  |
| **Non-ferrous metals and other non-ferrous materials** | | | | | | | |
| **N** green | N01<br>N10<br>N20<br>N30 | N05<br>N15<br>N25 | Aluminum and other non-ferrous metals (e.g. Cu, Mg), non-ferrous materials (e.g. GPR, CFRP) |  |  |  |  |
| **Special alloys and titanium** | | | | | | | |
| **S** brown | S01<br>S10<br>S20<br>S30 | S05<br>S15<br>S25 | High-temperature special alloy on the basis of iron, nickel and cobalt, titanium and titanium alloys |  |  |  |  |
| **Hard materials** | | | | | | | |
| **H** gray | H01<br>H10<br>H20<br>H30 | H05<br>H15<br>H25 | Hardened steel, hardened cast iron materials, cast iron for ingot casting |  |  |  |  |

[1] Increasing in direction of the arrow

# Designations for indexable inserts for cutting tools

cf. DIN ISO 1832 (2005-11)




**Designation examples:**

Indexable carbide insert with rounded corners (DIN 4968) without mounting hole

| Insert DIN | 4968 | – | T | N | G | N | 16 | 03 | 08 | T | – | P20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | ① | ② | ③ | ④ | ⑤ | ⑥ | ⑦ | ⑧ | ⑨ | ⑩ |

Indexable carbide insert with wiper edges (DIN 6590) without mounting hole

| Insert DIN | 6590 | – | S | P | E | N | 15 | 04 | ED | R | – | P10 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Standard number | | | ① | ② | ③ | ④ | ⑤ | ⑥ | ⑦ | ⑧ | ⑨ | ⑩ |

## ① Basic shape

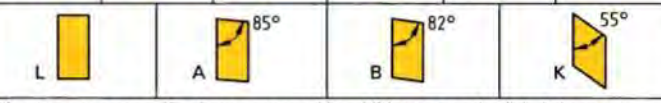
Equilateral, equiangular and round




Equilateral and non-equiangular




Non-equilateral and
L equiangular
A, B, K non-equiangular




Many company specific shapes are used in addition to standardizied shapes.

## ② Normal clearance angle $\alpha_n$ to the insert

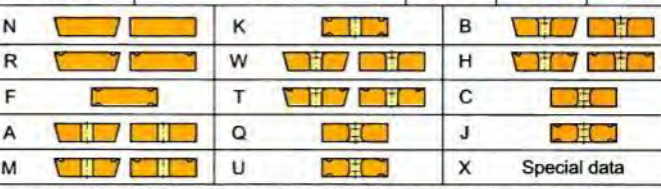
| A | B | C | D | E | F | G | N | P | O |
|---|---|---|---|---|---|---|---|---|---|
| 3° | 5° | 7° | 15° | 20° | 25° | 30° | 0° | 11° | special data |

## ③ Tolerance class

| Allow. dev. for | A | F | C | H | E | G |
|---|---|---|---|---|---|---|
| Control dim. $d$ | ± 0.025 | ± 0.013 | ± 0.025 | ± 0.013 | ± 0.025 | |
| Control dim. $m$ | ± 0.005 | | ± 0.013 | | ± 0.025 | |
| Insert thickness $s$ | ± 0.025 | | ± 0.025 | | ± 0.025 | ± 0.09 |

| Allow. dev. for | J | K | L | M | N | U |
|---|---|---|---|---|---|---|
| Control dim. $d$ | ± 0.05 ... ± 0.15 | | | ± 0.05 ... ± 0.15 | | ± 0.16 |
| Control dim. $m$ | ± 0.005 | ± 0.013 | ± 0.025 | ± 0.08 ... ± 0.20 | | ± 0.25 |
| Insert thickness $s$ | ± 0.025 | | | ± 0.09 | ± 0.025 | ± 0.13 |

## ④ Faces and clamping features




## ⑤ Insert size

The cutting length is the longer cutting edge for non-equilateral inserts, for round inserts it is the diameter.

## ⑥ Insert thickness

Insert thickness is given in mm without decimal places.

## ⑦ Cutting point configuration

**Code number** multiplied by factor 0.1 = corner radius $r_c$

| **1. Letter symbol** for cutting edge angle $\varkappa_r$ of main cutting edge | A | D | E | F | P |
|---|---|---|---|---|---|
| | 45° | 60° | 75° | 85° | 90° |

| **2. Letter symbol** for clearance angle $\alpha'_n$ on wiper edge (corner chamfer) | A | B | C | D | E | F | G | N | P |
|---|---|---|---|---|---|---|---|---|---|
| | 3° | 5° | 7° | 15° | 20° | 25° | 30° | 0° | 11° |

## ⑧ Cutting point

| F sharp | E rounded | T chamfered | S chamfered rounded | K double chamfered | P doub. chamfered and rounded |
|---|---|---|---|---|---|

## ⑨ Cutting direction

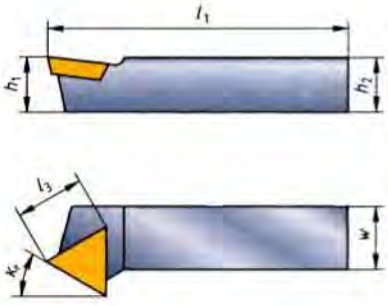
| R right hand cutting | L left hand cutting | N right and left hand cutting (neutral) |
|---|---|---|

## ⑩ Cutting tool material

Carbide with machining application group or cutting ceramic

# Designation of indexable and short indexable insert holders

cf. DIN 4983 (2004-07)




**Designation example:**

**Holder DIN 4984 – C T W N R 32 25 M 16**

- standard no. of holder
- holding method
- insert shape[1)]
- design of holder
- normal clear. angle of insert[1)] $\alpha_n$
- type of holder
- height of cutting edge $h_1 = h_2$ in mm
- shank width $w$ in mm
- length of holder $l_1$ in mm
- indexable insert size[1)]

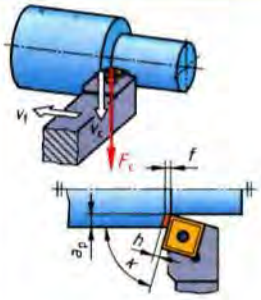
1) For indexable inserts, see page 296

| Designation | | Configurations | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Insert holding | Letter symbol | C | | | M | | | P | | | S | | | |
| | Holding of indexable insert | clamped from above | | | clamped from above and from hole | | | clamped from hole | | | countersink hole and screw | | | |
| Design of holder | Letter symbol | A | B | D | E | M | N | V | G | H | J | R | T | |
| straight | Side cutting edge angle $\kappa_r$ | 90° | 75° | 45° | 60° | 50° | 63° | 72.5° | 90° | 107.5° | 93° | 75° | 60° | |
| | Type of holder | straight | | | | | | | offset | | | | | |
| offset | Letter symbol | C | F | K | S | U | W | Y | Forms D and S also available with round indexable inserts of basic form R | | | | | |
| | Side cutting edge angle $\kappa_r$ | 90° | 90° | 75° | 45° | 93° | 60° | 85° | | | | | | |
| | Type of holder | straight | offset | | | | | | | | | | | |
| Type of holder | Letter symbol | R | right holder L | | | | left holder N | | | | neutral (both sides) | | | |
| Length of holder | Letter symbol | A | B | C | D | E | F | G | H | J | K | L | M | |
| | $l_1$ in mm | 32 | 40 | 50 | 60 | 70 | 80 | 90 | 100 | 110 | 125 | 140 | 150 | |
| | Letter symbol | N | P | Q | R | S | T | U | V | W | X | Y | | |
| | $l_1$ in mm | 160 | 170 | 180 | 200 | 250 | 300 | 350 | 400 | 450 | Cust. lengths | | 500 | |

⇒ **Holder DIN 4984 – CTWNR 3225 M 16:** holder with square shank, clamped above (C), triangular indexable insert (T), $\kappa_r$ = 60° (W), $\alpha_n$ = 0° (N), right hand (R), $h_1 = h_2$ = 32 mm, $b$ = 25 mm, $l_1$ = 150 mm (M), $l_3$ = 16.5 mm (16).

# Forces and power in turning and drilling

## Turning




$F_c$ cutting force in N
$A$ chip section in mm²
$a_p$ cutting depth in mm
$f$ feed per revolution in mm
$h$ chip thickness in mm
$\varkappa$ cutting edge angle in degrees (°)
$C$ correction factor for the cutting speed
$v_c$ cutting speed in m/min
$k_c$ specific cutting force in N/mm² (page 299)
$P_c$ cutting power in kW
$P_1$ drive power of the machine tool in kW
$\eta$ efficiency of the machine tool

| Correction factor $C$ for the cutting speed | |
|---|---|
| Cutting speed $v_c$ in m/min | $C$ |
| 10–30 | 1.3 |
| 31–80 | 1.1 |
| 81–400 | 1.0 |

**Chip section**

$$A = a_p \cdot f$$

**Cutting force**

$$F_c = A \cdot k_c \cdot C$$

**Chip thickness**

$$h = f \cdot \sin\varkappa$$

**Cutting power**

$$P_c = F_c \cdot v_c$$

**Drive power**

$$P_1 = \frac{P_c}{\eta}$$

**Example:**

A shaft of 16MnCr5, $a_p = 5$ mm, $f = 0.32$ mm, $v_c = 110$ m/min, $\varkappa = 75°$

**Sought after:** $h$; $k_c$; $C$; $A$; $F_c$; $P_1$ with $\eta = 0.75$

**Solution:** $h = f \cdot \sin\varkappa = 0.32\text{ mm} \cdot \sin 75° = \mathbf{0.31\text{ mm}}$

$k_c = \mathbf{3735\text{ N/mm}^2}$ (see table on page 299),

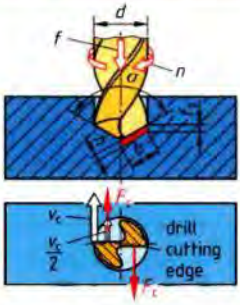
$C = \mathbf{1.0}$ (see correction factor table)

$A = a_p \cdot f = 5\text{ mm} \cdot 0.32\text{ mm} = \mathbf{1.6\text{ mm}^2}$

$$F_c = A \cdot k_c \cdot C = 1.6\text{ mm}^2 \cdot 3735\,\frac{\text{N}}{\text{mm}^2} \cdot 1.0 = \mathbf{5976\text{ N}}$$

$$P_1 = \frac{P_c}{\eta} = \frac{F_c \cdot v_c}{\eta} = \frac{5976\text{ N} \cdot 110\text{ m}}{0.75 \cdot 60\text{ s}} = 14608\text{ W} = \mathbf{14.6\text{ kW}}$$

## Drilling




$F_c$ cutting force per edge in N
$z$ number of cutting edges (twist drill $z = 2$)
$A$ chip section in mm²
$d$ drill diameter in mm
$f$ feed per revolution in mm
$f_z$ feed per cutting edge in mm
$\sigma$ drill point angle in degrees (°)
$h$ chip thickness in mm
$C$ correction factor for the cutting speed
$v_c$ cutting speed in m/min
$k_c$ specific cutting force in N/mm² (page 299)
$P_c$ cutting power in kW
$P_1$ drive power of the machine tool in kW
$\eta$ efficiency of the machine tool

| Correction factor $C$ for the cutting speed | |
|---|---|
| Cutting speed $v_c$ in m/min | $C$ |
| 10–30 | 1.3 |
| 31–80 | 1.1 |

**Chip section per cutting edge**

$$A = \frac{d \cdot f}{4}$$

**Cutting force per cutting edge**[1]

$$F_c = 1.2 \cdot A \cdot k_c \cdot C$$

**Chip thickness**

$$h = \frac{f}{2} \cdot \sin\frac{\sigma}{2}$$

**Cutting power**

$$P_c = \frac{z \cdot F_c \cdot v_c}{2}$$

**Drive power**

$$P_1 = \frac{P_c}{\eta}$$

**Example:**

Material 42CrMo4, $d = 16$ mm, $v_c = 28$ m/min, $f = 0.18$ mm, $\sigma = 118°$

**Sought after:** $h$; $k_c$; $C$; $A$; $F_c$; $P_c$

**Solution:** $h = \frac{f}{2} \cdot \sin\frac{\sigma}{2} = \frac{0.18\text{ mm}}{2} \cdot \sin 59° = \mathbf{0.08\text{ mm}}$

$k_c = \mathbf{6265\text{ N/mm}^2}$ (see table on page 299)

$$A = \frac{d \cdot f}{4} \cdot \frac{16\text{ mm} \cdot 0.18\text{ mm}}{4} = \mathbf{0.72\text{ mm}^2}$$

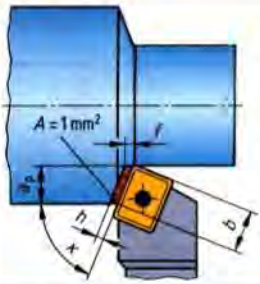
$C = \mathbf{1.3}$ (see correction factor table)

$$F_c = 1.2 \cdot A \cdot k_c \cdot C = 1.2 \cdot 0.72\text{ mm}^2 \cdot 6265\,\frac{\text{N}}{\text{mm}^2} \cdot 1.3 = \mathbf{7037\text{ N}}$$

$$P_c = \frac{z \cdot F_c \cdot v_c}{2} \cdot \frac{2 \cdot 7037\text{ N} \cdot 28\text{ m}}{60\text{ s} \cdot 2} = 3284\,\frac{\text{N} \cdot \text{m}}{\text{s}} = 3284\text{ W} = \mathbf{3.3\text{ kW}}$$

[1] The specific cutting force values $k_c$ are assessed in turning tests. The conversion to drilling is realized via the factor 1.2 in the formula.

# Specific cutting force




The specific cutting force $k_c$ is the the force that is required to separate a chip with a cross section of $A = 1$ mm² from a workpiece. The values are assessed in turning tests and form the basis of the calculation of the cutting forces and the drive power in chip-removing machining processes.

$k_c$ specific cutting force N/mm²
$h$ chip thickness in mm
$f$ feed in mm
$a_p$ cutting depth in mm
$\varkappa$ angle of incidence in degrees (°)

The chip thickness $h$ depends on the applied machining process. Calculation of chip thicknesses: pages 298 and 300.

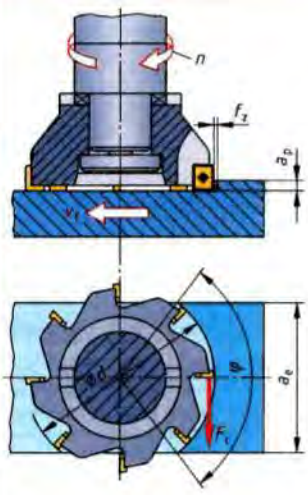
## Standard values for the specific cutting force[1)]

| Material | Specific cutting force $k_c$ in N/mm² for the chip thickness $h$ in mm | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0.05 | 0.08 | 0.10 | 0.15 | 0.20 | 0.25 | 0.30 | 0.40 | 0.50 | 0.80 | 1.00 | 1.50 | 2.00 |
| S235 | 3850 | 3555 | 3425 | 3195 | 3040 | 2930 | 2840 | 2705 | 2605 | 2405 | 2315 | 2160 | 2055 |
| E295 | 5635 | 4990 | 4705 | 4235 | 3930 | 3710 | 3535 | 3285 | 3100 | 2740 | 2585 | 2330 | 2160 |
| E355 | 4565 | 4215 | 4055 | 3785 | 3605 | 3470 | 3365 | 3205 | 3085 | 2850 | 2745 | 2560 | 2340 |
| C15, C15E | 4575 | 4125 | 3925 | 3590 | 3370 | 3210 | 3085 | 2895 | 2755 | 2485 | 2365 | 2165 | 2030 |
| C35, C35E | 4425 | 3895 | 3670 | 3290 | 3045 | 2865 | 2725 | 2525 | 2375 | 2095 | 1970 | 1765 | 1635 |
| C45, C45E | 4760 | 4210 | 3975 | 3575 | 3320 | 3130 | 2985 | 2770 | 2615 | 2315 | 2185 | 1965 | 1825 |
| C60, C60E | 4750 | 4365 | 4190 | 3895 | 3700 | 3555 | 3440 | 3265 | 3135 | 2880 | 2770 | 2575 | 2445 |
| 11SMnPb30 | 2675 | 2460 | 2360 | 2195 | 2085 | 2000 | 1935 | 1840 | 1765 | 1625 | 1560 | 1450 | 1375 |
| 16MnCr5 | 5950 | 5265 | 4965 | 4470 | 4150 | 3915 | 3735 | 3465 | 3270 | 2895 | 2730 | 2455 | 2280 |
| 20MnCr5 | 5775 | 5135 | 4855 | 4385 | 4085 | 3860 | 3690 | 3435 | 3245 | 2885 | 2730 | 2475 | 2295 |
| 18CrMo4 | 4955 | 4575 | 4405 | 4110 | 3915 | 3770 | 3655 | 3480 | 3350 | 3095 | 2975 | 2780 | 2645 |
| 34CrAlMo5 | 4930 | 4360 | 4115 | 3705 | 3435 | 3245 | 3095 | 2870 | 2710 | 2395 | 2260 | 2035 | 1890 |
| 42CrMo4 | 7080 | 6265 | 5915 | 5320 | 4940 | 4660 | 4445 | 4125 | 3890 | 3445 | 3250 | 2925 | 2715 |
| 50CrV4 | 6290 | 5565 | 5250 | 4725 | 4385 | 4140 | 3945 | 3660 | 3455 | 3060 | 2885 | 2595 | 2410 |
| 102Cr6 | 5895 | 4910 | 4500 | 3840 | 3435 | 3145 | 2930 | 2620 | 2400 | 2000 | 1835 | 1565 | 1400 |
| 90MnCrV8 | 5610 | 5080 | 4850 | 4455 | 4195 | 4000 | 3850 | 3625 | 3460 | 3135 | 2990 | 2745 | 2585 |
| X210CrW12 | 5155 | 4565 | 4305 | 3875 | 3595 | 3395 | 3235 | 3005 | 2835 | 2510 | 2365 | 2130 | 1975 |
| X5CrNi18-10 | 5730 | 5190 | 4955 | 4550 | 4285 | 4085 | 3935 | 3705 | 3535 | 3200 | 3055 | 2805 | 2640 |
| X30Cr13 | 5155 | 4565 | 4305 | 3875 | 3595 | 3395 | 3235 | 3005 | 2835 | 2510 | 2365 | 2130 | 1975 |
| TiAl6V4 | 3340 | 3025 | 2890 | 2655 | 2495 | 2385 | 2295 | 2160 | 2060 | 1985 | 1780 | 1635 | 1540 |
| GJL-150 | 2315 | 2100 | 2005 | 1840 | 1730 | 1650 | 1590 | 1500 | 1430 | 1295 | 1235 | 1135 | 1065 |
| GJL-200 | 2805 | 2495 | 2360 | 2130 | 1985 | 1875 | 1790 | 1670 | 1575 | 1405 | 1325 | 1200 | 1115 |
| GJL-400 | 4165 | 3685 | 3480 | 3130 | 2905 | 2740 | 2615 | 2425 | 2290 | 2025 | 1910 | 1720 | 1595 |
| GJS-400 | 2765 | 2455 | 2325 | 2100 | 1955 | 1845 | 1765 | 1645 | 1555 | 1380 | 1305 | 1180 | 1100 |
| GJS-600 | 3200 | 2955 | 2845 | 2655 | 2530 | 2435 | 2360 | 2250 | 2165 | 2000 | 1925 | 1795 | 1710 |
| GJS-800 | 5500 | 4470 | 4055 | 3390 | 2985 | 2710 | 2500 | 2200 | 1995 | 1625 | 1470 | 1230 | 1085 |
| AlCuMg1 | 2150 | 1930 | 1835 | 1670 | 1565 | 1485 | 1425 | 1335 | 1265 | 1135 | 1080 | 985 | 920 |
| AlMg3 | 2020 | 1810 | 1725 | 1570 | 1470 | 1395 | 1340 | 1250 | 1190 | 1065 | 1015 | 925 | 865 |
| AC-AlSi12 | 2150 | 1930 | 1835 | 1670 | 1565 | 1485 | 1425 | 1335 | 1265 | 1135 | 1080 | 985 | 920 |
| MgAl8Zn | 895 | 820 | 785 | 725 | 690 | 660 | 635 | 605 | 580 | 530 | 505 | 470 | 445 |
| CuZn40Pb2 | 1740 | 1600 | 1535 | 1425 | 1355 | 1300 | 1260 | 1195 | 1150 | 1055 | 1015 | 945 | 895 |
| CuSn7ZnPb | 1760 | 1565 | 1480 | 1335 | 1245 | 1175 | 1125 | 1045 | 990 | 880 | 830 | 750 | 700 |

[1)] The standard values apply to tools with hard metal edges. Tool wear increases the specific cutting force by approximately 30 %. The values specified in the table include this addition. For turning, drilling (page 298) and milling processes (page 300), the effect of the cutting speed on the standard values for the specific cutting force is considered via correction factors C in the upper table.

# Forces and power in milling

## Face milling




$F_c$ cutting force per tooth in N
$A$ chip section per tooth in mm²
$a_p$ cutting depth in mm
$a_e$ engagement (milling width) in mm
$h$ chip thickness in mm
$f$ feed per revolution in mm
$f_z$ feed per tooth in mm
$d$ cutter diameter in mm
$v_c$ cutting speed in m/min
$v_f$ feed rate in mm/min
$N$ number of teeth
$N_e$ number of teeth engaged
$\varphi$ angle of engagement in degrees (°)
$k_c$ specific cutting force in N/mm² (page 299)
$C$ correction factor for the cutting speed
$P_c$ cutting power in kW
$P_1$ drive power in kW
$\eta$ effective power of the machine tool

**Feed rate**

$$v_f = N \cdot f_z \cdot n$$

**Chip cross section per tooth**

$$A = a_p \cdot f_z$$

**Cutting force per tooth**[1]

$$F_c = 1.2 \cdot A \cdot k_c \cdot C$$

**Example:**

Material 16MnCr5; $d = 180$ mm; $N = 12$; $a_e = 120$ mm; $a_p = 6$ mm; $f_z = 0.10$ mm; $v_c = 85$ m/min; $\eta = 0.8$.

**Sought after:** $A$; $h$; $k_c$; $F_c$; $\varphi$; $N_e$; $P_c$; $P_1$

**Solution:**

$A = a_p \cdot f_z = 6\text{ mm} \cdot 0.1\text{ mm} = \mathbf{0.6\text{ mm}^2}$

$h = f_z = \mathbf{0.1\text{ mm}}$

$k_c = \mathbf{4965}\ \frac{\mathbf{N}}{\mathbf{mm^2}}$ (table on page 299)

$F_c = 1.2 \cdot A \cdot k_c \cdot C$; $C = 1.0$ (table of correction factors $C$)

$F_c = 1.2 \cdot 0.6\text{ mm}^2 \cdot 4965\ \frac{\text{N}}{\text{mm}^2} \cdot 1.0 = \mathbf{3575\text{ N}}$

$\frac{d}{a_e} = \frac{180\text{ mm}}{120\text{ mm}} = 1.5$; $\boldsymbol{\varphi = 83°}$ (angle of engagement $\varphi$ table)

$N_e = N \cdot \frac{\varphi}{360°} = 12 \cdot \frac{83°}{360°} = \mathbf{2.8}$

$P_c = N_e \cdot F_c \cdot v_c = 2.8 \cdot 3575\text{ N} \cdot \frac{85\text{ m}}{60\text{ s}} = 14181\ \frac{\text{N} \cdot \text{m}}{\text{s}} = \mathbf{14.2\text{ kW}}$

$P_1 = \frac{P_c}{\eta} = \frac{14.2\text{ kW}}{0.8} = \mathbf{17.8\text{ kW}}$

**Chip thickness for $d = (1.2–1.6) \cdot a_e$**[2]

$$h \approx f_z$$

**Number of teeth engaged**

$$N_e = N \cdot \frac{\varphi}{360°}$$

**Cutting power**

$$P_c = N_e \cdot F_c \cdot v_c$$

**Drive power**

$$P_1 = \frac{P_c}{\eta}$$

| Angle of engagement $\varphi$ | | | | | |
|---|---|---|---|---|---|
| $d/a_e$ | $\varphi$ in ° | $d/a_e$ | $\varphi$ in ° | $d/a_e$ | $\varphi$ in ° |
| 1.20 | 113 | 1.35 | 96 | 1.50 | 83 |
| 1.25 | 106 | 1.40 | 91 | 1.55 | 80 |
| 1.30 | 100 | 1.45 | 87 | 1.60 | 77 |

$\frac{d}{a_e} = \frac{\text{cutter diameter}}{\text{engagement}}$

| Correction factor $C$ for the cutting speed | |
|---|---|
| Cutting speed $v_c$ in m/min | $C$ |
| 30–80 | 1.1 |
| 81–400 | 1.0 |

[1] The values of the specific cutting force $k_c$ (page 299) are assessed in turning tests. The conversion to milling is achieved via the factor 1.2 in the formula.

[2] In order to ensure favorable cutting conditions, the cutter diameter should be selected in the range $d = (1.2–1.6) \cdot a_e$.

# Drilling

## Twist drills of high-speed steel (HSS)

cf. DIN 1414-1 (2006-11)




| Type[1] | Application | Helix angle[2] | Point angle[3] |
|---|---|---|---|
| N | Universal application for materials up to $R_m \approx 1000$ N/mm², e.g. structural, case-hardened, quenched and tempered steels | 30°–40° | 118° |
| H | Drilling of brittle, short-chipping non-ferrous metals and plastics, e.g. CuZn alloys and PMMA (Plexiglas) | 13°–19° | 118° |
| W | Drilling of soft, long-chipping non-ferrous metals and plastics, e.g. Al and Mg alloys, PA (polyamide) and PVC | 40°–47° | 130° |

[1] Tool application groups for HSS tools according to DIN 1835
[2] Depends on drill diameter and pitch
[3] Standard version

## Standard values for drilling with HSS twist drills[1]

| Material group | Workpiece material: Tensile strength $R_m$ in N/mm² or Hardness HB | Cutting speed[2] $v_c$ m/min | Drill diameter $d$ in mm: 2–3 | >3–6 | >6–12 | >12–25 | >25–50 |
|---|---|---|---|---|---|---|---|
| | | | Feed $f$ in mm/revolution | | | | |
| Steels, low strength | $R_m \le 800$ | 40 | 0.05 | 0.10 | 0.15 | 0.25 | 0.35 |
| Steels, high strength | $R_m > 800$ | 20 | 0.04 | 0.08 | 0.10 | 0.15 | 0.20 |
| Stainless steels | $R_m \le 800$ | 12 | 0.03 | 0.06 | 0.08 | 0.12 | 0.18 |
| Cast iron, malleable cast iron | ≤ 250 HB | 20 | 0.10 | 0.20 | 0.30 | 0.40 | 0.60 |
| Al alloys | $R_m \le 350$ | 45 | 0.10 | 0.20 | 0.30 | 0.40 | 0.60 |
| Cu alloys | $R_m \le 500$ | 60 | 0.10 | 0.15 | 0.30 | 0.40 | 0.60 |
| Thermoplastics | – | 50 | 0.10 | 0.15 | 0.30 | 0.40 | 0.60 |
| Thermoset plastics | – | 25 | 0.05 | 0.10 | 0.18 | 0.27 | 0.35 |

## Standard values for drilling with carbide drills[1]

| Material group | Workpiece material: Tensile strength $R_m$ in N/mm² or Hardness HB | Cutting speed[2] $v_c$ m/min | Drill diameter $d$ in mm: 2–3 | >3–6 | >6–12 | >12–25 | >25–50 |
|---|---|---|---|---|---|---|---|
| | | | Feed $f$ in mm/revolution | | | | |
| Steels, low strength | $R_m \le 800$ | 90 | 0.05 | 0.10 | 0.15 | 0.25 | 0.40 |
| Steels, high strength | $R_m > 800$ | 80 | 0.08 | 0.13 | 0.20 | 0.30 | 0.40 |
| Stainless steels | $R_m \le 800$ | 40 | 0.08 | 0.13 | 0.20 | 0.30 | 0.40 |
| Cast iron, malleable cast iron | ≤ 250 HB | 100 | 0.10 | 0.15 | 0.30 | 0.45 | 0.70 |
| Al alloys | $R_m \le 350$ | 180 | 0.15 | 0.25 | 0.40 | 0.60 | 0.80 |
| Cu alloys | $R_m \le 500$ | 200 | 0.12 | 0.16 | 0.30 | 0.45 | 0.60 |
| Thermoplastics | – | 80 | 0.05 | 0.10 | 0.20 | 0.30 | 0.40 |
| Thermoset plastics | – | 80 | 0.05 | 0.10 | 0.20 | 0.30 | 0.40 |

## Standard values for modified conditions

Standard values for cutting speed and feed are valid for **moderate usage conditions:**
• tool life approx. 30 min • average strength of material • hole depth < 5 · $d$ • short drill
Standard values are • **increased** for more favorable conditions,
• **decreased** for unfavorable conditions

[1] For cooling lubricants, see pages 292 and 293 [2] Values for coated drills

# Reaming and tapping

## Standard values for reaming with HSS reamers[1]

| Workpiece material: Material group | Tens. strength $R_m$ in N/mm² or Hardness HB | Cutting speed $v_c$ m/min | Tool diameter $d$ in mm: 2–3 | >3–6 | >6–12 | >12–25 | >25–50 | Reaming allow. for $d$ in mm: to 20 | >20–50 |
|---|---|---|---|---|---|---|---|---|---|
| | | | Feed $f$ in mm/revolution | | | | | | |
| Steels, low strength | $R_m \leq 800$ | 15 | 0.06 | 0.12 | 0.18 | 0.32 | 0.50 | 0.20 | 0.30 |
| Steels, high strength | $R_m > 800$ | 10 | 0.05 | 0.10 | 0.15 | 0.25 | 0.40 | | |
| Stainless steels | $R_m \leq 800$ | 8 | 0.05 | 0.10 | 0.15 | 0.25 | 0.40 | | |
| Cast iron, malleable cast iron | ≤ 250 HB | 15 | 0.06 | 0.12 | 0.18 | 0.32 | 0.50 | | |
| Al alloys | $R_m \leq 350$ | 26 | 0.10 | 0.18 | 0.30 | 0.50 | 0.80 | | |
| Cu alloys | $R_m \leq 500$ | 26 | 0.10 | 0.18 | 0.30 | 0.50 | 0.80 | 0.30 | 0.60 |
| Thermoplastics | – | 14 | 0.12 | 0.20 | 0.35 | 0.60 | 1.00 | | |
| Thermoset plastics | – | 14 | 0.12 | 0.20 | 0.35 | 0.60 | 1.00 | | |

## Standard values for reaming with carbide tooling[1]

| Workpiece material: Material group | Tens. strength $R_m$ in N/mm² or Hardness HB | Cutting speed $v_c$ m/min | Tool diameter $d$ in mm: 2–3 | >3–6 | >6–12 | >12–25 | >25–50 | Reaming allow. for $d$ in mm: to 20 | >20–50 |
|---|---|---|---|---|---|---|---|---|---|
| | | | Feed $f$ in mm/revolution | | | | | | |
| Steels, low strength | $R_m \leq 800$ | 15 | 0.06 | 0.12 | 0.18 | 0.32 | 0.50 | 0.20 | 0.30 |
| Steels, high strength | $R_m > 800$ | 10 | 0.05 | 0.10 | 0.15 | 0.25 | 0.40 | | |
| Stainless steels | $R_m \geq 800$ | 10 | 0.05 | 0.10 | 0.15 | 0.25 | 0.40 | | |
| Cast iron, malleable cast iron | ≤ 250 HB | 25 | 0.10 | 0.18 | 0.28 | 0.50 | 0.80 | | |
| Al alloys | $R_m \leq 350$ | 30 | 0.12 | 0.20 | 0.35 | 0.50 | 1.00 | | |
| Cu alloys | $R_m \leq 500$ | 30 | 0.12 | 0.20 | 0.35 | 0.50 | 1.00 | 0.30 | 0.60 |
| Thermoplastics | – | 20 | 0.12 | 0.20 | 0.35 | 0.50 | 1.00 | | |
| Thermoset plastics | – | 30 | 0.12 | 0.20 | 0.35 | 0.50 | 1.00 | | |

## Standard values for tapping and thread forming[1]

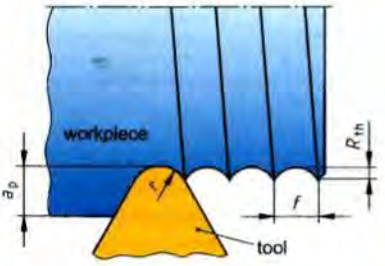
| Workpiece material: Material group | Tens. strength $R_m$ in N/mm² or Hardness HB | HSS tool: Tapping[2] | HSS tool: Thread forming[2] | Carbide tool: Tapping[2] | Carbide tool: Thread forming[2] |
|---|---|---|---|---|---|
| | | Cutting speed $v_c$ m/min | | Cutting speed $v_c$ m/min | |
| Steels, low strength | $R_m \leq 800$ | 40–50 | 40–50 | – | 40–60 |
| Steels, high strength | $R_m > 800$ | 20–30 | 15–20 | – | 20–30 |
| Stainless steels | $R_m \geq 800$ | 8–12 | 10–20 | – | 20–30 |
| Cast iron, malleable cast iron | ≤ 250 HB | 15–20 | – | 25–35 | – |
| Al alloys | $R_m \leq 350$ | 20–40 | 30–50 | 60–80 | 60–80 |
| Cu alloys | $R_m \leq 500$ | 30–40 | 25–35 | 30–40 | 50–70 |
| Thermoplastics | – | 20–30 | – | 50–70 | – |
| Thermoset plastics | – | 10–15 | – | 25–35 | – |

[1] For cooling lubricants, see pages 292 and 293

[2] Upper limit values: for material groups with lower strengths; short threads
Lower limit values: for material groups with higher strengths; long threads

# Turning

## Roughness depth depending on tool nose radius and feed




$R_{th}$ theoretical roughness depth
$r$ tool nose radius
$f$ feed
$a_p$ cutting depth

**Example:**

$R_{th} = 25\ \mu m;\ r = 1.2\ mm;\ f = ?$

$f \approx \sqrt{8 \cdot r \cdot R_{th}}$

$= \sqrt{8 \cdot 1.2\ mm \cdot 0.025\ mm} \approx \mathbf{0.5\ mm}$

**Theor. roughness depth**

$$R_{th} \approx \frac{f^2}{8 \cdot r}$$

$R_{th} \approx R_t$

| Roughn. depth $R_{th}$ in µm | Nose radius $r$ in mm | | | |
|---|---|---|---|---|
| | 0.4 | 0.8 | 1.2 | 1.6 |
| | Feed $f$ in mm | | | |
| 1.6 | 0.07 | 0.10 | 0.12 | 0.14 |
| 4 | 0.11 | 0.16 | 0.20 | 0.23 |
| 10 | 0.18 | 0.25 | 0.31 | 0.36 |
| 16 | 0.23 | 0.32 | 0.39 | 0.45 |
| 25 | 0.28 | 0.40 | 0.49 | 0.57 |

## Standard values for turning with HSS tools[1)2)]

| Workpiece material: Material group | Tensile strength $R_m$ in N/mm² or Hardness HB | Cutting speed $v_c$ in m/min | Feed $f$ in mm | Cutting depth $a_p$ in mm |
|---|---|---|---|---|
| Steels, low strength | $R_m \le 800$ | 40–80 | 0.1–0.5 | 0.5–4.0 |
| Steels, high strength | $R_m > 800$ | 30–60 | | |
| Stainless steels | $R_m \ge 800$ | 30–60 | | |
| Cast iron, malleable cast iron | ≤ 250 HB | 20–35 | | |
| Al alloys | $R_m \le 350$ | 120–180 | | |
| Cu alloys | $R_m \le 500$ | 100–125 | | |
| Thermoplastics | – | 100–500 | | |
| Thermoset plastics | – | 80–400 | | |

## Standard values for turning using coated carbide tools[2)]

| Workpiece material: Material group | Tensile strength $R_m$ in N/mm² or Hardness HB | Cutting speed $v_c$ in m/min | Feed $f$ in mm | Cutting depth $a_p$ in mm |
|---|---|---|---|---|
| Steels, low strength | $R_m \le 800$ | 200–350 | 0.1–0.5 | 0.3–5.0 |
| Steels, high strength | $R_m > 800$ | 100–200 | | |
| Stainless steels | $R_m \ge 800$ | 80–200 | | |
| Cast iron, malleable cast iron | ≤ 250 HB | 100–300 | | |
| Al alloys | $R_m \le 350$ | 400–800 | | |
| Cu alloys | $R_m \le 500$ | 150–300 | | |
| Thermoplastics | – | 500–2000 | | |
| Thermoset plastics | – | 400–1000 | | |

## Application of the cutting data range

**Example:** Standard values for turning of steels with lower strengths using carbide tools

| Upper values | Application | Lower values | Application |
|---|---|---|---|
| $v_c = 350$ m/min | • finish machining (finishing)<br>• stable tool and workpiece | $v_c = 200$ m/min | • premachining (roughing)<br>• unstable tool or workpiece |
| $f = 0.5$ mm, $a_p = 5.0$ mm | • premachining (roughing)<br>• stable tool and workpiece | $f = 0.1$ mm, $a_p = 0.3$ mm | • finish machining (finishing)<br>• unstable tool or workpiece |

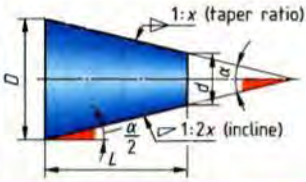
[1)] HSS lathe tools have for the most part been replaced by lathe tools with carbide indexable inserts.

[2)] Machining coolant, see pages 292 and 293

# Taper turning

## Terminology for tapers

cf. DIN ISO 3040 (1991-09)

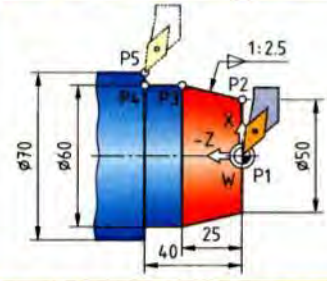



$D$ large taper diameter
$d$ small taper diameter
$L$ taper length
$\alpha$ taper angle
$\frac{\alpha}{2}$ taper-generating angle (setting angle)
$C$ taper ratio

$\frac{C}{2}$ taper incline

1 : $x$ taper: on a taper length of $x$ mm the taper diameter changes by 1 mm.

## Taper turning on CNC lathes

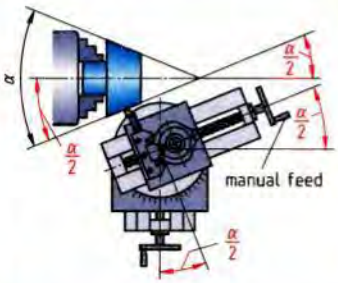



CNC program according to DIN 66025[1] to produce a workpiece with a taper (see figure):

| | | | | | |
|---|---|---|---|---|---|
| N10 | G00 | X0 | Z2 | | Approach at rapid speed |
| N20 | G01 | X0 | Z0 | F0.15 | Traversing motion to P1 |
| N30 | G01 | X50 | | | Traversing motion to P2 |
| N40 | G01 | X60 | Z-25 | | Traversing motion to P3 |
| N50 | G01 | | Z-40 | | Traversing motion to P4 |
| N60 | G01 | X72 | | | Traversing motion over P5 |
| N70 | G00 | X100 | Z150 | | Tool change point |

[1] Compare to page 387

## Taper turning by setting the compound rest




**Example:**

$D = 225$ mm, $d = 150$ mm, $L = 100$ mm;
$\frac{\alpha}{2} = ?$; $C = ?$

$$\tan\frac{\alpha}{2} = \frac{D-d}{2 \cdot L}$$

$$= \frac{(225 - 150)\text{ mm}}{2 \cdot 100\text{ mm}} = 0.375$$

$$\frac{\alpha}{2} = 20.556° = 20° 33' 22''$$

$$C = \frac{D-d}{L} = \frac{(225 - 150)\text{ mm}}{100\text{ mm}} = 0.75 = 1 : 1.33$$

**Setting angle**

$$\tan\frac{\alpha}{2} = \frac{C}{2}$$

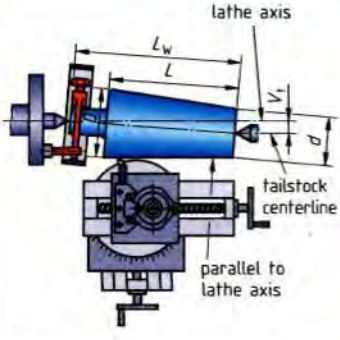
$$\tan\frac{\alpha}{2} = \frac{D-d}{2 \cdot L}$$

**Taper ratio**

$$C = \frac{D-d}{L}$$

$$C = 1 : x$$

## Taper turning by offsetting the tailstock




$V_T$ tailstock offset
$V_{T\,max}$ maximum allowable tailstock offset
$L_W$ workpiece length

**Example:**

$D = 20$ mm; $d = 18$ mm;
$L = 80$ mm; $L_W = 100$ mm
$V_T = ?$; $V_{T\,max} = ?$

$$V_T = \frac{D-d}{2} \cdot \frac{L_w}{L}$$

$$= \frac{(20 - 18)\text{ mm}}{2} \cdot \frac{100\text{ mm}}{80\text{ mm}} = 1.25\text{ mm}$$

$$V_{T\,max} \le \frac{L_w}{50} = \frac{100\text{ mm}}{50} = 2\text{ mm}$$

**Tailstock offset**

$$V_T = \frac{C}{2} \cdot L_w$$

$$V_T = \frac{D-d}{2} \cdot \frac{L_w}{L}$$

**Maximum allowable tailstock offset[1]**

$$V_{T\,max} \le \frac{L_w}{50}$$

[1] If the tailstock offset is too large the workpiece cannot be secured between the lathe centers.

# Milling

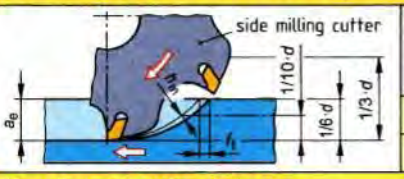
## Standard values for milling with HSS milling cutters

| Workpiece material: Material group | Tensile strength $R_m$ in N/mm² or Hardness HB | Cutting speed $v_c$ in m/min | Feed $f_t$ in mm: Milling cutter (except for end mill) | End mill $d$ in mm: 6 | 12 | 20 |
|---|---|---|---|---|---|---|
| Steels, low strength | $R_m \le 800$ | 50–100 | 0.05–0.15 | 0.06 | 0.08 | 0.10 |
| Steels, high strength | $R_m > 800$ | 30–60 | | | | |
| Stainless steels | $R_m \ge 800$ | 15–30 | | | | |
| Cast iron, malleable cast iron | ≤ 250 HB | 25–40 | | | | |
| Al alloys | $R_m \le 350$ | 50–150 | | | | |
| Cu alloys | $R_m \le 500$ | 50–100 | | | | |
| Thermoplastics | – | 100–400 | 0.10–0.20 | 0.10 | 0.15 | 0.20 |
| Thermoset plastics | – | 100–400 | | | | |

## Standard values for milling with coated carbide

| Workpiece material: Material group | Tensile strength $R_m$ in N/mm² or Hardness HB | Cutting speed $v_c$ in m/min | Feed $f_t$ in mm: Milling cutter (except for end mill) | End mill $d$ in mm: 6 | 12 | 20 |
|---|---|---|---|---|---|---|
| Steels, low strength | $R_m \le 800$ | 200–400 | 0.05–0.15 | 0.06 | 0.08 | 0.10 |
| Steels, high strength | $R_m > 800$ | 150–300 | | | | |
| Stainless steels | $R_m \ge 800$ | 150–300 | | | | |
| Cast iron, malleable cast iron | ≤ 250 HB | 150–300 | | | | |
| Al alloys | $R_m \le 350$ | 400–800 | | | | |
| Cu alloys | $R_m \le 500$ | 200–400 | | | | |
| Thermoplastics | – | 500–1500 | 0.10–0.20 | 0.10 | 0.15 | 0.20 |
| Thermoset plastics | – | 400–1000 | | | | |

## Increasing the recommended feed per cutting edge $f_t$ for slotting with side milling cutters




| Feed per tooth | Cutting depth $a_e$, based on the milling cutter Ø $d$: 1/3 · $d$ | 1/6 · $d$ | 1/10 · $d$ | 1/20 · $d$ |
|---|---|---|---|---|
| increase | 1 · $f_t$ | 1.15 · $f_t$ | 1.45 · $f_t$ | 2 · $f_t$ |
| to be adjusted | 0.25 mm | 0.29 mm | 0.36 mm | 0.50 mm |

## Meanings of cutting data ranges

**Example:** Standard values for milling of low-strength steels using HSS milling cutters

| Upper values | Application | Lower values | Application |
|---|---|---|---|
| $v_c$ = 100 m/min | • finish machining (finishing)<br>• rigid tool and workpiece | $v_c$ = 50 m/min | • premachining (roughing)<br>• low rigidity of tool or workpiece |
| $f_t$ = 0.15 mm | • premachining (roughing)<br>• rigid tool and workpiece | $f_t$ = 0.05 mm | • finish machining (finishing)<br>• low rigidity of tool or workpiece |

## Calculation of feed rate

$v_f$ feed rate in mm/min
$f_t$ feed per tooth in mm
$n$ rotational speed of milling cutter in 1/min
$N$ number of teeth

**Example:**

$v_c$ = 100 m/min; $d$ = 40 mm; $f_t$ = 0.12 mm; $N$ = 10

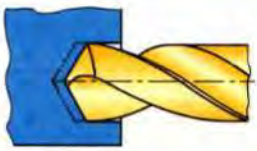
$$n = \frac{v_c}{\pi \cdot d} = \frac{100\ \text{m/min}}{\pi \cdot 0.04\ \text{m}} = 796\ \text{1/min};\quad v_f = n \cdot f_t \cdot N = 796/\text{min} \cdot 0.12\ \text{mm} \cdot 10 = \mathbf{955\ mm/min}$$

**Feed rate**

$$v_f = n \cdot f_t \cdot N$$

# Troubleshooting for drilling, turning and milling

## Drilling

| Drill point damaged | Wear on outside diameter | Hole too large | Chips stuck in flutes | Spalling of edges | Noncircular hole | Short tool life | Vibrations | Possible corrective measures |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | |  |
| • | • | • | | • | | | | Check cutting geometry |
| | | | • | | | • | | Increase supply of lubricant |
| | | ⇓ | ⇓ | | ⇓ | | ⇓ | Decrease feed $f$ |
| | | | ⇑ | ⇑ | | | | Increase cutting speed $v_c$ |
| • | • | | • | | | • | • | Decrease projection length |
| • | • | • | • | | | • | • | Check cutting parameters |
| • | • | | | • | | • | | Check type of carbide |

## Turning

| High wear clear. and rake surface | Deformation of cutting edge | Galling of cutting edge | Cracks perpendicular to the cutting edge | Spalling of the cutting edges | Fracture of indexable insert | Long spiral chips | Vibrations | |
|---|---|---|---|---|---|---|---|---|
| ⇓ | ⇓ | ⇑ | | ⇑ | | | ⇓ | Change cutting speed $v_c$ |
| | | | | | ⇓ | ⇑ | ⇑ | Change feed $f$ |
| | | | | | ⇓ | | ⇓ | Decrease cutting depth |
| • | • | | | | | | | Choose a more wear-resistant carbide type |
| | | | • | • | • | | | Choose tougher carbide type |
| • | | • | | • | | | • | Choose a positive cutting geometry |

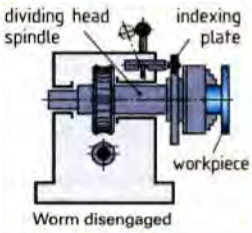
## Milling

| High wear clear. and rake surface | Deformation of cutting edge | Galling of cutting edge | Cracks perpendicular to the cutting edge | Spalling of the cutting edges | Fracture of indexable insert | Poor surface quality | Vibrations | |
|---|---|---|---|---|---|---|---|---|
| ⇓ | ⇓ | ⇑ | ⇓ | ⇑ | | | | Change cutting speed $v_c$ |
| ⇑ | | ⇑ | | ⇑ | ⇓ | ⇓ | ⇑ | Change feed $f_t$ |
| | • | | | | | • | | Choose a more wear-resistant carbide type |
| | | | • | • | • | | | Choose tougher carbide type |
| | | | | | | | • | Use milling cutter with wider spacing |
| | | | | | | • | • | Change milling cutter position |
| | | • | • | • | | | | Dry milling |

1) • problem to be solved ⇑ increase value of cutting parameter ⇓ decrease value of cutting parameter

# Indexing with a dividing head

## Direct indexing




In direct indexing the dividing head spindle, along with the indexing plate and workpiece, is turned by the desired indexing step. The worm is disengaged from the worm wheel.

$D$ no. of divisions $\alpha$ angular division
$n_h$ no. of holes in the indexing plate
$n_i$ indexing step; no. of hole spacings to be indexed

**Example:**

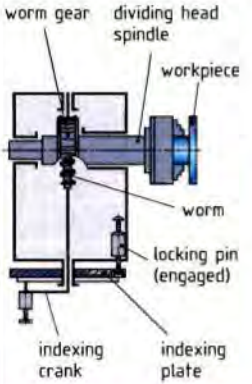
$n_h = 24;\ D = 8;\ n_i = ?$ $\quad n_i = \frac{n_h}{D} = \frac{24}{8} = \mathbf{3}$

**Indexing step**

$$n_i = \frac{n_h}{D}$$

$$n_i = \frac{\alpha \cdot n_h}{360°}$$

## Indirect indexing




In indirect indexing the dividing head spindle is driven by the worm and worm wheel.

$D$ no. of divisions $\alpha$ angular division
$i$ gear ratio of dividing head
$n_c$ indexing step; no. of indexing crank revolutions for one division

**Example 1:**

$D = 68;\ i = 40;\ n_c = ?$ $\quad n_c = \frac{i}{D} = \frac{40}{68} = \mathbf{\frac{10}{17}}$

**Example 2:**

$\alpha = 37.2°;\ i = 40;\ n_c = ?$

$$n_c = \frac{i \cdot \alpha}{360°} = \frac{40 \cdot 37.2°}{360°} = \frac{37.2}{9} = \frac{186}{9 \cdot 5} = \mathbf{4\frac{2}{15}}$$

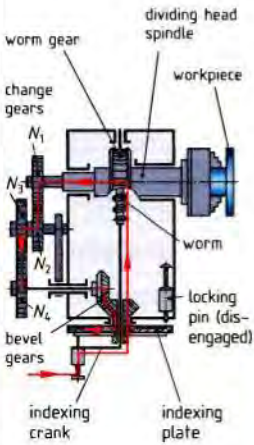
**Indexing step**

$$n_c = \frac{i}{D}$$

$$n_c = \frac{i \cdot \alpha}{360°}$$

| Circles of holes on indexing plates | | | | | |
|---|---|---|---|---|---|
| 15 | 16 | 17 | 18 | 19 | 20 |
| 21 | 23 | 27 | 29 | 31 | 33 |
| 37 | 39 | 41 | 43 | 47 | 49 |
| or | | | | | |
| 17 | 19 | 23 | 24 | 26 | 27 |
| 28 | 29 | 30 | 31 | 33 | 37 |
| 39 | 41 | 42 | 43 | 47 | 49 |
| 51 | 53 | 57 | 59 | 61 | 63 |

## Differential indexing




In differential indexing the dividing head spindle is driven with worm and worm wheel like indirect indexing. Simultaneously the dividing head spindle drives the indexing plate using change gears.

$D$ no. of divisions $\alpha$ angular division
$D'$ auxiliary no. of divisions
$i$ gear ratio of dividing head
$n_c$ indexing step; no. of indexing crank revolutions for one division
$N_{dg}$ no. of teeth of driving gears ($N_1$, $N_3$)
$N_{dn}$ no. of teeth of driven gears ($N_2$, $N_4$)

For selecting $D'$ the following applies:
$D' > D$: Indexing crank and indexing plate must rotate in the same direction.
$D' < D$: Indexing crank and indexing plate must rotate in opposite directions

If necessary the required direction of rotation is achieved by means of an idle gear.

**Example:**

$i = 40;\ D = 97;\ n_c = ?;\ \frac{N_{dg}}{N_{dn}} = ?;\ D'\text{ selected} = 100$

(Indexing crank and indexing plate must rotate in the same direction).

$$n_c = \frac{i}{D'} = \frac{40}{100} = \mathbf{\frac{8}{20}}$$

$$\frac{N_{dg}}{N_{dn}} = \frac{i}{D'} \cdot (D' - D) = \frac{40}{100} \cdot (100 - 97) = \frac{2}{5} \cdot 3 = \frac{6}{5} = \mathbf{\frac{48}{40}}$$

**Indexing step**

$$n_c = \frac{i}{D'}$$

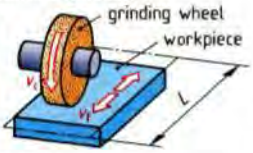
**No. of teeth on change gears**

$$\frac{N_{dg}}{N_{dn}} = \frac{i}{D'} \cdot (D' - D)$$

| No. of teeth on change gears | | | |
|---|---|---|---|
| 24 | 24 | 28 | 32 |
| 36 | 40 | 44 | 48 |
| 56 | 64 | 72 | 80 |
| 84 | 86 | 96 | 100 |

# Grinding

**Surface grinding**




**Cylindrical grinding**




$v_c$ cutting speed
$d_g$ diameter of grinding wheel
$n_g$ rotational speed of grinding wheel
$v_f$ feed rate
$L$ travel
$n_s$ no. of strokes
$d_1$ diameter of workpiece
$n$ workpiece rotational speed
$q$ speed ratio

**Cutting speed**

$$v_c = \pi \cdot d_g \cdot n_g$$

**Feed rate**

Surface grinding: $v_f = L \cdot n_s$

Cylindrical grinding: $v_f = \pi \cdot d_1 \cdot n$

**Example:**

$v_c = 30$ m/s; $v_f = 20$ m/min; $q = ?$

$$q = \frac{v_c}{v_f} = \frac{30 \text{ m/s} \cdot 60 \text{ s/min}}{20 \text{ m/min}} = \frac{1800 \text{ m/min}}{20 \text{ m/min}} = 90$$

**Speed ratio**

$$q = \frac{v_c}{v_f}$$

## Standard values for cutting speed $v_c$, feed rate $v_f$, speed ratio $q$

| Material | Surface grinding | | | | | | Cylindrical grinding | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Peripheral grinding | | | Side wheeling | | | External cyl. grinding | | | Internal cyl. grinding | | |
| | $v_c$ m/s | $v_f$ m/min | $q$ | $v_c$ m/s | $v_f$ m/min | $q$ | $v_c$ m/s | $v_f$ m/min | $q$ | $v_c$ m/s | $v_f$ m/min | $q$ |
| Steel | 30 | 10–35 | 80 | 25 | 6–25 | 50 | 35 | 10 | 125 | 25 | 19–23 | 80 |
| Cast iron | 30 | 10–35 | 65 | 25 | 6–30 | 40 | 25 | 11 | 100 | 25 | 23 | 65 |
| Carbide | 10 | 4 | 115 | 8 | 4 | 115 | 8 | 4 | 100 | 8 | 8 | 60 |
| Al alloys | 18 | 15–40 | 30 | 18 | 24–45 | 20 | 18 | 24–30 | 50 | 16 | 30–40 | 30 |
| Cu alloys | 25 | 15–40 | 50 | 18 | 20–45 | 30 | 30 | 16 | 80 | 25 | 25 | 50 |

## Grinding data for steel and cast iron with corundum or silicon carbide grinding wheels

| Processes | Grain size | Grinding allowance | Depth of cut in mm | Rz in µm |
|---|---|---|---|---|
| Rough grind | 30–46 | 0.5–0.2 | 0.02–0.1 | 3–10 |
| Finishing | 46–80 | 0.02–0.1 | 0.005–0.05 | 1–5 |
| Precision grinding | 80–120 | 0.005–0.02 | 0.002–0.008 | 1.6–3 |

## Maximum speed of grinding wheels

cf. DIN EN 12413 (2007-09)

| Shape of grinding wheel | Type of grinding machine | Guide[1] | Maximum speed $v_c$ in m/s for bond type[2] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | B | BF | E | M | R | RF | PL | V |
| Straight grinding wheel | stationary | pd or ho | 50 | 63 | 40 | 25 | 50 | – | 50 | 40 |
| | hand-held grinder | free-hand | 50 | 80 | – | – | 50 | 80 | 50 | – |
| Straight cutting wheel | stationary | pd or ho | 80 | 100 | 63 | – | 63 | 80 | – | – |
| | hand-held grinder | free-hand | – | 80 | – | – | – | – | – | – |

[1] pd positively driven: feed by mechanical means; ho hand operated: feed by operator; free-hand grinding: grinding machine is guided entirely by hand; [2] Type of bond, see page 309

## Restrictions for use of grinding tools[3]*

cf. BGV D12[4] (2001-10)

| VE | Meaning | VE | Meaning |
|---|---|---|---|
| VE1 | Not allowed for free-hand or hand operated grinding | VE6 | Not allowed for side wheeling |
| | | VE7 | Not allowed for free-hand grinding |
| VE2 | Not allowed for free-hand abrasive cutting | VE8 | Not allowed with backing pad |
| VE3 | Not allowed for wet grinding | VE10 | Not allowed for dry grinding |
| VE4 | Not allowed in enclosed work area | VE11 | Not allowed for free-hand or hand operated abrasive cutting |
| VE5 | Not allowed without vacuum exhaust | | |

[3] If no restriction is given, the grinding tool is suitable for all applications.

## Color stripes for maximum allowable peripheral speeds ≥ 50 m/s*

cf. BGV D12[4] (2001-10)

| Color stripe | blue | yellow | red | green | blue & yellow | blue & red | blue & green |
|---|---|---|---|---|---|---|---|
| $v_{c\,max}$ in m/s | 50 | 63 | 80 | 100 | 125 | 140 | 160 |
| **Color stripe** | **yellow & red** | **yell. & green** | **red & green** | **blue & blue** | **yellow & yell.** | **red & red** | **green & green** |
| $v_{c\,max}$ in m/s | 180 | 200 | 225 | 250 | 280 | 320 | 360 |

[4] BGV Berufsgenossenschaftliche Vorschrift (Employers' Liability Insurance Association Provisions)

*) According to European Standards

# Abrasives, Bonds

## Abrasives

cf. DIN ISO 525 (2000-08)

| Symbol | Abrasive | Chemical composition | Knoop-hardness | Areas of application |
|---|---|---|---|---|
| A | Norm. corundum | $Al_2O_3$ + additions | 18000 | Carb. steel, unhardened steel, cast steel, malleable cast iron |
| | white fused alumina | $Al_2O_3$ in crystalline form | 21000 | High and low alloyed steel, hardened steel, case hardened steel, tool steel, titanium |
| Z | zircon corundum | $Al_2O_3 + ZrO_2$ | – | Stainless steels |
| C | silicon carbide | SiC + additions | 24800 | Hard materials: carbide, cast iron, HSS, ceramic, glass; soft materials: copper, aluminum, plastics |
| BK | boron carbide | $B_4C$ in crystalline form | 47000 | Lapping, polishing of carbide and hardened steel |
| CBN | boron nitride | BN in crystalline form | 60000 | High-speed steels, cold and hot work steels |
| D | diamond | C in crystalline form | 70000 | Carbide, cast iron, glass, ceramic, stone, non-ferrous metals, not for steel; dressing of grinding wheels |

## Hardness grade

cf. DIN ISO 525 (2000-08)

| Designation | Hardn. grade | Application | Designation | Hardn. grade | Application |
|---|---|---|---|---|---|
| extremely soft<br>very soft | A B C D<br>E F G | Deep and side wheeling of hard materials | hard<br>very hard<br>extremely hard | P Q R S<br>T U V W<br>X Y Z | External cylindrical grinding; soft materials |
| soft<br>medium | H I J K<br>L M N O | Conventional metal grinding | | | |

## Grain size

cf. DIN ISO 525 (2000-08)

**Grain designation for bonded abrasives**

| Grain ranges | coarse | medium | fine | very fine |
|---|---|---|---|---|
| Grain designation | F4, F5, F6 to F24 | F30, F36, F46 to F60 | F70, F80, F90 to F220 | F230 to F1200 |
| Attainable *Rz* in µm | ≈ 10–5 | ≈ 5–2.5 | ≈ 2.5–1.0 | ≈ 1.0–0.4 |

## Structure

cf. DIN ISO 525 (2000-08)

Code **0 1 2 3 4 5 6 7 8 9 10 11 12 13 14, etc. up to 30**

Structure **dense (nonporous)** ⟵ ⟶ **open (porous)**

## Bond

cf. DIN ISO 525 (2000-008) and VDI 3411 (2000-08)

| Code | Type of bond | Properties | Areas of application |
|---|---|---|---|
| B<br>BF | synthetic resin bond,<br>fiber reinforced | Nonporous or porous, elastic, resistant to oil, cool grinding | Rough or cut-off grinding, form grinding with diam. and boron nitride, high pressure grinding |
| E | shellac bond | Sensitive to temperature, tough elastic, impact resistant | Saw tooth grinding, form grinding, control wheel for centerless grinding |
| G | galvanic bond | Tight grip due to protruding grains | Internal grinding of carbide, hand grinding |
| M | metal bond | Nonporous or porous, tough, insensitive to pressure and heat | Form and tool grinding using diamond or boron nitride, wet grinding |
| MG | magnesite bond | Soft, elastic, sensitive to water | Dry grinding, knife grinding |
| PL | plastic bond | Soft, elastic depending upon plastic and degree of hardening | Plastic abrasive material for finishing, precision finishing and polishing |
| R<br>RF | rubber bond,<br>fiber reinforced | Elastic, cold grinding, sensitive to oil and heat | Cut-off grinding |
| V | vitrified (ceramic) bond | Porous, brittle, insensitive to water, oil, heat | Rough and finish grinding of steels using corundum and silicon carbide |

⇒ **Grinding wheel ISO 603-1 1 N-300 x 50 x 76.2 – A/F 36 L 5 V – 50:** Form 1 (straight grinding wheel), wheel face N, outside diameter 300 mm, width 50 mm, hole diameter 76.2 mm, abrasive A (normal corundum or white fused alumina), grain size F36 (medium), hardness grade L (medium), structure 5 vitrified (ceramic) bond (V), maximum peripheral speed 50 m/s.

# Selecting grinding wheels

## Standard values for selecting grinding wheels (excluding diamond and boron nitride)

### Cylindrical grinding

| Material | Abrasive | Roughing | | Finishing with wheel diameter up to 500 mm | | Finishing with wheel diameter over 500 mm | | Fine finishing | |
|---|---|---|---|---|---|---|---|---|---|
| | | Grain size | Hardness | Grain size | Hardness | Grain size | Hardness | Grain size | Hardness |
| Steel, unhardened | A | 54 | M–N | 80 | M–N | 60 | L–M | 180 | L–M |
| Steel, hard., unalloy. and alloy. | A | 46 | L–M | 80 | K–L | 60 | J–K | 240–500 | H–N |
| Steel, hardened, high alloyed | A, C | 80 | M–N | 80 | N–O | 60 | M–N | 240–500 | H–N |
| Carbide, ceramic | C | 60 | K | 80 | K | 60 | K | 240–500 | H–N |
| Cast iron | A, C | 60 | L | 80 | L | 60 | L | 100 | M |
| Non-ferr. met., e.g. Al, Cu, CuZn | C | 46 | K | 60 | K | 60 | K | – | – |

### Internal cylindrical grinding

| Material | Abrasive | Grinding wheel diameter in mm: up to 20 | | from 20 to 40 | | from 40 to 80 | | over 80 | |
|---|---|---|---|---|---|---|---|---|---|
| | | Grain size | Hardness | Grain size | Hardness | Grain size | Hardness | Grain size | Hardness |
| Steel, unhardened | A | 80 | M | 60 | L–M | 54 | L–M | 46 | K |
| Steel, hard., unalloy. and alloy. | A | 80 | K–L | 120 | M–N | 80 | M–N | 80 | L |
| Steel, hardened, high alloyed | A, C | 80 | J–K | 100 | K | 80 | K | 60 | J |
| Carbide, ceramic | C | 80 | G | 120 | H | 120 | H | 80 | G |
| Cast iron | A | 80 | L–M | 80 | K–L | 60 | M | 46 | M |
| Non-ferr. met., e.g. Al, Cu, CuZn | C | 80 | I–J | 120 | K | 60 | J–K | 54 | J |

### Peripheral face grinding

| Material | Abrasive | Cup wheel $D < 300$ mm | | Straight grinding wheels $D \le 300$ mm | | Straight grinding wheels $D > 300$ mm | | Abrasive segments | |
|---|---|---|---|---|---|---|---|---|---|
| | | Grain size | Hardness | Grain size | Hardness | Grain size | Hardness | Grain size | Hardness |
| Steel, unhardened | A | 46 | J | 46 | J | 36 | J | 24 | J |
| Steel, hard., unalloy. and alloy. | A | 46 | J | 60 | J | 46 | J | 36 | J |
| Steel, hardened, high alloyed | A | 46 | H–J | 60 | I–J | 46 | I–J | 36 | I–J |
| Carbide, ceramic | C | 46 | J | 60 | J | 60 | J | 46 | J |
| Cast iron | A | 46 | J | 46 | J | 46 | J | 24 | J |
| Non-ferr. met., e.g. Al, Cu, CuZn | C | 46 | J | 60 | J | 60 | J | 36 | J |

### Tool grinding

| Cutting tool material | Abrasive | Straight grinding wheels $D \le 225$ | Straight grinding wheels $D > 225$ | | Dish wheels $D \le 100$ | Dish wheels $D > 100$ | | Cup wheels | |
|---|---|---|---|---|---|---|---|---|---|
| | | Grain size | Grain size | Hardness | Grain size | Grain size | Hardness | Grain size | Hardness |
| Tool steel | A | 80 | 60 | M | 80 | 60 | M | 46 | K |
| High-speed steel | A | 60 | 46 | K | 60 | 46 | K | 46 | H |
| Carbide | C | 80 | 54 | K | 80 | 54 | K | 46 | H |

### Cutting on stationary machines

| Material | Abrasive | Straight cut-off wheels $v_c$ up to 80 m/s: $D \le 200$ mm | | $D > 200$ mm | | Straight cut-off wheels $v_c$ up to 100 m/s: $D \le 500$ mm | | $D > 500$ mm | |
|---|---|---|---|---|---|---|---|---|---|
| | | Grain size | Hardness | Grain size | Hardness | Grain size | Hardness | Grain size | Hardness |
| Steel, unhardened | A | 80 | Q–R | 46 | Q–R | 24 | U | 20 | Q–R |
| Cast iron | A | 60 | Q–R | 46 | Q–R | 24 | U–V | 20 | U–V |
| Non-ferr. met., e.g. Al, Cu, CuZn | A | 60 | Q–R | 46 | Q–R | 30 | S | 24 | S |

### Grinding and cutting with hand tools

| Material | Abrasive | Cut-off wheels $v_c$ up to 80 m/s | | Rough grinding wheels $v_c$ up to 45 m/s | | Rough grinding wheels $v_c$ up to 80 m/s | | Mounted points | |
|---|---|---|---|---|---|---|---|---|---|
| | | Grain size | Hardness | Grain size | Hardness | Grain size | Hardness | Grain size | Hardness |
| Steel, unhardened | A | 30 | T | 24 | M | 24 | R | 36 | Q–R |
| Steel, corrosion resistant | A | 30 | R | 16 | M | 24 | R | 36 | S |
| Cast iron | A, C | 30 | T | 20 | R | 24 | R | 30 | T |
| Non-ferr. met., e.g. Al, Cu, CuZn | A, C | 30 | R | 20 | R | – | – | – | – |

# Grinding with diamond and boron nitride

## Grain designation ranges

cf. DIN ISO 848 (1998-03)

| Areas of application | Rough grind | Finishing | Precision grinding | Lapping |
|---|---|---|---|---|
| Grain designation[1] diamond | D251–D151 | D126–D76 | D64, D54, D46 | D20, D15, D7 |
| Grain designation[1] boron nitride | B251–B151 | B126–B76 | B64, B54, B46 | B30, B6 |
| Attainable *Ra* in µm | ≈ 0.55–0.50 | ≈ 0.45–0.33 | ≈ 0.18–0.15 | ≈ 0.05–0.025 |

[1] Mesh size of test sieve in µm

## Standard values for cutting speeds

| Process | Abrasive | Cutting speed $v_c$ in m/s by bond type[1] B dry | B wet | M dry | M wet | G dry | G wet | V dry | V wet |
|---|---|---|---|---|---|---|---|---|---|
| Surface grinding | CBN | – | 30–50 | – | 30–60 | – | 30–60 | – | 30–60 |
| | D | – | 22–50 | – | 22–27 | 20–30 | 22–50 | – | 25–50 |
| External cylindrical grinding[2] | CBN | – | 30–50 | – | 30–60 | – | 30–60 | – | 30–60 |
| | D | – | 22–40 | – | 20–30 | 20–30 | 22–40 | – | 25–50 |
| Internal cylindrical grinding | CBN | 27–35 | 30–60 | – | 30–60 | 24–40 | 30–50 | – | 30–50 |
| | D | 12–18 | 15–30 | 8–15 | 18–27 | 12–20 | 18–40 | – | 25–50 |
| Tool grinding | CBN | 27–35 | 30–50 | 22–30 | 30–40 | 27–35 | 30–50 | – | 30–50 |
| | D | 15–22 | 22–50 | 15–22 | 15–27 | 15–30 | 22–35 | – | – |
| Cut-off grinding | CBN | 27–35 | 30–50 | – | 30–60 | 27–40 | 30–60 | – | – |
| | D | 12–18 | 22–35 | – | 22–27 | 18–30 | 22–40 | – | – |

[1] Bond types, see page 309 [2] Approx. four times the value for high speed grinding (HSG)

## Standard values for depth of cut and feed of diamond grinding wheels

| Process | Depth per stroke in mm for grain size D181 | D126 | D64 | Feed m/min | Crossfeed relative to wheel width *w* |
|---|---|---|---|---|---|
| Face grinding[1] | 0.02–0.04 | 0.01–0.02 | 0.005–0.01 | 10–15 | $^1/_4 - {}^1/_2 \cdot w$ |
| External cyl. grinding[1] | 0.01–0.03 | 0.0–0.02 | 0.005–0.01 | 0.3– 2.0 | – |
| Internal cyl. grinding | 0.002–0.007 | 0.002–0.005 | 0.001–0.003 | 0.5– 2.0 | – |
| Tool grinding | 0.01–0.03 | 0.005–0.015 | 0.002–0.005 | 0.3– 4.0 | – |
| Groove grinding | – | 1.0–5.0 | 0.5–3.0 | 0.01– 2.0 | – |

[1] Approx. three times the value for high speed grinding (HSG)

## Standard values for depth of cut and feed of CBN grinding wheels

| Process | Depth per stroke in mm for grain size B252/B181 | B151/B126 | B91/B76 | Feed m/min | Crossfeed relative to wheel width *w* |
|---|---|---|---|---|---|
| Surface grinding | 0.03–0.05 | 0.02–0.04 | 0.01–0.015 | 20–30 | $^1/_4 - {}^1/_3 \cdot w$ |
| External cyl. grinding | 0.02–0.04 | 0.02–0.03 | 0.015–0.02 | 0.5–2.0 | – |
| Internal cyl. grinding | 0.005–0.015 | 0.005–0.01 | 0.002–0.005 | 0.5–2.0 | – |
| Tool grinding | 0.002–0.1 | 0.01–0.005 | 0.005–0.015 | 0.5–4.0 | – |
| Groove grinding | 1.0–10 | 1.0–5.0 | 0.5–3.0 | 0.01–2.0 | – |

## High-performance grinding with CBN grinding wheels

cf. VDI 3411 (2000-08)

Grinding processes achieving extremely high material removal rates by utilization of special machines and tools with increased cutting speeds (> 80 m/s) and appropriate machine coolant. Predominantly used for side and external cylindrical grinding of metallic materials.

**Grinding wheel preparation (conditioning)**

| Processing step | Dressing: Truing | Dressing: Sharpening | Cleaning |
|---|---|---|---|
| Action | Removal of grain and bond | Reduction of the bond | No effect on abrasive layer |
| Goal | Establishing concentricity and wheel profile | Creating the grinding wheel surface structure | Remove chips from pores |

**Maximum allowable peripheral speeds in high-performance grinding**

| Bond type[1] | B | V | M | G |
|---|---|---|---|---|
| Highest allowable peripheral speed in m/s | 140 | 200 | 180 | 280 |

[1] Bond types, see page 309

# Honing




$v_c$ cutting speed
$v_a$ axial speed
$v_p$ peripheral speed
$\alpha$ angle of intersection betw. abrading tracks
$p$ contact pressure
$A$ contact area of honing stone
$F_r$ radial infeed force
$n$ number of honing stones
$w$ width of honing stones
$l$ length of honing stones

**Example:**

Hardened steel, finish honing, $v_p$ = ?; $v_a$ = ?; $v_c$ = ?; $\alpha$ = ?
read from table: $v_p$ = 25 m/min; $v_a$ = 12 m/min

$$v_c = \sqrt{{v_a}^2 + {v_p}^2} = \sqrt{\left(12\frac{m}{min}\right)^2 + \left(25\frac{m}{min}\right)^2} \approx 28\frac{m}{min}$$

$$\tan\frac{\alpha}{2} = \frac{v_a}{v_p} = \frac{12\ m/min}{25\ m/min} = 0.48;\quad \alpha = \mathbf{51.3°}$$

**Cutting speed**

$$v_c = \sqrt{{v_a}^2 + {v_p}^2}$$

**Angle of intersection**

$$\tan\frac{\alpha}{2} = \frac{v_a}{v_p}$$

**Contact pressure**

$$p = \frac{F_r}{A}$$

$$p = \frac{F_r}{n \cdot w \cdot l}$$

**Cutting speed and machining allowances**

| Material | Peripheral speed $v_p$ in m/min | | Axial speed $v_a$ in m/min | | Machining allowances in mm for hole diameter in mm | | |
|---|---|---|---|---|---|---|---|
| | Rough honing | Finish honing | Rough honing | Finish honing | 2–15 | 15–100 | 100–500 |
| Steel, unhardened | 18–40 | 20–40 | 9–20 | 10–20 | 0.02–0.05 | 0.03–0.15 | 0.06–0.3 |
| Steel, hardened | 14–40 | 15–40 | 5–20 | 6–20 | 0.01–0.03 | 0.02–0.05 | 0.03–0.1 |
| Alloy steels | 23–40 | 25–40 | 10–20 | 11–20 | 0.02–0.05 | 0.03–0.15 | 0.06–0.3 |
| Cast iron | 23–40 | 25–40 | 10–20 | 11–20 | | | |
| Aluminum alloys | 22–40 | 24–40 | 9–20 | 10–20 | | | |

Honing with diamond grit $v_p$ up to 40 m/min and $v_a$ up to 60 m/min; $\alpha$ = 60°– 90°

**Contact pressure of honing tools**

| Honing process | Contact pressure $p$ in N/cm² | | | |
|---|---|---|---|---|
| | Ceramic honing stone | Plastic bonded honing stone | Diamond honing stick | Boron nitride honing stick |
| Rough honing | 50–250 | 200–400 | 300–700 | 200–400 |
| Finish honing | 20–100 | 40–250 | 100–300 | 100–200 |

**Selection of corundum, silicon carbide, CBN and diamond honing stones**

| Material | Tensile strength N/mm² | Process | Roughness depth $Rz$ µm | Honing stone made of corundum and silicon carbide[2] | | | | | CBN or diamond |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Honing abrasive | Grain size | Hardness | Bond | Structure | Grain size |
| Steel | < 500 (unhardened) | rough honing | 8–12 | A | 700 | R | | 1 | D126 |
| | | intermed. honing | 2–5 | | 400 | R | B | 5 | D54 |
| | | finish honing | 0.5–1.5 | | 1200 | M | | 2 | D15 |
| | 500–700 (hardened) | rough honing | 5–10 | A | 80 | R | | 3 | B76 |
| | | intermed. honing | 2–3 | | 400 | O | B | 5 | B54 |
| | | finish honing | 0.5–2 | | 700 | N | | 3 | B30 |
| Cast iron | – | rough honing | 5–8 | C | 80 | M | | 3 | D91 |
| | | finish honing | 2–3 | | 120 | K | V | 7 | D46 |
| | | plateau honing[1] | 3–6 | | 900 | H | | 8 | D25 |
| Non-ferrous metals | – | rough honing | 6–10 | A | 80 | O | | 3 | D64 |
| | | intermed. honing | 2–3 | A | 400 | O | V | 1 | D35 |
| | | finish honing | 0.5–1 | C | 1000 | N | | 5 | D15 |

[1] In plateau honing the peaks of the material surface are removed.

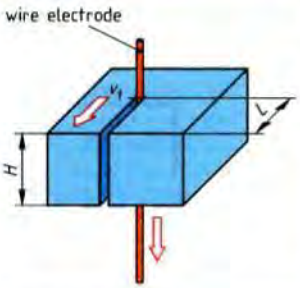
[2] see page 309

**Selection of honing stone made of diamond and cubic boron nitride (CBN)**

| Abrasive | Natural diamond | Synthetic diamond | CBN |
|---|---|---|---|
| Material | Steel, carbide | Cast iron, nitrided steel, non-ferrous metals, glass, ceramic | Hardened steel |

# Productive time and standard values for material removal

## Electric discharge machining (wire EDM)




$t_p$ productive time in min
$v_f$ feed rate in mm/min
$L$ travel, cutting length in mm
$H$ cutting height in mm
$T$ geometric tolerance in µm

**Productive time**

$$t_p = \frac{L}{v_f}$$

**Example:**

Material: Steel, $H$ = 30 mm; $L$ = 320 mm; $T$ = 30 µm; $v_f$ = ?; $t_p$ = ?

**$v_f$ = 1.8 mm/min** (from table)

$$t_p = \frac{L}{v_f} = \frac{320\ \text{mm}}{1.8\ \text{mm/min}} = \mathbf{178\ min}$$

### Feed rate $v_f$ (standard values)[1]

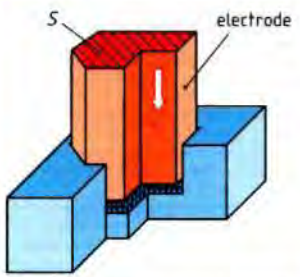
| Cutting height $H$ in mm | Feed rate $v_f$ in mm/min | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Steel eroding | | | | | Copper eroding | | | Carbide eroding | | |
| | Desired geometric tolerance $T$ in µm | | | | | | | | | | |
| | 60 | 40 | 30 | 20 | 10 | 40 | 20 | 10 | 80 | 20 | 10 |
| 10 | 9.0 | 8.5 | 4.0 | 3.9 | 2.1 | 7.5 | 3.5 | 2.0 | 4.5 | 0.7 | 0.6 |
| 20 | 5.1 | 5.5 | 2.5 | 2.5 | 1.5 | 4.7 | 2.4 | 1.5 | 3.1 | 0.3 | 0.3 |
| 30 | 3.7 | 4.0 | 1.8 | 1.8 | 1.1 | 4.0 | 1.9 | 1.1 | 2.3 | 0.2 | 0.2 |
| 50 | 2.5 | 2.5 | 1.2 | 1.2 | 0.8 | 2.6 | 1.4 | 0.7 | 1.4 | 0.2 | 0.2 |

[1] These standard values are average values from the main cut and all subsequent cuts required to reach geometric tolerance. With unfavorable flushing conditions the achievable feed rate drops considerably.

### Characteristics and application of common wire electrodes

| Wire material | El. conductivity in m/(Ω · mm²) | Tensile strength in N/mm² | Typical wire diameter in mm | Application |
|---|---|---|---|---|
| CuZn alloy | 13.5 | 400–900 | 0.2–0.33 | Universal |
| Molybdenum | 18.5 | 1900 | 0.025–0.125 | Cuts with very tight geometric tolerance |
| Tungsten | 18.2 | 2500 | 0.025–0.125 | Narrow slots, small corner radii |

## Electric discharge machining (sink EDM)




$t_p$ productive time in min
$S$ removal area of electrode in mm²
$V$ removal volume in mm³
$V_W$ removal rate in mm³/min

**Productive time**

$$t_p = \frac{V}{V_W}$$

**Example:**

Roughing of steel; graphite electrode, $S$ = 150 mm²; $V$ = 3060 mm³; $V_w$ = ?; $t_p$ = ?

**$V_W$ = 31 mm³/min** (from table)

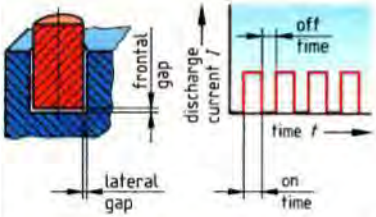
$$t_p = \frac{V}{V_W} = \frac{3060\ \text{mm}^3}{31\ \text{mm}^3/\text{min}} = \mathbf{99\ min}$$

### Removal rate $V_W$ (standard values)[1]

| Work-piece material | Electrode | Removal rate $V_w$ in mm³/min | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Roughing removal area $S$ in mm² | | | | | | Finishing desired roughness depth $Rz$ in µm | | | | |
| | | 10 to 50 | 50 to 100 | 100 to 200 | 200 to 300 | 300 to 400 | 400 to 600 | 2 to 3 | 3 to 4 | 4 to 6 | 6 to 8 | 8 to 10 |
| Steel | Graphite | 7.0 | 18 | 31 | 62 | 81 | 105 | – | – | – | 2 | 5 |
| | Copper | 13.3 | 22 | 28 | 51 | 85 | 105 | 0.1 | 0.5 | 1.9 | 3.8 | 5 |
| Carbide | Copper | 6.0 | 15 | 18 | 28 | 30 | 33 | – | 0.1 | 0.5 | 2.2 | 5.2 |

[1] Actual values will vary widely due to the effects of different processing methods. Refer to page 314.

# Process parameters in EDM erosion




$V_W$ removal rate in mm³/min
$V$ removal volume in mm³
$t$ removal time in min
$V_E$ absolute tool wear in mm³
$V_{rel}$ relative tool wear in %

**Removal rate**

$$V_W = \frac{V}{t}$$

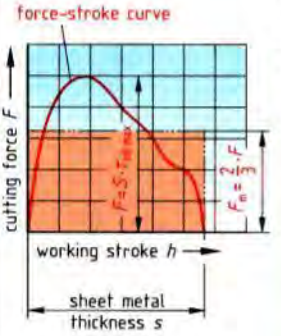
**Relative tool wear**

$$V_{rel} = \frac{V_E}{V} \cdot 100\%$$

| Parameter | | Explanations, characteristics and applications |
|---|---|---|
| **Electrode Material** | **Electrolytic copper** | Universal application; low wear behavior; high removal rate; for finish and rough machining; difficult to manufacture electrode by machining; high thermal expansion; no cracked edges; tendency to warp |
| | **Graphite** in various grain sizes | Universal application; very low wear; greater current density than Cu; low electrode weight; easy to manufacture electrode by machining; non-warping; low thermal expansion; more detailed electrodes are made by selecting a finer graphite grain; unsuitable for carbide machining |
| | **Tungsten-copper** | Detailed electrodes; very low wear; very high material removal rate with relatively low discharge currents even with large current densities; only manufactured in limited sizes, high electrode weight |
| | **Copper-graphite** | Special applications involving small electrode dimensions with simultaneous high electrode strength; wear and material removal rate play a subordinate role in these special applications |
| **Dielectric fluid** | **Synthetic oils**, filtered and cooled; according to machine manufacturer | Requirements for dielectric fluids:<br>• low and constant conductivity for stable sparking<br>• low viscosity for filtrability and penetrating ability in narrow gaps<br>• low evaporation to reduce hazardous vapors<br>• high flash point to avoid fire hazard<br>• high heat conductance value for good cooling<br>• extremely low health hazard for operators |
| **Flushing** | **Replacement of dielectric fluid** at the erosion site<br>**Remove eroded particles** from gap | Depending on requirements and available options, different flushing methods can be used to maintain stable erosion performance:<br>• flooding (most commonly used method, simultaneous heat rejection)<br>• pressure flushing through hollow electrodes or next to electrode<br>• vacuum flushing through hollow electrode or next to electrode<br>• interval flushing caused by retracting electrode<br>• movement flushing by relative movement between workpiece and electrode, without interrupting erosion cycle |
| **Polarity** | **positive** | Electrode is positively polarized; for low electrode burn rate during roughing with long pulse duration and low frequency |
| | **negative** | Electrode is negatively polarized; for erosion with short pulse duration and high frequency |
| **Gap** | **face** | Kept constant during feed (controlled by discharge voltage).<br>Control sensitivity set too high: Electrode continually pulses on and off, controlled discharge impossible.<br>Control sensitivity set too low: Abnormal discharges increase or gap remains too large for discharge. |
| | **side** | Determined primarily by duration and size of discharge pulse, depends on material matching and no-load voltage |
| **Discharge current** | **low** | Low removal performance, low tool wear on copper electrodes, high wear on graphite electrodes |
| | **high** | High removal performance, high tool wear on copper electrodes, low wear on graphite electrodes |
| **Pulse duration** | **short** | Electrode wear with positive polarity is larger, lower removal rate |
| | **long** | Electrode wear with positive polarity is smaller, higher removal rate |

# Cutting force, Operating conditions for presses

## Cutting force, cutting work




| | |
|---|---|
| $F$ | cutting force |
| $F_m$ | calculated cutting force |
| $S$ | shear area |
| $R_{m\,max}$ | maximum tensile strength |
| $\tau_{sB\,max}$ | maximum shear strength |
| $W$ | cutting work |
| $s$ | sheet metal thickness |

**Example:**

$S = 236\ mm^2$; $s = 2.5\ mm$; $R_{m\,max} = 510\ N/mm^2$

**Wanted:** $\tau_{sB\,max}$; $F$; $W$

**Solution:** $\tau_{sB\,max} = 0.8 \cdot R_{m\,max}$
$= 0.8 \cdot 510\ N/mm^2 = \mathbf{408\ N/mm^2}$

$F = S \cdot \tau_{sB\,max} = 236\ mm^2 \cdot 408\ N/mm^2$
$= 96\,288\ N = \mathbf{96.288\ kN}$

$W = \frac{2}{3} \cdot F \cdot s = \frac{2}{3} \cdot 96.288\ kN \cdot 2.5\ mm$
$\approx 160\ kN \cdot mm = \mathbf{160\ N \cdot m}$

**Cutting force**

$$F = S \cdot \tau_{sB\,max}$$

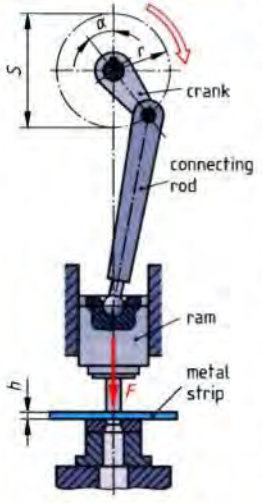
**Max. shear strength**

$$\tau_{sB\,max} \approx 0.8 \cdot R_{m\,max}$$

**Cutting work**

$$W = \frac{2}{3} \cdot F \cdot s$$

## Operating conditions for eccentric and crank presses




Press drives are usually designed such that the nominal pressing force is applied at crank angle $\alpha = 30°$.

Machines operate without interruption in continuous mode or can be stopped after each cycle in single-stroke mode. For presses with adjustable strokes, the allowable pressing force is less than the nominal pressing force.

| | |
|---|---|
| $F$ | cutting force, shaping force |
| $F_n$ | nominal pressing force |
| $F_{allow}$ | allow. pressing force for adjustable stroke |
| $S$ | stroke, maximum stroke for adjustable stroke |
| $S_a$ | adjusted stroke |
| $h$ | working distance (≙ sheet metal thickness $s$) |
| $\alpha$ | crank angle |
| $W$ | cutting work, shaping work |
| $W_c$ | work capacity in continuous mode |
| $W_s$ | work capacity in single-stroke mode |

**Work capacity in continuous mode**

$$W_c = \frac{F_n \cdot S}{15}$$

**Work capacity in single-stroke mode**

$$W_s = 2 \cdot W_c$$

| Operating conditions | |
|---|---|
| Fixed stroke | |
| $F \le F_n$<br>$W \le W_c$ or<br>$W \le W_s$ | |
| Adjustable stroke | |
| $F \le F_{allow}$<br>$F_{allow} = \frac{F_n \cdot S}{4 \cdot \sqrt{S_a \cdot h - h^2}}$<br>$W \le W_c$ or<br>$W \le W_s$ | |

**Example:**

Eccentric press with fixed stroke $F_n = 250\ kN$; $S = 30\ mm$; $F = 207\ kN$; $s = 4\ mm$

**Find:** $W$; $W_c$. Can the press be put into continuous mode?

**Solution:** $W = \frac{2}{3} \cdot F \cdot s = \frac{2}{3} \cdot 207\ kN \cdot 4\ mm = 552\ kN \cdot mm = \mathbf{552\ N \cdot m}$

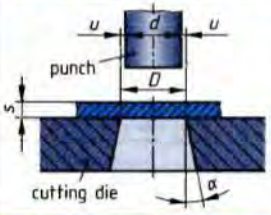
$W_c = \frac{F_n \cdot S}{15} = \frac{250\ kN \cdot 30\ mm}{15} = 500\ kN \cdot mm = \mathbf{500\ N \cdot m}$

If $F < F_n$, but $W > W_c$, the press cannot be used in continuous mode for this workpiece.

# Tool and workpiece dimensions

## Punch and cutting die dimensions

cf. VDI 3368 (1982-05)



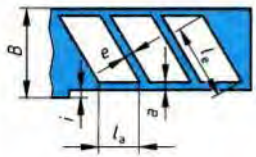

- $d$ punch dimension
- $D$ cutting die dimension
- $u$ die clearance
- $s$ sheet metal thickness
- $\alpha$ clearance angle

| Process | Piercing | Blanking |
|---|---|---|
| Shape of workpiece |  |  |
| Governing specified size is: | dimension of punch $d$ | dimension of cutting die $D$ |
| Dimension of opposite tool | cutting die $D = d + 2 \cdot u$ | punch $d = D - 2 \cdot u$ |

## Die clearance $u$ as a function of material and sheet metal thickness

| sheet metal thickness $s$ mm | Cutting die opening with clearance angle $\alpha$ | | | | Cutting die opening without clearance angle $\alpha$ | | | |
|---|---|---|---|---|---|---|---|---|
| | shear strength $\tau_{sB}$ in N/mm² | | | | shear strength $\tau_{sB}$ in N/mm² | | | |
| | up to 250 | 251–400 | 401–600 | over 600 | up to 250 | 251–400 | 401–600 | over 600 |
| | die clearance $u$ in mm | | | | die clearance $u$ in mm | | | |
| 0.4–0.6 | 0.01 | 0.015 | 0.02 | 0.025 | 0.015 | 0.02 | 0.025 | 0.03 |
| 0.7–0.8 | 0.015 | 0.02 | 0.03 | 0.04 | 0.025 | 0.03 | 0.04 | 0.05 |
| 0.9–1 | 0.02 | 0.03 | 0.04 | 0.05 | 0.03 | 0.04 | 0.05 | 0.05 |
| 1.5–2 | 0.03 | 0.05 | 0.06 | 0.08 | 0.05 | 0.07 | 0.09 | 0.11 |
| 2.5–3 | 0.04 | 0.07 | 0.10 | 0.12 | 0.08 | 0.11 | 0.14 | 0.17 |
| 3.5–4 | 0.06 | 0.09 | 0.12 | 0.16 | 0.11 | 0.15 | 0.19 | 0.23 |

## Web width, edge width, trim stop waste for metallic materials




Polygonal workpieces

- $a$ edge width
- $e$ web width
- $l_a$ edge length
- $l_e$ web length
- $B$ strip width
- $i$ trim stop waste (french stop waste)

**Polygonal workpieces:**

The web or edge length, whichever is larger, is used to determine web and edge widths.

**Round workpieces:**

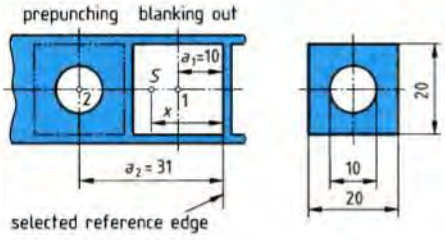
For all diameters values given for $l_e = l_a =$ 10 mm of polygonal workpieces apply to web and edge widths.

| Strip width $B$ mm | Web length $l_e$ Edge length $l_a$ mm | Web width $e$ Edge width $a$ | Sheet metal thickness $s$ in mm | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 0.1 | 0.3 | 0.5 | 0.75 | 1.0 | 1.25 | 1.5 | 1.75 | 2.0 | 2.5 | 3.0 |
| up to 100 mm | up to 10 | $e$ | 0.8 | 0.8 | 0.8 | 0.9 | 1.0 | 1.2 | 1.3 | 1.5 | 1.6 | 1.9 | 2.1 |
| | | $a$ | 1.0 | 0.9 | 0.9 | | | | | | | | |
| | 11–50 | $e$ | 1.6 | 1.2 | 0.9 | 1.0 | 1.1 | 1.4 | 1.4 | 1.6 | 1.7 | 2.0 | 2.3 |
| | | $a$ | 1.9 | 1.5 | 1.0 | | | | | | | | |
| | 51–100 | $e$ | 1.8 | 1.4 | 1.0 | 1.2 | 1.3 | 1.6 | 1.6 | 1.8 | 1.9 | 2.2 | 2.5 |
| | | $a$ | 2.2 | 1.7 | 1.2 | | | | | | | | |
| | over 100 | $e$ | 2.0 | 1.6 | 1.2 | 1.4 | 1.5 | 1.8 | 1.8 | 2.0 | 2.1 | 2.4 | 2.7 |
| | | $a$ | 2.4 | 1.9 | 1.5 | | | | | | | | |
| | trim stop waste $i$ | | 1.5 | | | | | 1.8 | 2.2 | 2.5 | 3.0 | 3.5 | 4.5 |
| over 100 mm to 200 mm | up to 10 | $e$ | 0.9 | 1.0 | 1.0 | 1.0 | 1.1 | 1.3 | 1.4 | 1.6 | 1.7 | 2.0 | 2.3 |
| | | $a$ | 1.2 | 1.1 | 1.1 | | | | | | | | |
| | 11–50 | $e$ | 1.8 | 1.4 | 1.0 | 1.2 | 1.3 | 1.6 | 1.6 | 1.8 | 1.9 | 2.2 | 2.5 |
| | | $a$ | 2.2 | 1.7 | 1.2 | | | | | | | | |
| | 51–100 | $e$ | 2.0 | 1.6 | 1.2 | 1.4 | 1.5 | 1.8 | 1.8 | 2.0 | 2.1 | 2.4 | 2.7 |
| | | $a$ | 2.4 | 1.9 | 1.5 | | | | | | | | |
| | 101–200 | $e$ | 2.2 | 1.8 | 1.4 | 1.6 | 1.7 | 2.0 | 2.0 | 2.2 | 2.3 | 2.6 | 2.9 |
| | | $a$ | 2.7 | 2.2 | 1.7 | | | | | | | | |
| | trim stop waste $i$ | | 1.5 | | | | | 1.8 | 2.0 | 2.5 | 3.0 | 3.5 | 4.0 | 5.0 |

# Location of punch holder shank, Utilization of strip stock

## Location of punch holder shank for punch geometry with known center of gravity

**Punch layout** **Workpiece**




$C_1$, $C_2$, $C_3$ ... circumferences of individual punches

$a_1$, $a_2$, $a_3$ ... distances from punch centers of gravity to selected reference edge

$x$ distance of center of forces $S$ from chosen reference edge

**Distance of the center of forces**

$$x = \frac{C_1 \cdot a_1 + C_2 \cdot a_2 + C_3 \cdot a_3 + \ldots}{C_1 + C_2 + C_3 + \ldots}$$

**Example:**

Based on the figure at left, calculate the distance $x$ of center of forces $S$.

**Solution:**

The outer perimeter of the cutting punch is chosen as reference edge.

Blanking punch: $C_1 = 4 \cdot 20$ mm = 80 mm; $a_1 = 10$ mm

Piercing punch: $C_2 = \pi \cdot 10$ mm = 31.4 mm; $a_2 = 31$ mm

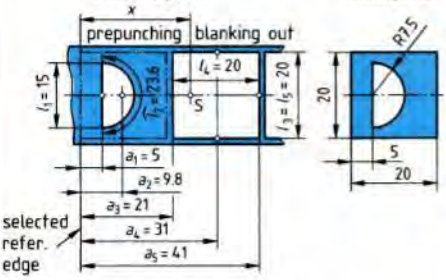
$$x = \frac{C_1 \cdot a_1 + C_2 \cdot a_2}{C_1 + C_2}$$

$$x = \frac{80\text{ mm} \cdot 10\text{ mm} + 31.4\text{ mm} \cdot 31\text{ mm}}{80\text{ mm} + 31.4\text{ mm}} \approx \mathbf{16\text{ mm}}$$

## Location of punch holder shank for punch geometry with unknown center of gravity

Center of forces corresponds to centroid of the line[1] of all cutting edges.

**Punch layout** **Workpiece**




$l_1$, $l_2$, $l_3$ to $l_n$ cutting edge lengths

$a_1$, $a_2$, $a_3$ to $a_n$ distance from line centroids to selected reference edges

$x$ distance from center of forces to selected reference edge

$n$ number of individual cutting edge

[1] For line centroids, see page 32

**Distance of the center of forces**

$$x = \frac{l_1 \cdot a_1 + l_2 \cdot a_2 + l_3 \cdot a_3 + \ldots}{l_1 + l_2 + l_3 + \ldots}$$

$$x = \frac{\Sigma l_n \cdot a_n}{\Sigma l_n}$$

**Example:**

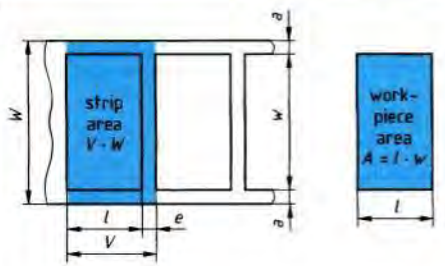
Calculate the location of the punch holder shank on the progressive die for the workpiece shown in the figure at the left.

**Solution:**

| $n$ | $l_n$ in mm | $a_n$ in mm | $l_n \cdot a_n$ in mm² |
|---|---|---|---|
| 1 | 15 | 5 | 75 |
| 2 | 23.6 | 9.8 | 231.28 |
| 3 | 20 | 21 | 420 |
| 4 | 2 · 20 | 31 | 1240 |
| 5 | 20 | 41 | 820 |
| Σ | 118.6 | – | 2786.28 |

$$x = \frac{\Sigma l_n \cdot a_n}{\Sigma l_n} = \frac{2786.28\text{ mm}^2}{118.6\text{ mm}} = \mathbf{23.5\text{ mm}}$$

## Utilization of strip stock for single row stamping




$l$ workpiece length

$w$ workpiece width

$W$ strip width

$a$ edge width

$e$ web width

$V$ strip feed

$A$ area of workpiece (including holes)

$R$ number of rows

$\eta$ degree of utilization

**Strip width**

$$W = w + 2 \cdot a$$

**Strip feed**

$$V = l + e$$

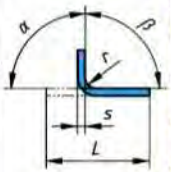
**Utilization factor**

$$\eta = \frac{R \cdot A}{V \cdot W}$$

# Bending radius, Bend allowances, Calculation of blank size

## Smallest allowable bending radius for bent parts of non-ferrous metals

cf. DIN 5520 (2002-07)




| Material | Material condition | Thickness $s$ in mm | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 0.8 | 1 | 1.5 | 2 | 3 | 4 | 5 | 6 |
| | | Smallest allowable bending radius $r$[1] in mm | | | | | | | |
| AlMg3-01 | spheroidized | 0.6 | 1 | 2 | 3 | 4 | 6 | 8 | 10 |
| AlMg3-H14 | cold work hardened | 1.6 | 2.5 | 4 | 6 | 10 | 14 | 18 | – |
| AlMg3-H111 | cold work hardened and annealed | 1 | 1.5 | 3 | 4.5 | 6 | 8 | 10 | – |
| AlMg4.5Mn-H112 | spheroidized straightened | 1 | 1.5 | 2.5 | 4 | 6 | 8 | 10 | 14 |
| AlMg4.5Mn-H111 | cold work hardened and annealed | 1.6 | 2.5 | 4 | 6 | 10 | 16 | 20 | 25 |
| AlMgSi1-T6 | solution annealed and artificially aged | 4 | 5 | 8 | 12 | 16 | 23 | 28 | 36 |
| CuZn37-R600 | hard | 2.5 | 4 | 5 | 8 | 10 | 12 | 18 | 24 |

[1] For bending angle $\alpha = 90°$, regardless of rolling direction

## Smallest allowable bending radius for cold bending steel

cf. DIN 6935 (1975-10)

| Minimum tensile strength $R_m$ in N/mm² over–to | Minimum bending radius[1] $r$ for sheet metal thickness $s$ in mm | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 1.5 | 2.5 | 3 | 4 | 5 | 6 | 7 | 8 | 10 | 12 | 14 | 16 | 18 | 20 |
| up to 390 | 1 | 1.6 | 2.5 | 3 | 5 | 6 | 8 | 10 | 12 | 16 | 20 | 25 | 28 | 36 | 40 |
| 390–490 | 1.2 | 2 | 3 | 4 | 5 | 8 | 10 | 12 | 16 | 20 | 25 | 28 | 32 | 40 | 45 |
| 490–640 | 1.6 | 2.5 | 4 | 5 | 6 | 8 | 10 | 12 | 16 | 20 | 25 | 32 | 36 | 45 | 50 |

[1] Values apply to bending angle $\alpha \leq 120°$ and bending transverse to rolling direction. Value of the next larger sheet metal thickness should be selected for bending longitudinal to rolling direction and bending angle $\alpha > 120°$.

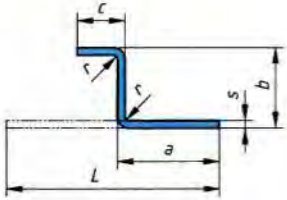
## Bend allowances $v$ for bending angle $\alpha = 90°$

cf. Supplement 2 to DIN 6935 (withdrawn)

| Bending radius $r$ in mm | Bend allowance $v$ per bend in mm for sheet metal thickness $s$ in mm | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0.4 | 0.6 | 0.8 | 1 | 1.5 | 2 | 2.5 | 3 | 3.5 | 4 | 4.5 | 5 | 6 | 8 | 10 |
| 1 | 1.0 | 1.3 | 1.7 | 1.9 | – | – | – | – | – | – | – | – | – | – | – |
| 1.6 | 1.3 | 1.6 | 1.8 | 2.1 | 2.9 | – | – | – | – | – | – | – | – | – | – |
| 2.5 | 1.6 | 2.0 | 2.2 | 2.4 | 3.2 | 4.0 | 4.8 | – | – | – | – | – | – | – | – |
| 4 | – | 2.5 | 2.8 | 3.0 | 3.7 | 4.5 | 5.2 | 6.0 | 6.9 | – | – | – | – | – | – |
| 6 | – | – | 3.4 | 3.8 | 4.5 | 5.2 | 5.9 | 6.7 | 7.5 | 8.3 | 9.0 | 9.9 | – | – | – |
| 10 | – | – | – | 5.5 | 6.1 | 6.7 | 7.4 | 8.1 | 8.9 | 9.6 | 10.4 | 11.2 | 12.7 | – | – |
| 16 | – | – | – | 8.1 | 8.7 | 9.3 | 9.9 | 10.5 | 11.2 | 11.9 | 12.6 | 13.3 | 14.8 | 17.8 | 21.0 |
| 20 | – | – | – | 9.8 | 10.4 | 11.0 | 11.6 | 12.2 | 12.8 | 13.4 | 14.1 | 14.9 | 16.3 | 19.3 | 22.3 |
| 25 | – | – | – | 11.9 | 12.6 | 13.2 | 13.8 | 14.4 | 15.0 | 15.6 | 16.2 | 16.8 | 18.2 | 21.1 | 24.1 |
| 32 | – | – | – | 15.0 | 15.6 | 16.2 | 16.8 | 17.4 | 18.0 | 18.6 | 19.2 | 19.8 | 21.0 | 23.8 | 26.7 |
| 40 | – | – | – | 18.4 | 19.0 | 19.6 | 20.2 | 20.8 | 21.4 | 22.0 | 22.6 | 23.2 | 24.5 | 26.9 | 29.7 |
| 50 | – | – | – | 22.7 | 23.3 | 23.9 | 24.5 | 25.1 | 25.7 | 26.3 | 26.9 | 27.5 | 28.8 | 31.2 | 33.6 |

## Calculation of blank size for 90° bent parts

cf. DIN 6935 (1975-10)




$L$ developed length[1]
$a, b, c$ length of leg
$s$ thickness
$r$ bending radius
$n$ number of bends
$v$ bend allowance

**Developed length**[2]

$$L = a + b + c + \ldots - n \cdot v$$

[2] Calculated developed length should be rounded off to a whole mm value.

**Example (see illus.):**

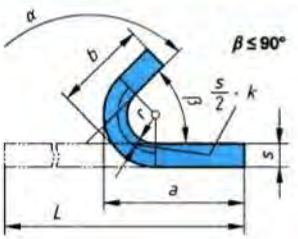
$a = 25$ mm; $b = 20$ mm; $c = 15$ mm; $n = 2$; $t = 2$ mm;
$r = 4$ mm; material S235JR; $v = ?$; $L = ?$
$v$ = **4.5 mm** (from table above)
$L = a + b + c - n \cdot v = (25 + 20 + 15 - 2 \cdot 4.5)$ mm = **51 mm**

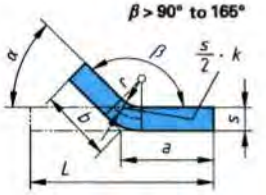
[1] If the ratio $r/s > 5$, the formula for developed length (page 24) can be used.

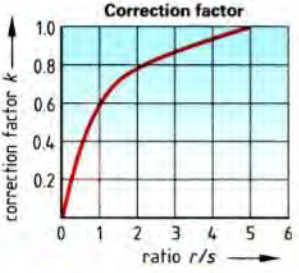
# Calculation of blank size, Springback in bending

## Calculation of blank size for parts with any selected bending angle

cf. DIN 6935 (1975-10)




$L$ developed length; $s$ sheet met. thickness
$a, b$ length of leg; $r$ bending radius
$v$ bend allowance; $\beta$ aperture angle
$k$ correction factor

**Developed length**[1]

$$L = a + b - v$$

**Bend allowance for $\beta$ = 0° to 90°**

$$v = 2 \cdot (r+s) - \pi \cdot \left(\frac{180° - \beta}{180°}\right) \cdot \left(r + \frac{s}{2} \cdot k\right)$$

**Bend allowance for $\beta$ over 90° to 165°**

$$v = 2 \cdot (r+s) \cdot \tan\frac{180° - \beta}{2} - \pi \cdot \left(\frac{180° - \beta}{180°}\right) \cdot \left(r + \frac{s}{2} \cdot k\right)$$

**Bending allowance for $\beta$ over 165° to 180°**

$v \approx 0$ (negligible)

**Correction factor**

$$k = 0.65 + 0.5 \cdot \log\frac{r}{s}$$

**Example:**

Bent part with $\beta = 60°$, $a = 16$ mm, $b = 21$ mm, $r = 6$ mm, $s = 5$ mm; $k = ?$; $v = ?$; $L = ?$;

$\frac{r}{s} = \frac{6\text{ mm}}{5\text{ mm}} = 1.2$; $\boldsymbol{k = 0.7}$ (from diagram);

$\boldsymbol{k = 0.689}$ (calculated by formula)

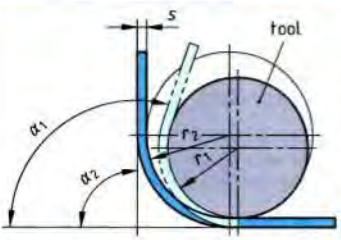
$$v = 2 \cdot (r+s) - \pi \cdot \left(\frac{180° - \beta}{180°}\right) \cdot \left(r + \frac{s}{2} \cdot k\right)$$

$$= 2 \cdot (6+5)\text{ mm} - \pi \cdot \left(\frac{180° - 60°}{180°}\right) \cdot \left(6 + \frac{5}{2} \cdot 0.7\right)\text{ mm} = \mathbf{5.77\ mm}$$

$L = a + b - v = 16\text{ mm} + 21\text{ mm} - 5.77\text{ mm} \approx \mathbf{32\ mm}$

[1] For $r/s > 5$ the developed length (page 24) is sufficiently accurate for calculations.

## Springback in bending




$\alpha_1$ angle of bend before springback (on tool)
$\alpha_2$ angle of bend after springback (on workpiece)
$r_1$ radius on tool
$r_2$ bending radius on workpiece
$k_R$ springback factor
$s$ sheet metal thickness

**Radius on tool**

$$r_1 = k_R \cdot (r_2 + 0.5 \cdot s) - 0.5 \cdot s$$

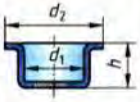
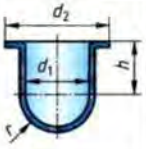
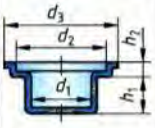
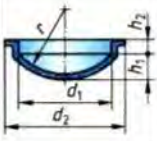
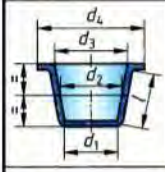
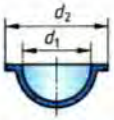
**Angle of bend before springback**

$$\alpha_1 = \frac{\alpha_2}{k_R}$$

| Material of bent part | Springback factor $k_R$ for the ratio $r_2/s$ | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 1.6 | 2.5 | 4 | 6.3 | 10 | 16 | 25 | 40 | 63 | 100 |
| DC04 | 0.99 | 0.99 | 0.99 | 0.98 | 0.97 | 0.97 | 0.96 | 0.94 | 0.91 | 0.87 | 0.83 |
| DC01 | 0.99 | 0.99 | 0.99 | 0.97 | 0.96 | 0.96 | 0.93 | 0.90 | 0.85 | 0.77 | 0.66 |
| X12CrNi18-8 | 0.99 | 0.98 | 0.97 | 0.95 | 0.93 | 0.89 | 0.84 | 0.76 | 0.63 | – | – |
| E-Cu-R20 | 0.98 | 0.97 | 0.97 | 0.96 | 0.95 | 0.93 | 0.90 | 0.85 | 0.79 | 0.72 | 0.6 |
| CuZn33-R29 | 0.97 | 0.97 | 0.96 | 0.95 | 0.94 | 0.93 | 0.89 | 0.86 | 0.83 | 0.77 | 0.73 |
| CuNi18Zn20 | – | – | – | 0.97 | 0.96 | 0.95 | 0.92 | 0.87 | 0.82 | 0.72 | – |
| EN AW-Al99.0 | 0.99 | 0.99 | 0.99 | 0.99 | 0.98 | 0.98 | 0.97 | 0.97 | 0.96 | 0.95 | 0.93 |
| EN AW-AlCuMg1 | 0.92 | 0.90 | 0.87 | 0.84 | 0.77 | 0.67 | 0.54 | – | – | – | – |
| EN AW-AlSiMgMn | 0.98 | 0.98 | 0.97 | 0.96 | 0.95 | 0.93 | 0.90 | 0.86 | 0.82 | 0.76 | 0.72 |

# Deep drawing

## Calculation of blank diameter

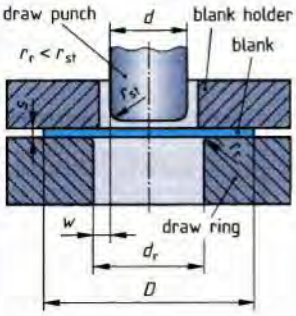
| Drawn part | Blank diameter D | Drawn part | Blank diameter D |
|---|---|---|---|
|  | without flange $d_2$<br>$D = \sqrt{d_1^2 + 4 \cdot d_1 \cdot h}$<br>with flange $d_2$<br>$D = \sqrt{d_2^2 + 4 \cdot d_1 \cdot h}$ |  | without flange $d_2$<br>$D = \sqrt{2 \cdot d_1^2 + 4 \cdot d_1 \cdot h}$<br>with flange $d_2$<br>$D = \sqrt{2 \cdot d_1^2 + 4 \cdot d_1 \cdot h + (d_2^2 - d_1^2)}$ |
|  | without flange $d_3$<br>$D = \sqrt{d_2^2 + 4 \cdot (d_1 \cdot h_1 + d_2 \cdot h_2)}$<br>with flange $d_3$<br>$D = \sqrt{d_3^2 + 4 \cdot (d_1 \cdot h_1 + d_2 \cdot h_2)}$ |  | without flange $d_2$<br>$D = \sqrt{d_1^2 + 4 \cdot h_1^2 + 4 \cdot d_1 \cdot h_2}$<br>with flange $d_2$<br>$D = \sqrt{d_1^2 + 4 \cdot h_1^2 + 4 \cdot d_1 \cdot h_2 + (d_2^2 - d_1^2)}$ |
|  | without flange $d_4$<br>$D = \sqrt{d_1^2 + 4 \cdot d_2 \cdot l}$<br>with flange $d_4$<br>$D = \sqrt{d_1^2 + 4 \cdot d_2 \cdot l + (d_4^2 - d_3^2)}$ |  | without flange $d_2$<br>$D = \sqrt{2 \cdot d_1^2} = 1.414 \cdot d$<br>with flange $d_2$<br>$D = \sqrt{d_1^2 + d_2^2}$ |

**Example:**

Cylindrical drawn part with flange $d_2$ (see figure, upper left) with $d_1 = 50$ mm, $h = 30$ mm; $D = ?$

$D = \sqrt{d_1^2 + 4 \cdot d_1 \cdot h} = \sqrt{50^2\ \text{mm}^2 + 4 \cdot 50\ \text{mm} \cdot 30\ \text{mm}} = \mathbf{92.2\ mm}$

## Drawing gap and radii on draw ring and draw punch




| | |
|---|---|
| $w$ | drawing gap |
| $s$ | sheet metal thickness |
| $k$ | material factor |
| $r_r$ | radius on draw ring |
| $r_{st}$ | radius of draw punch |
| $D$ | blank diameter |
| $d$ | punch diameter |
| $d_r$ | draw ring diameter |

**Drawing gap in mm**

$$w = s + k \cdot \sqrt{10 \cdot s}$$

**Radius of draw ring in mm**

$$r_r = 0.035 \cdot [50 + (D - d)] \cdot \sqrt{s}$$

For each redraw the radius of the draw ring should be reduced by 20 to 40 %.

**Drawing gap**

$$w = \frac{d_r - d}{2}$$

**Radius of draw punch in mm**

$$r_{st} = (4 \text{ to } 5) \cdot s$$

| Material factor $k$ | |
|---|---|
| Steel | 0.07 |
| Aluminum | 0.02 |
| Other non-ferrous metals | 0.04 |

**Example:**

Steel sheet; $D = 51$ mm; $d = 25$ mm; $s = 2$ mm; $w = ?$; $r_r = ?$; $r_{st} = ?$

$k$ = **0.07** (from table)

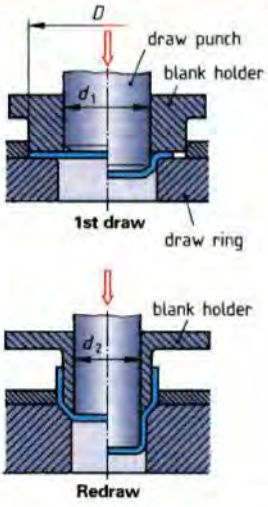
$w = s + k \cdot \sqrt{10 \cdot s} = 2 + 0.07 \cdot \sqrt{10 \cdot 2} =$ **2.3 mm**

$r_r = 0.035 \cdot [50 + (D - d)] \cdot \sqrt{s} = 0.035 \cdot [50 + (51 - 25)] \cdot \sqrt{2} =$ **3.8 mm**

$r_{st} = 4.5 \cdot s = 4.5 \cdot 2\ \text{mm} =$ **9 mm**

# Deep drawing

## Drawing steps and drawing ratios




$D$ blank diameter
$d$ inside diameter of finished drawn part
$d_1$ punch diameter for 1st draw
$d_2$ punch diameter for 2nd draw
$d_n$ punch diameter for nth draw
$\beta_1$ drawing ratio for 1st draw
$\beta_2$ drawing ratio for 2nd draw
$\beta_{tot}$ total drawing ratio
$s$ sheet metal thickness

**Example:**

Cup without flange made of DC04 (St 14) with $d$ = 50 mm; $h$ = 60 mm; $D$ = ?; $\beta_1$ = ?; $\beta_2$ = ?; $d_1$ = ?; $d_2$ = ?

$$D = \sqrt{d^2 + 4 \cdot d \cdot h}$$
$$= \sqrt{(50\ \text{mm})^2 + 4 \cdot 50\ \text{mm} \cdot 60\ \text{mm}} \approx \mathbf{120\ mm}$$

$\beta_1$ = **2.0**; $\beta_2$ = **1.3** (according to table below)

$$d_1 = \frac{D}{\beta_1} = \frac{120\ \text{mm}}{2.0} = \mathbf{60\ mm}$$

$$d_2 = \frac{d_1}{\beta_2} = \frac{60\ \text{mm}}{1.3} = \mathbf{46\ mm}$$

Two draws sufficient since $d_2 < d$

**Drawing ratio**

1st draw

$$\beta_1 = \frac{D}{d_1}$$

2nd draw

$$\beta_2 = \frac{d_1}{d_2}$$

**Total drawing ratio**

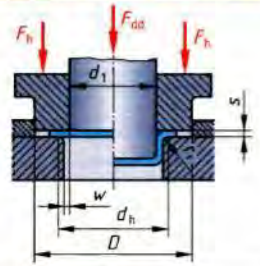
$$\beta_{tot} = \beta_1 \cdot \beta_2 \cdot \ldots$$

$$\beta_{tot} = \frac{D}{d_n}$$

| Material | Max. drawing ratios[1] $\beta_1$ | $\beta_2$ | $R_m$[2] N/mm² | Material | Max. drawing ratios[1] $\beta_1$ | $\beta_2$ | $R_m$[2] N/mm² | Material | Max. drawing ratios[1] $\beta_1$ | $\beta_2$ | $R_m$[2] N/mm² |
|---|---|---|---|---|---|---|---|---|---|---|---|
| DC01 (St12) | 1.8 | 1.2 | 410 | CuZn30-R270 | 2.1 | 1.3 | 270 | Al99.5 H111 | 2.1 | 1.6 | 95 |
| DC03 (St13) | 1.9 | 1.3 | 370 | CuZn37-R300 | 2.1 | 1.4 | 300 | AlMg1 H111 | 1.9 | 1.3 | 145 |
| DC04 (St14) | 2.0 | 1.3 | 350 | CuZn37-R410 | 1.9 | 1.2 | 410 | AlCu4Mg1 T4 | 2.0 | 1.5 | 425 |
| X10CrNi18-8 | 1.8 | 1.2 | 750 | CuSn6-R350 | 1.5 | 1.2 | 350 | AlSi1MgMn T6 | 2.1 | 1.4 | 310 |

[1] Values apply up to $d_1 : s = 300$; they were determined for $d_1$ = 100 mm and $s$ = 1 mm. Values change negligibly for other sheet metal thicknesses and punch diameters.
[2] maximum tensile strength

## Tearing force, deep drawing force, blank holding force




| Blank holding pressure $p$ in N/mm² | |
|---|---|
| Steel | 2.5 |
| Cu alloys | 2.0–2.4 |
| Al alloys | 1.2–1.5 |

$F_t$ tearing force
$F_{dd}$ deep drawing force
$d_1$ punch diameter
$s$ sheet metal thickness
$R_m$ tensile strength
$\beta$ drawing ratio
$\beta_{max}$ max. possible drawing ratio
$F_h$ blank holding force
$D$ blank diameter
$d_h$ support diameter of blank holding force
$p$ blank holding pressure
$r_r$ radius on draw ring
$w$ drawing gap

**Tearing force**

$$F_t = \pi \cdot (d_1 + s) \cdot s \cdot R_m$$

**Deep drawing force**

$$F_{dd} = \pi \cdot (d_1 + s) \cdot s \cdot R_m \cdot 1.2 \cdot \frac{\beta - 1}{\beta_{max} - 1}$$

**Blank holding force**

$$F_h = \frac{\pi}{4} \cdot (D^2 - d_h^2) \cdot p$$

**Support diameter of blank holding force**

$$d_h = d_1 + 2 \cdot (r_r + w)$$

**Example:**

$D$ = 210 mm; $d_1$ = 140 mm; $s$ = 1 mm; $R_m$ = 380 N/mm²; $\beta$ = 1.5; $\beta_{max}$ = 1.9; $F_{dd}$ = ?

$$F_{dd} = \pi \cdot (d_1 + s) \cdot s \cdot R_m \cdot 1.2 \cdot \frac{\beta - 1}{\beta_{max} - 1} = \pi \cdot (140\ \text{mm} + 1\ \text{mm}) \cdot 1\ \text{mm} \cdot 380 \frac{\text{N}}{\text{mm}^2} \cdot 1.2 \cdot \frac{1.5 - 1}{1.9 - 1} = \mathbf{112\,218\ N}$$

# Welding processes, Positions, General tolerances

## Welding, cutting, soldering and related processes

cf. DIN EN ISO 4063 (2000-04)

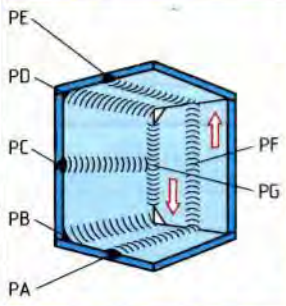
| N[1] | Method, process | N[1] | Method, process | N[1] | Method, process |
|---|---|---|---|---|---|
| **1** | **Arc welding** | 24<br>25 | flash butt welding<br>upset welding | **7** | **Other welding methods** |
| 101<br>111 | metal arc welding<br>shielded metal arc welding | **3** | **Gas welding** | 73<br>74 | electrogas welding<br>induction welding |
| 11 | metal arc welding<br>without shielding gas | 311 | oxyacetylene welding | 75<br>753 | light beam welding<br>infrared welding |
| 12<br>13 | submerged arc welding<br>gas shielded metal arc welding | 312 | gas welding with oxygen/<br>propane flame | 78<br>788 | stud welding<br>friction stud welding |
| 131<br>135 | gas metal arc welding<br>metal active gas welding (MAG) | **4** | **Pressure welding** | **8** | **Cutting** |
| 136 | flux cored arc welding<br>with active gas shield | 41<br>42 | ultrasonic welding<br>friction welding | 81<br>82 | oxygen cutting<br>arc cutting |
| 137 | flux cored arc welding<br>with inert gas shield | 45<br>47 | diffusion welding<br>pressure gas welding | 83<br>84 | plasma cutting<br>laser beam cutting |
| 14<br>141 | tungsten gas shield. arc welding<br>gas tungsten arc welding | **5** | **Beam welding** | **9** | **Brazing, soldering** |
| 15<br>151 | plasma arc welding<br>plasma TIG welding | 51<br>52 | electron beam welding<br>laser beam welding | 91<br>912 | brazing<br>torch brazing |
| **2** | **Resistance welding** | 512 | electron beam<br>welding, nonvacuum | 914<br>924 | metal bath brazing<br>vacuum brazing |
| 21<br>22 | resistance spot welding<br>seam welding | 521 | solid-state laser beam<br>in atmosphere | 94<br>944 | soldering<br>metal bath soldering |
| 225<br>23 | foil butt seam welding<br>projection welding | 522 | gas laser beam welding | 946<br>952 | induction soldering<br>iron soldering |

⇒ **Process ISO 4063–111:** Specified welding process → manual arc welding (111)

[1] N Reference number for designating methods and processes in drawings, operating procedures and data processing

## Welding positions

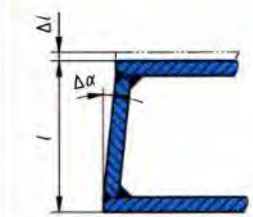
cf. DIN EN ISO 6947 (1997-05)




| Code | Name | Main position, description |
|---|---|---|
| PA | flat welding position | weld axis vertical, horizontal work, final pass at top |
| PB | horizontal position | horizontal work, final pass at top |
| PC | transverse position | weld axis horizontal, horizontal work direction |
| PD | horizontal<br>overhead position | horizontal work direction, overhead, final pass at bottom |
| PE | overhead position | horizontal work direction, weld axis vertical, final pass at bottom |
| PF | vertical up position | upward work direction |
| PG | vertic. down position | downward work direction |

## General tolerances for weldments

cf. DIN EN ISO 13920 (1996-11)

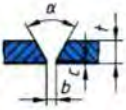
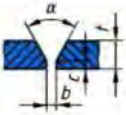
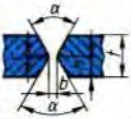
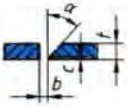
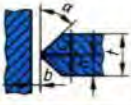
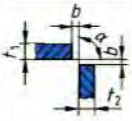



[1] *l* shorter leg

| Degree of accuracy | Allowable deviations for length dimensions Δ*l* in mm nominal size range *l*[1] | | | | | | Allowable deviations for angle dimensions Δα in ° and ′ nominal size range *l*[1] | | |
|---|---|---|---|---|---|---|---|---|---|
| | to 30 | over 30 to 120 | over 120 to 400 | over 400 to 1000 | over 1000 to 2000 | over 2000 to 4000 | to 400 | over 400 to 1000 | over 1000 |
| A | ±1 | ±1 | ±1 | ±2 | ±3 | ± 4 | ±20′ | ±15′ | ±10′ |
| B | ±1 | ±2 | ±2 | ±3 | ±4 | ± 6 | ±45′ | ±30′ | ±20′ |
| C | ±1 | ±3 | ±4 | ±6 | ±8 | ±11 | ±1° | ±45′ | ±30′ |

# Weld preparation

cf. DIN EN ISO 9692-1 (2004-05), replaces DIN EN 29692

| Name, weld symbol weld<br>pages 93–95 | Work-piece thickness $t$ mm | D[1] | Weld preparation<br>Edge form | Dimension<br>gap $b$ mm | web $c$ mm | angle $\alpha$ in ° | Preferred welding method[2] | Remarks |
|---|---|---|---|---|---|---|---|---|
| **Flare-V groove weld** | 0–2 | s |  | – | – | – | 3, 111, 141, 512 | Thin sheet welding, usually without filler material |
| **butt weld** | 0–4 | s |  | ≈ $t$ | – | – | 3, 111, 141 | Little filler material, no weld preparation |
| | 0–8 | d | | ≈ $t/2$ | – | – | 111, 141 | |
| | | | | ≤ $t/2$ | – | – | 13 | |
| **V groove weld** | 3–10 | s |  | ≤ 4 | ≤ 2 | 40°–60° | 3 | – |
| | 3–40 | d | | ≤ 3 | ≤ 2 | ≈ 60° | 111, 141 | With backing run |
| | | | | | | 40°–60° | 13 | |
| **Y-butt weld** | 5–40 | s |  | 1–4 | 2–4 | ≈ 60° | 111, 13, 141 | – |
| | > 10 | d | | 1–3 | 2–4 | ≈ 60° | 111, 141 | With root and backing run |
| | | | | | | 40°–60° | 13 | |
| **double V-weld** | > 10 | d |  | 1–3 | ≤ 2 | ≈ 60° | 111, 141 | Symmetrical edge form, $h = t/2$ |
| | | | | | | 40°–60° | 13 | |
| **bevel groove weld** | 3–10 | s |  | 2–4 | 1–2 | 35°–60° | 111, 13, 141 | – |
| | 3–30 | d | | 1–4 | ≤ 2 | 35°–60° | 111, 13, 141 | With backing run |
| **double bevel weld** | > 10 | d |  | 1–4 | ≤ 2 | 35°–60° | 111, 13, 141 | Symmetrical edge form, $h = t/2$ or $t/3$ |
| **Fillet weld** | > 2 | s |  | ≤ 2 | – | 70°–100° | 3, 111, 13, 141 | T-joint |
| | > 3 | d |  | ≤ 2 | – | 70°–110° | 3, 111, 13, 141 | Double fillet weld, corner joint |

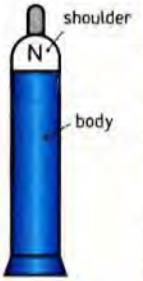
[1] D Design: s single-V weld; d double-V weld

[2] For welding methods, see page 322

# Compressed gas cylinders, Gas welding rods

## Compressed gas cylinders*

cf. DIN EN 1089-3 (2004-06)




| Type of gas | Color coding[1] as per DIN EN 1089-3 body | shoulder | previous | Connection threads | Volume $V$ $l$ | Filling pressure $p_F$ bar | Filling quantity |
|---|---|---|---|---|---|---|---|
| Oxygen | blue | white | blue | R3/4 | 40<br>50 | 150<br>200 | 6 m³<br>10 m³ |
| Acetylene | chestnut-brown | chestnut-brown | yellow | Quick connect | 40<br>50 | 19<br>19 | 8 kg<br>10 kg |
| Hydrogen | red | red | red | W21.80x1/14 | 10<br>50 | 200<br>200 | 2 m³<br>10 m³ |
| Argon | gray | dark-green | gray | W21.80x1/14 | 10<br>50 | 200<br>200 | 2 m³<br>10 m³ |
| Helium | gray | brown | gray | W21.80x1/14 | 10<br>50 | 200<br>200 | 2 m³<br>10 m³ |
| Argon-carbon dioxide mixture | gray | fluorescent green | gray | W21.80x1/14 | 20<br>50 | 200<br>200 | 4 m³<br>10 m³ |
| Carbon dioxide | gray | gray | gray | W21.80x1/14 | 10<br>50 | 58<br>58 | 7.5 kg<br>20 kg |
| Nitrogen | gray | black | dark-green | W24.32x1/14 | 40<br>50 | 150<br>200 | 6 m³<br>10 m³ |

[1] Changeover to the new color coding should be completed by July 1, 2006. During the transition period the hazardous substance label (page 331) is the only legally valid designation.

*) According to European Standards

## Gas welding rods for steel joint welding

cf. DIN EN 12536 (2000-08), replaces DIN 8554-1

### Classification, weld metal analysis, weld behavior

| Designation new | Designation prev. | Weld metal analysis in % (standard values) C | Si | Mn | Mo | Ni | Cr | Weld behavior Flow behavior | Spatter | Tendency for pores |
|---|---|---|---|---|---|---|---|---|---|---|
| O I | G I | <0.1 | <0.20 | <0.65 | – | – | – | highly fluid | high | yes |
| O II | G II | <0.2 | <0.25 | <1.20 | – | – | – | less highly fluid | low | yes |
| O III | G III | <0.15 | <0.25 | <1.25 | – | <0.80 | – | semifluid | none | no |
| O IV | G IV | <0.15 | <0.25 | <1.20 | <0.65 | – | <1.20 | semifluid | none | no |
| O V | G V | <0.10 | <0.25 | <1.20 | <0.65 | – | <1.20 | semifluid | none | no |

### Areas of application, mechanical properties

| Areas of application | Steel type | Welding rod, code | T[1] | Yield strength $R_e$ N/mm² | Tensile strength $R_m$ N/mm² | Elongation at fracture $A$ % | NI[2] $K_v$ J |
|---|---|---|---|---|---|---|---|
| Sheet, tube | S235, S275 | O I | U | > 260 | 360–410 | > 20 | > 30 |
| Vessels, pipes | S235, S275, P235GH, P265GH | O II | U | > 300 | 390–440 | > 20 | > 47 |
| | S235, S275 P235GH, P265GH | O III | U | > 310 | 400–460 | > 22 | > 47 |
| Boilers, pipes, temperature resistant up to 530 °C | S235, S355, S275, P235, P235GH, P265GH, P295GH, 16Mo3 | O IV | U | > 260 | 440–490 | > 22 | > 47 |
| Boilers, pipes, temperature resistant up to 570 °C | 13CrMo4-5, 16CrMo3 | O V | T | > 315 | 490–590 | > 18 | > 47 |
| ⇒ | **Rod EN 12536 – O IV:** Gas welding rod of Class IV | | | | | | |

[1] T Treatment condition of the weld: U untreated (weld condition); T tempered

[2] NI notch impact energy at +20 °C, determined using an ISO-V test specimen

# Shielding gases, Wire electrodes*

## Shielding gases for arc welding of steel

cf. DIN EN 439 (1995-05)

| Codes | Composition[1] | Gas type, effect | Welding methods | Materials; Applications |
|---|---|---|---|---|
| R1<br>R2 | $H_2$ < 15%, balance Ar or He<br>(15–35)% $H_2$, balance Ar or He | reduction gases | TIG, plasma-welding | high-alloy steels, Ni, Ni alloys |
| I1<br>I2<br>I3 | 100% Ar<br>100% He<br>He < 95%, balance Ar | inert gases (neutral behavior) | MIG, TIG, plasma-welding | Al, Al alloys, Cu, Cu alloys |
| M11<br>M12<br>M13 | $CO_2$ ≤ 5%, $H_2$ ≤ 5%, balance Ar or He<br>(3–10)% $CO_2$, balance Ar or He<br>$O_2$ < 3%, balance Ar | gas mixtures, weak oxidizing | MAG welding | alloyed Cr-Ni steels; mainly stainless and acid-resistant steels |
| M21<br>M22<br>M23 | (5–25)% $CO_2$, balance Ar or He<br>(3–10)% $CO_2$, balance Ar or He<br>$CO_2$ ≤ 5%, (3–10)% $O_2$, balance Ar or He | mixed gases, more strongly oxidizing | MAG welding | low-alloyed and medium-alloyed steels |
| M31<br>M32<br>M33 | (25–50)% $CO_2$, balance Ar or He<br>(10–15)% $O_2$, balance Ar or He<br>(5–50)% $CO_2$, (8–15)% $O_2$, balance Ar or He | mixed gases, medium oxidizing | MAG welding | unalloyed and low alloyed steels; heavy plate |
| C1<br>C2 | 100% $CO_2$<br>$O_2$ ≤ 30%, balance $CO_2$ | strongly oxidizing gases | MAG welding | unalloyed steels |
| ⇒ | **Shielding gas EN 439-I3:** Inert gas with up to 95% Helium, balance Argon | | | |

[1] Ar argon He helium $O_2$ oxygen $CO_2$ carbon dioxide $H_2$ hydrogen

## Wire electrodes and deposits for gas-shielded metal arc welding of non-alloy and fine grain structural steels

cf. DIN EN 440 (1994-11)

**Designation example (weld metal):**

EN 440 – G 46 3 M G3Si1

- EN 440 – Standard number
- G – Designation for gas shielded metal arc welding
- 46 – Code digit for the mechanical properties of the weld metal (page 327)
- 3 – Code digit for notch impact energy of the weld metal (page 327)
- M – Designation for shielding gases

| Code letter | Shielding gases DIN 439 |
|---|---|
| M | M21, M22, M23, M24 |
| C | C1 |

**Chemical composition of the wire electrodes (examples)**

| Designation | Main alloying elements | Designation | Main alloying elements |
|---|---|---|---|
| G0 | All compositions agreed upon | G2Ti | 0.5–0.8% Si, 0.9–1.4% Mn, 0.05–0.25% Ti |
| G3Si1 | 0.7–1.0% Si, 1.3–1.6% Mn | G2Ni2 | 0.4–0.8% Si, 0.8–1.4% Mn, 2.1–2.7% Ni |
| ⇒ | **EN 440 – G 46 4 M G3Si1:** Properties of weld metal: Minimum yield strength $R_e$ = 460 N/mm², notch impact energy at –40 °C = 47 J; mixed gas M21–M24, electrode with 0.7–1.0% Si, 1.3–1.6% Mn | | |

**Wire electrodes** (selection)

| Designation as per DIN EN 440 | Welding methods | Shielding gases | Usable on steels, examples | Applications, properties, examples |
|---|---|---|---|---|
| G 46 4 M G3Si1 | MAG | M21–M24, C1 | S185–S355, E295, E335, P235–P355, GP240R, L210–L360 | joint and build-up welding |
| G 50 4 M G4Si1 | MAG | M21–M24, C1 | | like G3Si1, but higher mechanical strength properties |
| G 46 M G2Ni2 | MAG | M21 | 12Ni14, 13MnNi6-3, S(P)275–S(P)420 | fine grain structural steels and steels with low-temp. toughness |

*) According to European Standards

# Standard values for gas shielded metal arc welding, Filler metals for aluminum

| Weld design | | | | Settings | | | | Efficiency values | |
|---|---|---|---|---|---|---|---|---|---|
| Weld seam type | Weld thickness *a* mm | Wire diameter mm | Number of passes | Voltage V | Current A | Wire feed rate[1] m/min | Shielding gas l/min | Filler metal g/m | Productive time min/m |
| **MAG welding, standard values for unalloyed structural steel** | | | | | | | | | |
| Welding position: PB | Wire electrode DIN EN 440 – G 46 4 M G3Si1 | | | | | Shielding gas DIN EN 439 – M21 | | | |
|  | 2 | 0.8 | 1 | 20 | 105 | 7 | 10 | 45 | 1.5 |
| | 3 | 1.0 | | 22 | 215 | 11 | | 90 | 1.4 |
| | 4 | 1.0 | | 23 | 220 | 11 | | 140 | 2.1 |
| | 5 | 1.0 | 1 | 30 | 300 | 10 | 15 | 215 | 2.6 |
| | 6 | 1.0 | 1 | | | | | 300 | 3.5 |
| | 7 | 1.2 | 3 | | | | | 390 | 4.6 |
| | 8 | 1.2 | 3 | 30 | 300 | 10 | 15 | 545 | 6.4 |
| | 10 | | 4 | | | | | 805 | 9.5 |
| **MIG welding, standard values for aluminum alloys** | | | | | | | | | |
| Welding position: PA | Filler metal DIN 1732 – SG – AlMg5 | | | | | Shielding gas DIN EN 439 – I1 | | | |
|  | 4 | 1.2 | 1 | 23 | 180 | 3 | 12 | 30 | 2.9 |
| | 5 | 1.6 | | 25 | 200 | 4 | 18 | 77 | 3.3 |
| | 6 | 1.6 | | 26 | 230 | 7 | 18 | 147 | 3.9 |
|  | 5 | 1.6 | 1 | 22 | 160 | 6 | 18 | 126 | 4.2 |
| | 6 | | 2 | 22 | 170 | 6 | | 147 | 4.6 |
| | 8 | | 2 | 26 | 220 | 7 | | 183 | 5.0 |

[1] For MIG welding: welding travel speed

| **TIG welding, standard values for aluminum alloys** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Welding position: PA | Filler metal DIN 1732 – SG – AlMg5 | | | | | Shielding gas DIN EN 439 – I1 | | | |
|  | 1 | 3.0 | 1 | – | 75 | 0.3 | 5 | 19 | 3.8 |
| | 1.5 | | | | 90 | 0.2 | | 22 | 4.3 |
| | 2 | 3.0 | 1 | – | 110 | 0.2 | 6 | 28 | 1.8 |
| | 3 | | | | 125 | | | | 5.9 |
| | 4 | 3.0 | 1 | – | 160 | 0.2 | 8 | 38 | 6.7 |
| | 5 | | | | 185 | 0.1 | 10 | 47 | 7.1 |
| | 6 | | | | 210 | 0.1 | 10 | 47 | 12 |
|  | 5 | 4.0 | 1st layer 2nd layer | – | 165 | 0.1 0.2 | 12 | 105 | 13 |
| | 6 | 4.0 | 1st layer 2nd layer | – | 165 | 0.1 0.2 | 12 | 190 | 16 |

## Welding fillers for aluminum

cf. DIN 1732 (1988-06)

| Designations[1] | | Material number | Application for base metals (Designation without adding EN AW) |
|---|---|---|---|
| SG-Al99.8 | (EL-Al99.8) | 3.0286 | Al99.7, Al99.5 |
| SG-Al99.5Ti | (EL-Al99.5Ti) | 3.0805 | Al99.0, Al99.5 |
| SG-AlMn1 | (EL-AlMn1) | 3.0516 | AlMn1, AlMn1Cu |
| SG-AlMg3 | | 3.3536 | AlMg1(C), AlMg3 |
| SG-AlMg5 | | 3.3556 | AlMg3, AlMg4, AlMg5, AlSi1MgMn, AlMg1SiCu, AlZn4.5Mg1, G-AlMg5, G-AlMgSi, G-AlMg3, G-AlMg3Si |
| SG-AlMg4.5Mn | | 3.3548 | AlMg4, AlMg5, AlSi1MgMn, AlMg1SiCu, AlZn4.5Mg1, G-AlMg5, G-AlMgSi |
| SG-AlSi5 | (EL-AlSi5) | 3.2245 | AlMgSi1Cu, AlZn4.5Mg1 |
| SG-AlSi12 | (EL-AlSi12) | 3.2585 | G-AlSi1, G-AlSi9Mg, G-AlSi7Mg, G-AlSi5Mg |

[1] SG metal fillers with bare surfaces; EL coated rod electrodes

# Rod electrodes for arc welding

## Coated rod electrodes for unalloyed steels and fine grain steels

cf. DIN EN ISO 2560 (2006-03) replaces DIN EN 499

Classification of rod electrodes according to
- Yield strength
- Notch impact energy 47 J

or
- Tensile strength
- Notch impact energy 27 J

Designation example: **ISO 2560-A – E 46 3 1NiB 54 H5**

- Standard number
- A classification according to yield strength and notch impact energy 47 J
- E coated rod electrode
- H hydrogen content 5 -> 5 ml/100 g weld metal

**Code numbers for the mechanical properties of weld metal**

| Code number | Minimum yield strength N/mm² | Tensile strength N/mm² | Minimum elongation at fracture $EL_5$ in % |
|---|---|---|---|
| 35 | 355 | 440–570 | 22 |
| 38 | 380 | 470–600 | 20 |
| 42 | 420 | 500–640 | 20 |
| 46 | 460 | 530–680 | 20 |
| 50 | 500 | 560–720 | 18 |

**Code letter for the notch impact energy of weld metal**

| Code letter/ code number | Minimum notch impact energy 47 J at °C |
|---|---|
| Z | no requirements |
| A | + 20 |
| 0 | 0 |
| 2 | – 20 |
| 3 | – 30 |
| 4 | – 40 |

**Code letters for the chemical composition**

| Code letters | Maximum content in % Mn | Mo | Ni |
|---|---|---|---|
| None | 2.0 | – | – |
| Mo | 1.4 | 0.3–0.6 | – |
| MnMo | 1.4–2.0 | 0.3–0.6 | – |
| 1Ni | 1.4 | – | 0.6–1.2 |
| 2Ni | 1.4 | – | 1.8–2.6 |
| Mn1Ni | 1.4–2.0 | – | 0.6–1.2 |
| 1NiMo | 1.4 | 0.3–0.6 | 0.6–1.2 |

**Code numbers for the welding position**

| Code number | Welding position |
|---|---|
| 1 | all positions |
| 2 | all positions, except vertical down welds |
| 3 | butt weld in flat position, fillet weld in flat and horizontal position |
| 4 | butt and fillet weld in flat position |
| 5 | for vertical down weld and as in number 3 |

**Code number for the efficiency and the type of current**

| Code number | Efficiency % | Type of current |
|---|---|---|
| 1 | > 105 | AC and DC |
| 2 | > 105 | DC |
| 3 | > 105 ≤ 125 | AC and DC |
| 4 | > 105 ≤ 125 | DC |
| 5 | > 125 ≤ 160 | AC and DC |
| 6 | > 125 ≤ 160 | DC |
| 7 | > 160 | AC and DC |
| 8 | > 160 | DC |

**Code letters for the type of coating**

| Code letters | Type of coating |
|---|---|
| A | acid coating |
| B | basic coating |
| C | cellulose coating |
| R | rutile coating |
| RA | rutile acid coating |
| RB | rutile basic coating |
| RC | rutile cellulose coating |
| RR | thick rutile coating |

⇒ **ISO 2560-A – E 42 2 RB 12:** A rod electrode with guaranteed yield strength and notch impact energy, 42 yield strength $R_e$ = 420 N/mm², 2 notch impact energy 47 J at –20 °C, RB rutile basic coating, 1 efficiency > 105 %, 2 all welding positions except for vertical down welds.

# Coating of rod electrodes, Weld design

## Coating of rod electrodes used for arc welding

The coating of rod electrodes has a decisive influence on the **welding properties** and the **mechanical properties** of the weld metal.

The coating consists of a homogeneous mixture of the following components:

- slag formers
- deoxidizers
- inert gas formers
- arc stabilizers
- binders
- alloy contents, if applicable

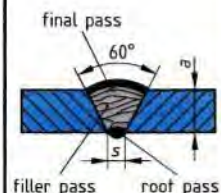
The addition of iron powder increases the efficiency of the weld metal.

**Properties, application and welding position according to the type of coating[1)]**

| Type of coating | Properties, application | Welding position (page 322) |
|---|---|---|
| acid coating | With thick coated rod electrodes, fine drip transition with flat, smooth welds, risk of solidification cracking | Limited application in constrained positions |
| basic coating | High notch impact energy, particularly at low temperatures, low crack sensitivity | PA, PB, PC, PD, PE, PF |
| cellulose coating | Intense arc with particular suitability for vertical down welding | PG |
| rutile coating | Good drip transition, suitable for the welding of thin sheets | PA, PB, PC, PD, PE, PF |
| rutile acid coating | Typically thick coated rod electrodes, same properties as electrodes with acid coating | PA, PB, PC, PD, PE, PF |
| rutile basic coating | Good welding and mechanical properties | PA, PB, PC, PD, PE, PF |
| rutile cellulose coating | Good drip transition, suitable for welding of thin sheets, also in vertical down position | PA, PB, PC, PD, PE, PF, PG |

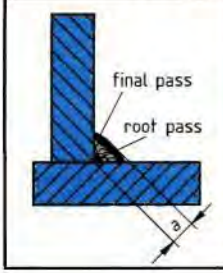
1) The specifications apply to rod electrodes designated according to the yield strength and the notch impact energy (page 327).

**Weld design for arc welded V joints**




| Weld thickness $a$ mm | Gap $s$ mm | Number and type of pass[1)] | Electrode dimensions $d \times l$ mm | Spec. electrode consump. $z_s$ piece/m | Weld weight per pass $m_s$ g/m | Weld weight total $m$ g/m |
|---|---|---|---|---|---|---|
| 4 | 1 | 1 R<br>1 FP | 3.2 x 450<br>4 x 450 | 3<br>2 | 75<br>80 | 155 |
| 5 | 1.5 | 1 R<br>1 FP | 3.2 x 450<br>4 x 450 | 4<br>2.9 | 100<br>110 | 210 |
| 6 | 2 | 1 R<br>2 FP | 3.2 x 450<br>4 x 450 | 4<br>4.7 | 100<br>185 | 285 |
| 8 | 2 | 1 R<br>1 F<br>1 FP | 3.2 x 450<br>4 x 450<br>5 x 450 | 4<br>3.7<br>3.5 | 100<br>145<br>215 | 460 |
| 10 | 2 | 1 R<br>1 F<br>1 FP | 3.2 x 450<br>4 x 450<br>5 x 450 | 4<br>4<br>6.2 | 100<br>195<br>380 | 675 |

**Weld design for arc welded fillet welds**

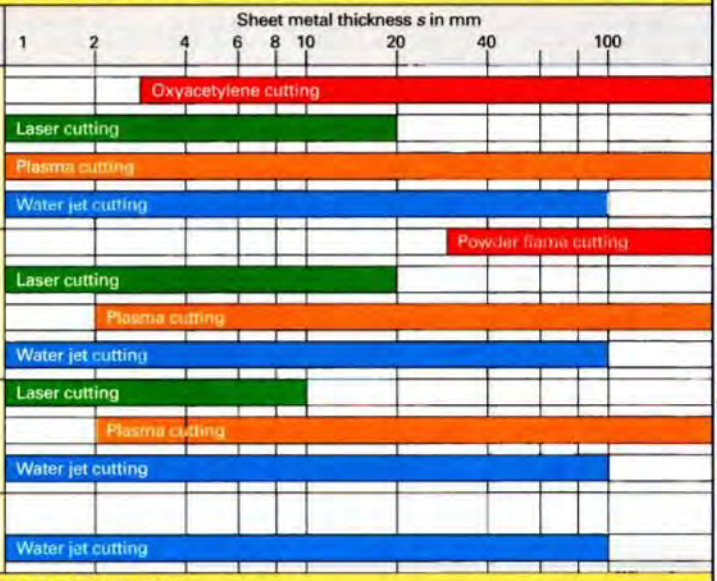



| | | | | | | |
|---|---|---|---|---|---|---|
| 3<br>4 | –<br>– | 1<br>1 | 3.2 x 450<br>4 x 450 | 3.2<br>3.6 | 80<br>140 | 80<br>140 |
| 5<br>6 | –<br>– | 3<br>3 | 3.2 x 450<br>4 x 450 | 8.6<br>8 | 215<br>310 | 215<br>310 |
| 8 | – | 1 R<br>2 FP | 4 x 450<br>5 x 450 | 3<br>7 | 120<br>430 | 550 |
| 10 | – | 1 R<br>4 FP | 4 x 450<br>5 x 450 | 3<br>12.3 | 120<br>745 | 865 |
| 12 | – | 1 R<br>4 FP | 4 x 450<br>5 x 450 | 3<br>18.5 | 120<br>1125 | 1245 |

1) R root pass; F filler pass; FP final pass

# Areas of application and standard values for beam cutting

## Areas of application for cutting processes




## Standard values for oxyacetylene cutting

**Material: unalloyed structural steel; fuel gas: acetylene**

| Sheet met. thickn. $s$ mm | Cutting nozzle mm | Width of cut mm | Oxygen pressure cutting bar | Oxygen pressure heating bar | Acetylene pressure bar | Total oxygen consumption $m^3/hr$ | Acetylene consumption $m^3/hr$ | Cutting rate quality cut m/min | Cutting rate standard cut m/min |
|---|---|---|---|---|---|---|---|---|---|
| 5 | 3–10 | 1.5 | 2.0 | 2.0 | 0.2 | 1.67 | 0.27 | 0.69 | 0.84 |
| 8 | | | 2.5 | | | 1.92 | 0.32 | 0.64 | 0.78 |
| 10 | | | 3.0 | | | 2.14 | 0.34 | 0.60 | 0.74 |
| 10 | 10–25 | 1.8 | 2.5 | 2.5 | 0.2 | 2.46 | 0.36 | 0.62 | 0.75 |
| 15 | | | 3.0 | | | 2.67 | 0.37 | 0.52 | 0.69 |
| 20 | | | 3.5 | | | 2.98 | 0.38 | 0.45 | 0.64 |
| 25 | 25–40 | 2.0 | 4.0 | 2.5 | 0.2 | 3.20 | 0.40 | 0.41 | 0.60 |
| 30 | | | 4.3 | | | 3.42 | 0.42 | 0.38 | 0.57 |
| 35 | | | 4.5 | | | 3.54 | 0.44 | 0.36 | 0.55 |

## Standard values for plasma cutting[1)]

| | **Material: high-alloyed structural steels Cutting method: argon-hydrogen** | | | | | | | **Material: aluminum Cutting method: argon-hydrogen** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sheet met. thickn. $s$ mm | Electrical current qual. cut A | Electrical current stand. cut A | Cutting rate quality cut m/min | Cutting rate stand. cut m/min | Consumption values argon $m^3/hr$ | Consumption values hydrogen $m^3/hr$ | Consumption values nitrogen $m^3/hr$ | Electrical current quality cut A | Electrical current stand. cut A | Cutting rate quality cut m/min | Cutting rate stand. cut m/min | Consumption values argon $m^3/hr$ | Consumption values hydrogen $m^3/hr$ |
| 4 | 70 | 120 | 1.4 | 2.4 | 0.6 | – | 1.2 | 70 | 120 | 3.6 | 6.0 | 1.2 | 0.5 |
| 5 | | | 1.1 | 2.0 | 0.6 | – | 1.2 | | | 1.9 | 5.0 | | |
| 10 | | | 0.65 | 0.95 | 1.2 | 0.24 | – | | | 1.1 | 1.6 | | |
| 15 | 70 | 120 | 0.35 | 0.6 | 1.2 | 0.24 | – | 70 | 120 | 0.6 | 1.3 | 1.2 | 0.5 |
| 20 | | | 0.25 | 0.45 | 1.2 | 0.24 | – | | | 0.35 | 0.75 | | |
| 25 | | | 0.35 | 0.35 | 1.5 | 0.48 | – | | | 0.2 | 0.5 | | |

[1)] Values apply to an arc power of approx. 12 kW and 1.2 mm cutting noozle diameter.

# Standard values, Quality and dimensional tolerances for beam cutting

## Standard values for laser cutting[1]

| M[2] | Sheet met. thickness $s$ mm | Cutting speed $v$ m/min | Cutting gas | Cutting gas press. $p$ bar | Cutting speed $v$ m/min | Cutting gas | Cutting gas press. $p$ bar | Cutting speed $v$ m/min | Cutting gas | Cutting gas press. $p$ bar |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Laser power 1 kW | | | Laser power 1.5 kW | | | Laser power 2 kW | | |
| Unalloyed steel | 1 | 5.0–8.0 | $O_2$ | 1.5–3.5 | 7.0–10 | $O_2$ | 1.5–3.5 | 7.0–10 | $O_2$ | 1.5–3.5 |
| | 1.5 | 4.0–7.0 | | | 5.5–7.5 | | | 5.6–7.4 | | |
| | 2 | 4.0–6.0 | | | 4.8–6.2 | | | 4.8–6.1 | | |
| | 2.5 | 3.5–5.0 | | | 4.2–5.0 | | | 4.2–5.0 | | |
| | 3 | 3.5–4.0 | | | 3.5–4.2 | | | 3.6–2.8 | | |
| | 4 | 2.5–3.0 | | | 2.8–3.3 | | | 2.8–3.4 | | |
| | 5 | 1.8–2.3 | | | 2.3–2.7 | | | 2.5–3.0 | | |
| | 6 | 1.3–1.6 | | | 1.9–2.2 | | | 2.1–2.5 | | |
| Stainless steel | 1 | 4.0–5.5 | $N_2$ | 8 | 5.0–7.0 | $N_2$ | 6 | 4.5–9.0 | $N_2$ | 12 |
| | 1.5 | 2.8–3.6 | | 10 | 3.5–5.2 | | 10 | 3.8–6.6 | | 13 |
| | 2 | 2.2–2.8 | | 14 | 2.0–4.0 | | 10 | 3.4–5.3 | | 14 |
| | 2.5 | 1.6–2.0 | | | 1.9–3.2 | | 14 | 2.7–3.8 | | |
| | 3 | 1.3–1.4 | | 15 | 1.8–.2.4 | | 14 | 2.2–2.7 | | 14 |
| | 4 | – | | – | 1.0–1.1 | | 15 | 1.4–1.8 | | 16 |

[1] The table values apply a the focal length of $f = 127$ mm (5") and a cutting gap width of $w = 0.15$ mm.
[2] M material group

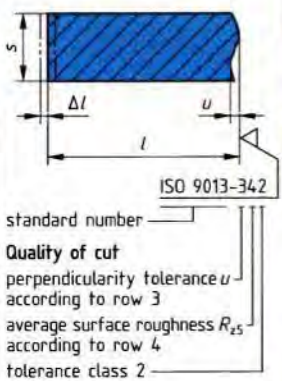
## Cutting quality and dimensional tolerances for thermal cuts

cf. DIN EN ISO 9013 (2003-07)

The specifications apply to
- oxy-fuel gas cutting,
- plasma cutting,
- laser beam cutting.

The quality of the cut surfaces is determined by
- the perpendicularity tolerance $u$,
- the average surface roughness $R_{z5}$.

$l$ nominal length
$s$ workpiece thickness
$u$ perpendicularity tolerance
$R_{z5}$ average surface roughness
$\Delta l$ limit deviations from the nominal length $l$




### Quality of cut surfaces

| Range | Perpendicularity tolerance $u$ in mm | Average surface roughness $R_{z5}$ in µm | Comments |
|---|---|---|---|
| 1 | $u < 0.05 + 0.03 \cdot s$ | $R_{z5} < 10 + 0.6 \cdot s$ | Put in workpiece thickness in mm |
| 2 | $u < 0.15 + 0.07 \cdot s$ | $R_{z5} < 40 + 0.8 \cdot s$ | |
| 3 | $u < 0.4 + 0.01 \cdot s$ | $R_{z5} < 70 + 1.2 \cdot s$ | |
| 4 | $u < 1.2 + 0.035 \cdot s$ | $R_{z5} < 110 + 1.8 \cdot s$ | |

### Limit deviations from the nominal length

| Workpiece thickness $s$ in mm | Limit deviations $\Delta l$ from nominal lengths $l$ in mm | | | | | |
|---|---|---|---|---|---|---|
| | Tolerance class 1 | | | Tolerance class 2 | | |
| | > 35 ≤ 125 | > 125 ≤ 315 | > 315 ≤ 1000 | > 35 ≤ 125 | > 125 ≤ 315 | > 315 ≤ 1000 |
| > 1 ≤ 3.15 | ± 0.3 | ± 0.3 | ± 0.4 | ± 0.5 | ± 0.7 | ± 0.8 |
| > 3.15 ≤ 6.3 | ± 0.4 | ± 0.4 | ± 0.5 | ± 0.8 | ± 0.9 | ± 1.1 |
| > 6.3 ≤ 10 | ± 0.6 | ± 0.7 | ± 0.7 | ± 1.3 | ± 1.4 | ± 1.5 |
| > 10 ≤ 50 | ± 0.7 | ± 0.7 | ± 0.8 | ± 1.8 | ± 1.9 | ± 2.3 |
| > 50 ≤ 100 | ± 1.3 | ± 1.4 | ± 1.7 | ± 2.5 | ± 2.6 | ± 3.0 |
| > 100 ≤ 150 | ± 1.9 | ± 2.0 | ± 2.1 | ± 3.3 | ± 3.4 | ± 3.7 |

**Example:** oxy-fuel gas cutting according to tolerance class 2, $l = 450$ mm, $s = 12$ mm, cutting quality according to range 4

**Sought after:** $\Delta l$; $u$; $R_{z5}$

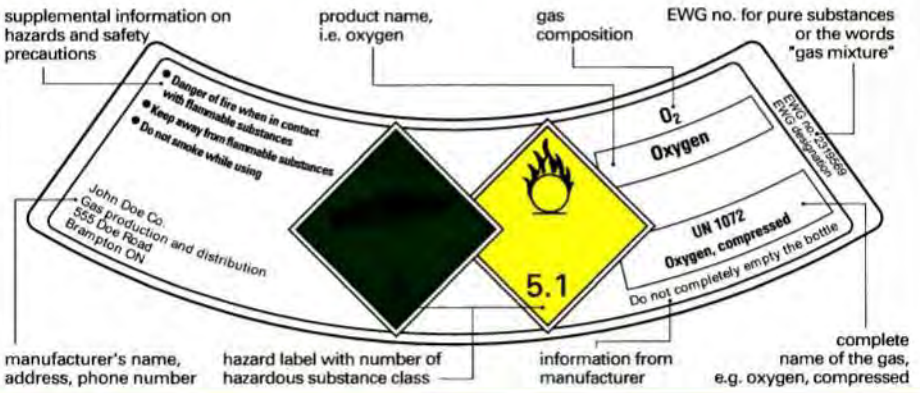
**Solution:**
$\Delta l = \pm 2.3$ mm
$u = 1.2 + 0.035 \cdot s = 1.2$ mm $+ 0.035 \cdot 12$ mm $= 1.62$ mm
$R_{z5} = 110 + 1.8 \cdot s = 110$ µm $+ 1.8 \cdot 12$ µm $= 131.6$ µm

# Gas cylinders – Identification*

## Hazardous substance labels

cf. DIN EN ISO 7225 (2008-02)

A hazardous substance label must be applied to individual gas cylinders to identify their contents and any possible hazards from these contents. Up to three hazard labels warn of the main hazards.
Example:




## Hazard label




non-combustible, non-toxic | combustible | toxic | flammable | corrosive

## Color coding

cf. DIN EN 1089-3 (2004-06)

Color coding of the cylinder shoulder is used as additional information about the properties of the gases.
It is readily recognized when the hazardous substance label is illegible from a distance.
This color coding does not apply to liquid gases.

## General color coding




toxic and/or corrosive | flammable | oxidizing | inert 2)

## Color coding for special gases




Oxygen | Acetylene | Argon | Nitrogen | Carbon dioxide | Helium

1) N = new 2) Non-toxic, non-corrosive, non-flammable, non-oxidizing
*) According to European Standards

# Gas cylinders – Identification*

**Pure gases and gas mixtures for industrial use**
**Color coding (examples)** cf. Information sheet from Industrial Gases Association

| Coding old | Coding new[1) 2)] |
|---|---|
| **Oxygen** | |
| blue / blue | white / blue |
| **Acetylene** | |
| yellow / yellow (black) | chestnut brown / chestnut brown |
| **Argon** | |
| gray / gray | dark green / gray |
| **Nitrogen** | |
| dark green / dark green | black / gray |
| **Carbon dioxide** | |
| gray / gray | gray / gray |
| **Helium** | |
| gray / gray | brown / gray |
| **Xenon, Krypton, Neon** | |
| gray / gray (black) | flourescent green / gray |
| **Hydrogen** | |
| red / red | red / red |
| **Forming gas (mixture of nitrogen/hydrogen)** | |
| red / red (dark green) | red / gray |
| **Mixture of argon/carbon dioxide** | |
| gray / gray | flourescent green / gray |
| **Compressed air** | |
| gray / gray | flourescent green / gray |

[1)] For gas cylinders color coded as per DIN EN 1089, the letter "N" (= new) must be put on the shoulder of the cylinder two times (opposite sides). The "N" is not required on cylinders whose color coding has not changed.

[2)] The cylinder body may be another color. However, this must not lead to confusion regarding the hazardous nature of the cylinder contents.

*) According to European Standards

# Brazing

## Brazing heavy non-ferrous metals

cf. DIN EN 1044 (1999-07)

### Silver containing brazing materials

| Brazing material: Group | Designation[1] | Material number | Alloy designation as per ISO 3677[2] | Working temperature °C | Brazing joint[3] | Solder feed[4] | Information for use: Materials |
|---|---|---|---|---|---|---|---|
| AgCuCdZn | AG 301 | 2.5143 | B-Ag50CdZnCu-620/640 | 640 | G | f, l | precious metals, steels, copper alloys |
| | AG 302 | 2.5146 | B-Ag45CdZnCu-605/620 | 620 | G | f, l | |
| | AG 304 | 2.5141 | B-Ag45ZnCdCu-595/630 | 610 | G | f, l | steels, malleable cast iron, copper, copper alloys, nickel, nickel alloys |
| | AG 309 | 2.1215 | B-Cu40ZnAgCd-605/765 | 750 | G, V | f, l | |
| AgCuZn(Sn) | AG 104 | 2.5158 | B-Ag45CuZnSn-640/680 | 670 | G | f, l | steels, malleable cast iron, copper, copper alloys, nickel, nickel alloys |
| | AG 106 | 2.5157 | B-Cu36AgZnSn-630/730 | 710 | G | f, l | |
| | AG 203 | 2.5147 | B-Ag44CuZn-675/735 | 730 | G | f, l | |
| | AG 205 | 2.1216 | B-Cu40ZnAg-700/790 | 780 | G | f, l | |
| Silver content below 20% | AG 207 | 2.1207 | B-Cu48ZnAg(Si)-800/830 | 830 | G | f, l | steels, malleable cast iron, copper, copper alloys, nickel, nickel alloys |
| | AG 208 | 2.1205 | B-Cu55ZnAg(Si)-820/870 | 860 | G, V | f, l | |
| | CP 102 | 2.1210 | B-Cu80AgP-645/800 | 710 | G, V | f, l | copper and nickel-free copper alloys. **Unsuitable** for materials containing Fe or Ni |
| | CP 104 | 2.1466 | B-Cu89PAg-645/815 | 710 | G, V | f, l | |
| | CP 105 | 2.1467 | B-Cu92PAg-645/825 | 710 | G, V | f, l | |
| Special brazing | AG 351 | 2.5160 | B-Ag50CdZnCuNi-635/655 | 660 | G | f, l | Cu alloys |
| | AG 403 | 2.5162 | B-Ag56CuInNi-600/710 | 730 | G | f, l | chrome, chrome-nickel steels |
| | AG 502 | 2.5156 | B-Ag49ZnCuMnNi-680/705 | 690 | G | f, l | carbide onto steel, tungsten and molybdenum materials |

### Copper based brazing materials

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| CU 104 | 2.0091 | B-Cu100(P)-1085 | 1100 | G | l | steels |
| CU 201 | 2.1021 | B-Cu94Sn(P)-910/1040 | 1040 | G | l | iron and nickel materials |
| CU 202 | 2.1055 | B-Cu88Sn(P)-825/990 | 990 | G | l | |
| CU 301 | 2.0367 | L-CuZn40 | 900 | G, V | f, l | steels, malleab. iron, Cu, Ni, Cu & Ni alloys |
| CU 305 | 2.0711 | B-Cu48ZnNi(Si)-890/920 | 910 | G, V | f, l | steels, malleable iron, Ni, Ni alloys |
| | | | | V | f | cast iron |
| CP 202 | 2.1463 | B-Cu93P-710/820 | 720 | G | f, l | Cu, Fe-free and Ni-free Cu alloys |

### Nickel based brazing materials for high-temperature brazing

| | | | | | | |
|---|---|---|---|---|---|---|
| NI 101 | 2.4140 | B-Ni73CrFeSiB(C)-960/1060 | [5] | [5] | [5] | nickel, cobalt, nickel and cobalt alloys, unalloyed and alloyed steels |
| NI 103 | 2.4143 | B-Ni92SiB-980/1040 | | | | |
| NI 105 | 2.4148 | B-Ni71CrSi-1080/1135 | | | | |
| NI 107 | 2.4150 | B-Ni76CrP-890 | | | | |

### Aluminum based brazing materials

| | | | | | | |
|---|---|---|---|---|---|---|
| AL 102 | 3.2280 | B-Al92Si-575/615 | 610 | G | f, l | aluminum and Al alloy types AlMn, AlMgMn, G-AlSi; especially for Al alloy types AlMg, AlMgSi up to 2% Mg content |
| AL 103 | 3.2282 | B-Al90Si-575/590 | 600 | G | f, l | |
| AL 104 | 3.2285 | B-Al88Si-575/585 | 595 | G | f, l | |

[1] The two letters indicate the alloy group, while the three digit numbers are purely numbers increasing sequentially.

[2] Numbers at the end indicate the melting range. Alloy components, see pages 116 and 117.

[3] G suitable for gap brazing; V suitable for V-joint brazing

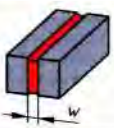
[4] f filled brazing; l lapped brazing

[5] Refer to manufacturer's data.

**Brazing joint**

Gap brazing: $w < 0.25$ mm

V-joint brazing: $w > 0.3$ mm



# Solders and flux

## Solders

cf. DIN EN ISO 9453 (2006-12)

| Alloy group[1] | Alloy no.[2] | Alloy designation as per ISO 3677[3] | Previous designation DIN 1707 | Working temperature °C | Application examples |
|---|---|---|---|---|---|
| tin-lead | 101 | S-Sn63Pb37 | L-Sn63Pb | 183 | precision mechanics |
| | 102 | S-Sn63Pb37E | L-Sn63Pb | 183 | electronics, printed circuit boards |
| | 103 | S-Sn60Pb40 | L-Sn60Pb | 183–190 | printed circuit boards, high-grade steel |
| lead-tin | 111 | S-Pb50Sn50 | L-Sn50Pb | 183–215 | electronics industry, tin plating |
| | 114 | S-Pb60Sn40 | L-PbSn40 | 183–235 | thin-sheet packaging, metal goods |
| | 116 | S-Pb70Sn30 | – | 183–255 | plumbing work, zinc, zinc alloys |
| | 124 | S-Pb98Sn2 | L-PbSn2 | 320–325 | radiator manufacturing |
| tin-lead-antimony | 131 | S-Sn63Pb37Sb | – | 183 | precision mechanics |
| | 132 | S-Sn60Pb40Sb | L-Sn60Pb(Sb) | 183–190 | precision mechanics, electrical industry |
| | 134 | S-Pb58Sn40Sb2 | L-PbSn40Sb | 185–231 | radiator manufacturing, wiping solder |
| | 136 | S-Pb74Sn25Sb1 | L-PbSn25Sb | 185–263 | wiping solder, lead solders |
| tin-lead-bismuth | 141 | S-Sn60Pb38Bi2 | – | 180–185 | precision solders |
| | 142 | S-Pb49Sn48Bi3 | – | 138 | low-temperature solder, safety fuses |
| tin-lead-cadmium | 151 | S-Sn50Pb32Cd18 | L-SnPbCd18 | 145 | thermal fuses, cable joints |
| tin-lead-copper | 161 | S-Sn60Pb39Cu1 | L-SnPbCu3 | 230–250 | electronic devices, precision mechanics |
| | 162 | S-Sn50Pb49Cu1 | L-Sn50PbCu | 183–215 | |
| tin-lead-silver | 171 | S-Sn60PbAg | L-Sn60PbAg | 178–180 | electrical devices, printed circuit boards |
| lead-tin-silver | 182 | S-Pb95Ag5 | L-PbAg5 | 304–365 | for high operating temperatures |
| | 191 | S-Pb93Sn5Ag2 | – | 296–301 | electric motors, electrical equipment |

[1] Filler metals for aluminium are no longer in EN ISO 9453.
[2] The alloy numbers replace the material numbers as per DIN 1707.
[3] With traces (<0.5%) of Sb, Bi, Cd, Au, In, Al, Fe, Ni, Zn: see pages 116 and 117.

## Flux for soldering

cf. DIN EN 29454-1 (1994-02)

| Designation by main constituents | | | | Classification by effect | | |
|---|---|---|---|---|---|---|
| Flux type | Flux basis | Flux activator | Flux form | Designations DIN EN | DIN 8511 | Effect of residues |
| 1 rosin | 1 colophonium<br>2 without colophonium | 1 without activator<br>2 activated by halogens<br>3 activated without halogens | A liquid<br>B solid<br>C paste | 3.2.2...<br>3.1.1... | F-SW11<br>F-SW12 | very corrosive |
| 2 organic | 1 water soluble<br>2 not water soluble | | | 3.2.1...<br>3.1.1... | F-SW13<br>F-SW21 | somewhat corrosive |
| 3 inorganic | 1 salts | 1 with ammonium chloride<br>2 without ammonium chloride | | 2.1.3...<br>2.1.2... | F-SW23<br>F-SW25 | |
| | 2 acids | 1 phosphoric acid<br>2 other acids | | 1.2.2... | F-SW28 | |
| | 3 alkaline | 1 amine and/or ammonia | | 1.1.1...<br>1.2.3... | F-SW31<br>F-SW33 | non-corrosive |
| ⇒ | **Flux ISO 9454 – 1.2.2.C:** Flux of type rosin (1), base without colophonium (2), activated by halogens (2), available in paste form (C) | | | | | |

## Flux for brazing

cf. DIN EN 1045 (1997-08)

| Flux | Activation temper. | Instructions for use |
|---|---|---|
| FH10 | 550–800 °C | Multi-purpose flux; residues rinsed off or chemically stripped. |
| FH11 | 550–800 °C | Cu-Al alloys; residues rinsed off or chemically stripped. |
| FH12 | 550–850 °C | Stainless and high-alloy steels, carbide; residues chemically stripped. |
| FH20 | 700–1000 °C | Multi-purpose flux; residues rinsed off or chemically stripped. |
| FH21 | 750–1100 °C | Multi-purpose flux; residues removed mechanically or chemically stripped. |
| FH30 | over 1000 °C | For copper and nickel solder; residues removed mechanically. |
| FH40 | 650–1000 °C | Boron-free flux; residues rinsed off or chemically stripped. |
| FL10 | 400–700 °C | Light alloys; residues are rinsed off or chemically stripped. |
| FL20 | 400–700 °C | Light alloys; residues are non-corrosive, but should be protected from moisture. |

# Soldered and brazed joints

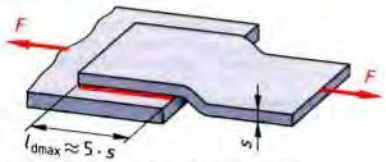
## Classification of soldering and brazing processes

| Differentiating characteristics | Soldering and brazing processes | | |
|---|---|---|---|
| | Soldering | Brazing | High temperature brazing |
| Working temperature | < 450 °C | > 450 °C | > 900 °C |
| Energy source | soldering iron, soldering bath, electrical resistance | flame, furnace | flame, laser beam, electric induction |
| Base material | Cu, Ag, Al alloys, stainless steel, steel, Cu, Ni alloys | steel, carbide inserts | steel, carbide |
| Soldering or filler material | Sn, Pb alloys | Cu, Ag alloys | Ni-Cr alloys, Ag-Au-Pd alloys |
| Auxiliary materials | Flux | flux, vacuum | vacuum, shielding gas |

## Standard values for soldering gap widths

| Base material | Soldering gap width in mm | | | |
|---|---|---|---|---|
| | for solders | for brazing materials primarily of | | |
| | | copper | brass | silver |
| unalloyed steel | 0.05–0.2 | 0.05–0.15 | 0.1–0.3 | 0.05–0.2 |
| Alloy steel | 0.1–0.25 | 0.1–0.2 | 0.1–0.35 | 0.1–0.25 |
| Cu, Cu alloys | 0.05–0.2 | – | – | 0.05–0.25 |
| Carbide | – | 0.3–0.5 | – | 0.3–0.5 |

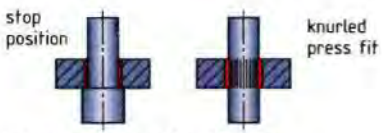
## Design rules for soldered joints




Soldered joint under shearing load



Load on solder joint reduced by folded seam




Production process simplification



Soldered pipe fitting

**Preconditions**

- Soldering gap should be large enough so that flux and solder adequately fill the gap by capillary action (table above)
- The two surfaces to be soldered should be parallel.
- Surface roughness due to machining can remain for Cu soldering $Rz$ = 10–16 µm, for Ag soldering at $Rz$ = 25 µm.

**Load transfer**

- The load on the soldered joint should be in shear (transverse forces) if at all possible. In particular, solder seams should not be loaded with tensile or peeling stress.
- Soldering gap depths $l_d > 5 \cdot s$ do not fill with solder reliably. Therefore load capacity cannot be increased by a larger gap depth.
- Load capacity can be increased by design features such as folds

**Production process simplification**

- In soldering there should be a means for assuring proper positioning of the parts to be joined, e.g. by part shape or by knurled press fit.

**Application examples**

- pipes and fittings
- sheet metal parts
- tools with brazed carbide cutters

# Adhesives, Preparation of joint surfaces

## Properties and conditions of use for adhesives[1]

| Adhesive | Trade name | Curing conditions | | max. operating temperature °C | Comb. tensile and shear strength $\tau_B$ N/mm² | Elasticity | Applications, special characteristics |
|---|---|---|---|---|---|---|---|
| | | Temperature °C | Time | | | | |
| Acrylic resins | Agomet M, Acronal, Stabilit-Express | 20 | 24 hr | 120 | 6–30 | low | metals, thermosets, ceramics, glass |
| Epoxy resins (EP) | Araldit, Metallon, Uhu-Plus | 20–200 | 1 hr to 12 hr | 50–200 | 10–35 | low | metals, thermosets, glass, ceramics, concrete, wood; long curing time |
| Phenolic resins (PF) | Porodur, Pertinax, Bakelite | 120–200 | 60 s | 140 | 20 | low | metals, thermosets, glass, elastomers, wood, ceramics |
| Polyvinyl chloride (PVC) | Hostalit, Isodur, Macroplast | 20 | > 24 hr | 60 | 60 | low | metals, thermosets, glass, elastomers, wood, ceramics |
| Polyurethane (PUR) | Desmocoll, Delopur, Baydur | 50 | 24 hr | 40 | 50 | present | metals, elastomers, glass, wood, some thermoplastics |
| Polyester resins (UP) | Fibron, Leguval, Verstopal | 25 | 1 hr | 170 | 60 | low | metals, thermosets, ceramics, glass |
| Polychloroprene (CR) | Baypren, Contitec, Fastbond | 50 | 1 hr | 110 | 5 | present | contact glue for metals and plastics |
| Cyanoacrylate | Permabond, Sicomet 77 | 20 | 40 s | 85 | 20–25 | low | fast-curing adhesive for metals, plastics, elastomers |
| Hot glue | Jet-Melt, Ecomelt, Vesta-Melt | 20 | > 30 s | 50 | 2–5 | present | all types of materials; adhesive action through cooling |

[1] Due to varying chemical compositions of adhesives, the values given are only approximate values. For detailed information please refer to information from the manufacturer.

## Preparation of parts for bonded joints

cf. VDI 2229 (1979-06)

| Material | Treatment sequence[1] for load severity[2] | | | Material | Treatment sequence[1] for load severity[2] | | |
|---|---|---|---|---|---|---|---|
| | low | medium | high | | low | medium | high |
| Al alloys | | 1-6-5-3-4 | 1-2-7-8-3-4 | Steel, bright | | 1-6-2-3-4 | 1-7-2-3-4 |
| Mg alloys | 1-2-3-4 | 1-6-2-3-4 | 1-7-2-9-3-4 | Steel, galvanized | 1-2-3-4 | 1-2-3-4 | 1-2-3-4 |
| Ti alloys | | 1-6-2-3-4 | 1-2-10-3-4 | Steel, phosphatized | | 1-2-3-4 | 1-6-2-3-4 |
| Cu alloys | 1-2-3-4 | 1-6-2-3-4 | 1-7-2-3-4 | Other metals | 1-2-3-4 | 1-6-2-3-4 | 1-7-2-3-4 |

[1] **Code numbers for type of treatment**

1 **Cleaning** of dirt, scale, rust
2 **Removing grease** with organic solvent or aqueous cleaning agent
3 **Rinsing** with clear water
4 **Drying** in hot air up to 65 °C
5 **Removing grease** with simultaneous etching
6 **Mechanical roughing** by grinding or brushing
7 **Mechanical roughing** by shot blasting
8 **Etching 30 min**, at 60 °C in 27.5% sulfuric acid solution
9 **Etching 1 min**, at 20 °C in 20% nitric acid solution
10 **Etching 3 min**, at 20 °C in 15% hydrofluoric acid solution

[2] **Load severity for bonded joints**

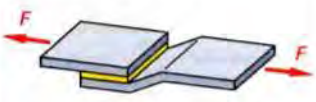
**Low:** Tensile shear strength up to 5 N/mm²; dry environment; for precision mechanics, electrical equipment
**Medium:** Tensile shear strength up to 10 N/mm²; humid air; contact with oil; for machine and vehicule manufacturing
**High:** Tensile shear strength up to 10 N/mm²; direct contact with liquids; for aircraft, ship, and container manufacturing

# Design of adhesive bonded joints, Test methods

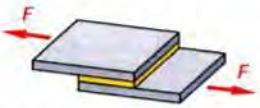
## Design examples

Bonded joints should be loaded in compression or shearing if possible.
Tensile, peeling or bending loads should be avoided.

**Butt joint/overlap joint**

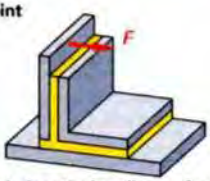



**good**, since the bonding surfaces only have a shear load

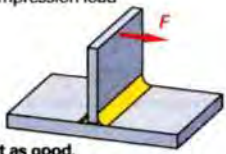



**not as good**, since peeling forces act due to off-center application of force

**T-joint**

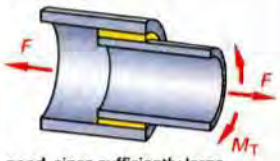



**good**, since the bonding surfaces only have a shear and compression load




**not as good**, since peeling forces act due to bending load

**Tube joint**




**good**, since sufficiently large bonding surfaces can withstand shear load



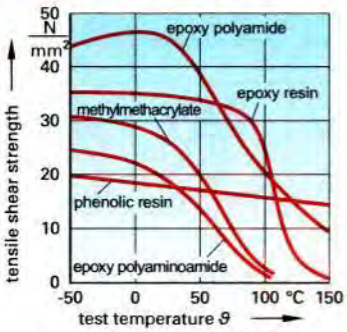

**not as good**, since small bonding surfaces cannot withstand tensile and shear load

## Test methods

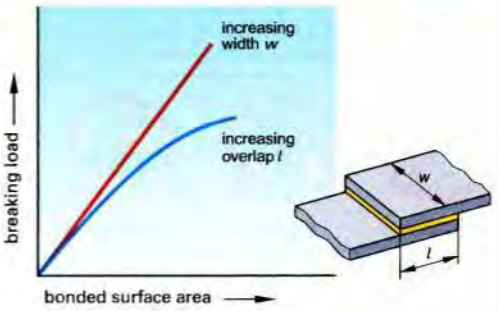
| Test method standard | Contents |
|---|---|
| **Bending peel test** DIN 54461 | Tests resistance of bonded joints against peeling forces |
| **Tensile shear test** DIN EN 1465 | Tests tensile shear strength of high-strength bonded lap joints |
| **Fatigue test** DIN EN ISO 9664 | Tests fatigue properties of structural adhesives under tensile-shear loads |
| **Tensile test** DIN EN 26922 | Tests tensile strength of bonded butt joints perpendicular to bonded surface |
| **Roller peel test** DIN EN 1464 | Tests resistance to peeling forces |
| **Compression shear test** DIN EN 15337 | Tests shear strength, primarily of anaerobic[1] adhesives |

[1] Sets with exclusion of air

## Adhesive behavior as a function of temperature and size of bonding surface




**Tensile shear strength of overlap bonded joints**




**Effect of adhesive joint surface area on breaking load**

# Safety colors, Prohibitive signs*

## Safety colors

cf. DIN 4844-1 (2005-05) and BGV A8[1] (2002-04)

| Color | red | yellow | green | blue |
|---|---|---|---|---|
| **Meaning** | stop, prohibited | caution! potential danger | safety, first aid | mandatory signs, notices |
| **Contrast color** | white | black | white | white |
| **Color of graphic symbol** | black | black | white | white |
| **Application examples** (see pages 340 and 341) | Stop signs, emergency stop prohibitive signs, fire fighting equipment | Notice of hazards (e.g. fire, explosion, radiation); notice of obstructions (e.g. speed bumps, holes) | Identification of ambulances and emergency exits; first aid and emergency aid stations | Requirement to wear personal protective equipment (PPE); location of a telephone |

## Prohibitive signs

cf. DIN 4844-2 (2001-02) and BGV A8[1] (2002-04)



| | | | | | |
|---|---|---|---|---|---|
| Prohibited | No smoking | No fires, open flame or smoking | Pedestrian access prohibited | Do not extinguish with water | Non-potable water |
| Access prohibited for unauthorized persons | Access by forklifts prohibited | Do not touch | Do not touch – live voltage | Do not connect | No access for persons with pacemaker |
| Placement or storage prohibited | Transport of passengers prohibited | Walking in this area prohibited | No spraying with water | No cell phones | No food or drink allowed |
| No magnetic or electronic data media allowed | Climbing prohibited for unauthorized persons | Do not use this device in the bathtub, shower or sink | Do not reach in | Operating with long hair prohibited | Hand-held or manually operated grinding not allowed |

[1] German Employer's Liability Insurance Association – Accident Prevention Regulations (Berufsgenossenschaftliche Unfallverhütungsvorschrift) BGV A8 (replaces VGB 125)

*) According to European Standards

# Warning signs*

**Warning signs** cf. DIN 4844-2 (2001-02) and BGV A8[1] (2002-04)

| | | | | | |
|---|---|---|---|---|---|
|  Warning: Hazardous area |  Warning: Combustible materials |  Warning: Explosive substances |  Warning: Toxic substances |  Warning: Corrosive substances |  Warning: Radioactive materials or ionizing radiation |
|  Warning: Suspended load |  Warning: Forklift traffic |  Danger: High voltage |  Warning: Optical radiation |  Warning: Laser beam radiation |  Warning: Oxidizing substances |
|  Warning: Non-ionic, electromagnetic radiation |  Warning: Strong magnetic field |  Warning: Danger of tripping |  Warning: Danger of falling |  Warning: Biological hazard |  Warning: Extreme cold |
|  Warning: Substances hazardous to health or irritants |  Warning: Gas cylinders |  Warning: Hazards due to batteries |   Warning: Explosive atmosphere |  Warning: Milling shaft |  Warning: Crushing hazard |
|  Warning: Danger of tipping when rolling |  Warning: Automatic start-up |  Warning: Hot surface |  Warning: Risk of hand injury |  Warning: Danger of slipping |  Warning: Moving conveyor on track |

[1] German Employer's Liability Insurance Association – Accident Prevention Regulations (Berufsgenossenschaftliche Unfallverhütungsvorschrift) BGV A8 (replaces VGB 125)

*) According to European Standards

# Safety signs*

cf. DIN 4844-2 (2001-02) and BGV A8[1] (2002-04)

## Mandatory signs


General mandatory sign


Wear safety glasses


Wear hard hat


Wear ear protection


Wear respirator


Wear safety shoes


Wear protective gloves


Wear protective clothing


Wear face protection


Use safety belt


For pedestrians


Use safety harness


Use crosswalk


Disc. plug from power bef. opening


Disconnect before working


Wear life preserver


Sound horn


Follow instructions

## Escape and rescue signs for escape routes and emergency exits


Direction arrows for escape routes and emergency exits[2]


First aid stations, emergency exits[2]


First aid


Medical stretcher


Emergency shower


Eye rinsing equipment


Emergency telephone


Doctor


Defibrillator



Escape route/Emergency exit


Meeting point

## Fire protection symbols and additional symbols



Directional arrows


Wall hydrant and fire hose

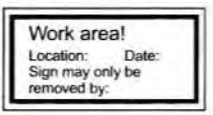

Ladder


Fire extinguisher

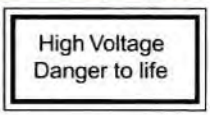

Fire alarm telephone


Fire fighting equipment


Manual fire alarm



Extra sign which gives more information to supplement the safety sign



Extra sign which gives more information to supplement the safety sign

[1] German Employer's Liability Insurance Association – Accident Prevention Regulations (Berufsgenossenschaftliche Unfallverhütungsvorschrift) BGV A8

[2] only in combination with other escape route and rescue signs

*) According to European Standards

# Safety signs*

cf. DIN 4844-2 (2001-02) and BGV A8[1] (2002-04)

## Information signs

Discharge time longer than 1 minute

In case of failure part can have live voltage

Before touching:
- discharge
- ground
- short circuit

5 Safety rules
Before beginning work
- Employ safety disconnect
- Lock out to prevent restart
- Check for no voltage
- Ground and short circuit
- Cover or enclose adjacent parts which have live voltage

## Combination signs




Do not connect




Warning of high voltage

Combination signs for escape routes or emergency exits with corresponding direction indicated by arrows










First aid station




Prohibited! Walking on roof is prohibited.




Fire blanket for fighting fire




Danger of toxic gases

[1] German Employer's Liability Insurance Association – Accident Prevention Regulations (Berufsgenossenschaftliche Unfallverhütungsvorschrift) BGV A8 (replaces VGB 125)

*) According to European Standards

## Danger symbols and description of hazards*

RL 67/548/EWG (2004-04)[1]

| Code letter, danger symbol, hazard description | Danger criteria of materials | Code letter, danger symbol, hazard description | Danger criteria of materials | Code letter, danger symbol, hazard description | Danger criteria of materials |
|---|---|---|---|---|---|
| **T+**<br>  <br>**Very toxic** | When consumed in very small amounts leads to death or may cause acute or chronic damage to health.<br>T = toxic | **Xi**<br>  <br>**Irritant** | Contact with skin or mucus membranes can cause inflammation.<br>X = St. Andrew's cross<br>i = irritating | **F**<br>  <br>**Flammable** | Solid material can be easily ignited by a source of ignition. Liquid material with flash point < 21 °C.<br>F = flammable |
| **T**<br>  <br>**Toxic** | When consumed in small amounts leads to death or may cause acute or chronic damage to health.<br>T = toxic | **E**<br>  <br>**Danger of explosion** | Risk of explosion by shock, friction, fire or other sources of ignition.<br>E = explosive | **N**<br>  <br>**Environmentally dangerous** | Substances change water, ground, air, climate, animals, plants, etc. in such a way that the environment is endangered.<br>N = noxious (harmful) |
| **Xn**<br>  <br>**Harmful to health** | When ingested may result in death or cause acute or chronic harm to health.<br>X = St. Andrew's cross<br>n = noxious | **O**<br>  <br>**Oxidizing** | Substances that substantially increase the risk and severity of a fire, because they produce oxygen.<br>O = oxidizing | **T with R 45**<br>  <br>**Carcinogenic** | Substance may cause cancer from inhaling, swallowing or from contact with the skin.<br>R 45: May cause cancer<br>T = toxic |
| **C**<br>  <br>**Corrosive** | Living tissue can be damaged by contact.<br>C = corrosive | **F+**<br>  <br>**Highly flammable** | Liquid substances with flash point < 0 °C and boiling point < 35 °C; gaseous substances, which are flammable in contact with air.<br>F = flammable | **T with R 46**<br>  <br>**Mutagenic substances** | Substances which can have a mutagenic effect on humans.<br>R 46: May cause heritable genetic damage.<br>T = toxic |
| **Xn with R 40**<br>  <br>**Limited evidence of mutagenic effect** | Substance which can cause concern due to possible mutagenic effect on humans. However, there is not yet sufficient information available to give conclusive proof.<br>X = St. Andrew's cross<br>n = noxious<br>R 40 = irreversible damage possible (page 199) | **T with R 60, R 61**<br>  <br>**Danger to fertility** | Substances which are known to impair fertility or reproduction.<br>T = toxic<br>R 60 = may impair fertility<br>R 61 = may cause harm to the unborn child | **Xn with R 62, R 63**<br>  <br>**Limited evidence of influence on fertility** | Substances which cause concern due to possible impairment of fertility of humans.<br>X = St. Andrew's cross<br>n = noxious<br>R 62 = possible risk of impaired fertility<br>R 63 = possible risk of harm to unborn child |

[1] EU-Directive, Appendix II *) According to European Standards

# Identification of pipe lines*

cf. DIN 2403 (2007-05)

## Area of application and requirements

**Area of application:** A precise identification marking of pipe lines, indicating the substance being conveyed, is necessary for reasons of safety, fire fighting and proper maintenance and repairs. The identification marking is intended to indicate possible hazards and help to prevent accidents and damage to health.

**Requirements concerning identification marking**

- Identification marking must be clearly visible and long-lasting.
- Identification can be established by painting, lettering (e.g. via self-adhesive foil strips) or signs.
- Particularly operation-critical and hazardous places should be marked (e.g. beginning and end of branch pipes, wall penetrations, fittings).
- Marking must be repeated at least every 10 m of pipe length.
- Indication of the group and supplemental color (see table below).
- Indication of the flow direction by means of an arrow.
- Indication of the conveyed substance by specifying the name (e.g. water) or the chemical formula (e. g. $H_2O$).
- With hazardous materials, additional indication of hazard signs (page 342) or warning signs (page 339) if general hazards are implied.

## Color assignment according to conveyed substances

| Conveyed substance | Group | Group color | RAL | Supplem. color | RAL | Color of lettering | RAL |
|---|---|---|---|---|---|---|---|
| Water | 1 | green | 6032 | – | – | white | 9003 |
| Steam | 2 | red | 3001 | – | – | white | 9003 |
| Air | 3 | gray | 7004 | – | – | black | 9004 |
| Flammable gases | 4 | yellow | 1003 | red | 3001 | black | 9004 |
| Non-flammable gases | 5 | yellow | 1003 | black | 9004 | black | 9004 |
| Acids | 6 | orange | 2010 | – | – | white | 9003 |
| Lyes | 7 | purple | 4008 | – | – | white | 9003 |
| Flammable liquids and solid materials | 8 | brown | 8002 | red | 3001 | white | 9003 |
| Non-flammable liquids and solid materials | 9 | brown | 8002 | black | 9004 | white | 9003 |
| Oxygen | 0 | blue | 5005 | – | – | white | 9003 |

## Identification of special pipe lines

**Fire extinguishing lines** must be fitted with a red/white/red color marking. The white field contains the graphical symbol of the safety sign "Fire fighting equipment and materials" (cf. page 340) in the color of the extinguishing agent.

**Potable water lines** must be fitted with a green/white/green color marking. **Non-potable water lines** have a green/blue/green marking. The code letters and their colors are listed in the table below.

| Description | Code | Color | Description | Code | Color |
|---|---|---|---|---|---|
| Potable water line<br>Potable water line, cold | PW<br>PWC | green | Potable water line, hot, circulating | PWH-C | purple |
| Potable water line, hot | PWH | red | Non-potable water line | NPW | white |

**Examples of identification marking**

Heating oil




Fire extinguishing unit (water)




Potable water




Compressed air




Oxygen (fire-promoting, O)




Acetylene (highly flammable, F+)




*) According to European Standards

# Sound and noise*

## Sonic terms

| Term | Explanation |
|---|---|
| **Sound** | Sound comes from mechanical vibrations. It propagates in gaseous, liquid and solid bodies. |
| **Frequency** | Number of oscillations per second. Unit: 1 Hertz = 1 Hz = 1/s. Pitch increases with frequency. Frequency range of human hearing: 16 Hz–20.000 Hz. |
| **Sound level** | Measure of the sound strength (sound energy). |
| **Noise** | Undesirable, annoying or painful sound waves; damage depends on strength, duration, frequency and regularity of exposure. For a noise level of 85 dB (A) and higher there is danger of permanent hearing loss. |
| **Decibel (dB)** | Standardized unit for sound level. |
| **dB (A)** | Since the human ear perceives tones of different heights (frequencies) to have different strengths when they are actually at the same sound levels, noise must be appropriately dampened with filters for certain frequencies. Frequency weighting curve with Filter A compensates for this and indicates the subjective auditory impression. A difference of 3 dB (A) corresponds approximately to a doubling (or halving) of the sound intensity. |

## Sound level

| Type of sound | dB (A) | Type of sound | dB (A) | Type of sound | dB (A) |
|---|---|---|---|---|---|
| Threshold of auditory sensitivity | 4 | normal speech at distance of 1 m | 70 | heavy stamping | 95–110 |
| Breathing at distance of 30 cm | 10 | machine tools | 75–90 | angle grinder | 95–115 |
| Soft rustling of leaves | 20 | loud talking at distance of 1 m | 80 | car horn at distance of 5 m | 100 |
| Whispering | 30 | welding torch, lathe | 85 | disco music | 100–115 |
| Tearing paper | 40 | hammer drill, motorcycle | 90 | hammer and anvil | 110 |
| Quiet conversation | 50–60 | engine test stand, walkman | 90–110 | jet engine | 120–130 |

## Noise protection regulations

cf. Accident Prevention Regulations on "Noise" BGV B3 (1997-01)

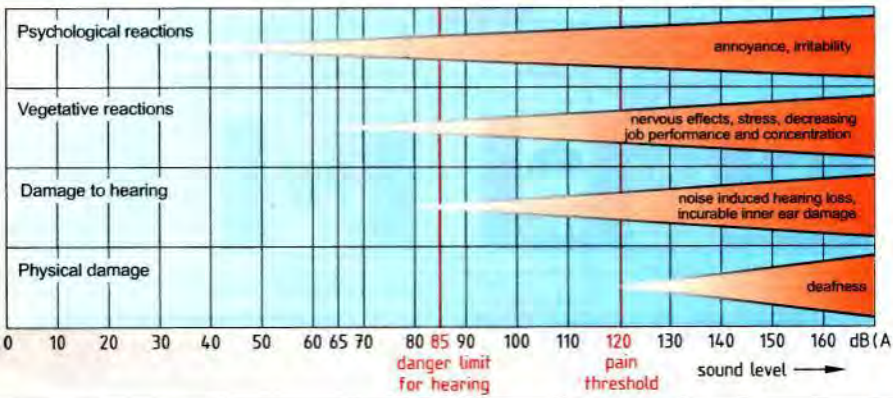
**Accident prevention regulations for noise producing operations**

- Requirem. to post signage for noise ranges 90 dB (A) and above.
- Above 85 dB (A) sound protection devices must be available, and they must be used above 90 dB (A).
- If the risk of accidents increases due to noise, appropriate measures must be taken.
- Regular preventative medical checkups are compulsory.
- New operational equipment must conform to the most advanced level of noise reduction.

**§ 15 Workplace regulation**

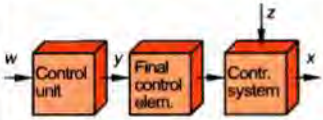
| Noise limit value for: | max. dB (A) |
|---|---|
| predominantly mental activities | 55 |
| simple, predominantly mechanized activities | 70 |
| all other activities (value may be exceeded by 5 dB ) | 85 |
| break rooms, ready rooms and first-aid rooms | 55 |

## Noise harmful to health



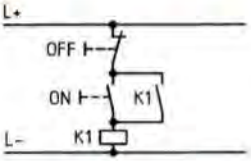

*) According to European Standards

# 7 Automation and Information Technology





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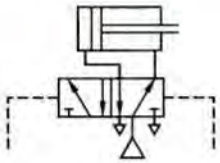


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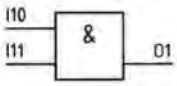




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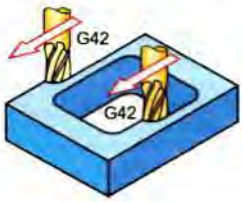


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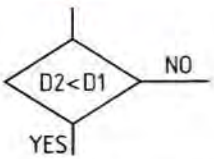


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# Basic terminology of open loop and closed loop control systems

## Basic terminology

cf. DIN 19226-1 to -5 (1994-02)

### Open loop control

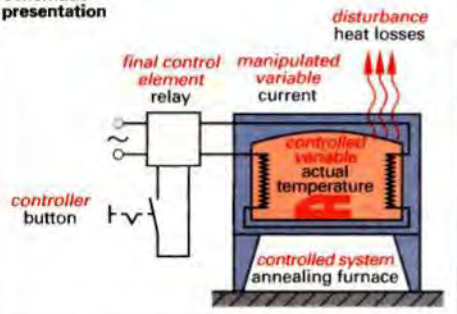
For open loop control the output variable, such as the temperature in a hardening furnace, is influenced by the input variable, such as the current in the heating coil. The output variable does not have an effect on the input variable. Open loop control has an open action flow.

### Closed loop control

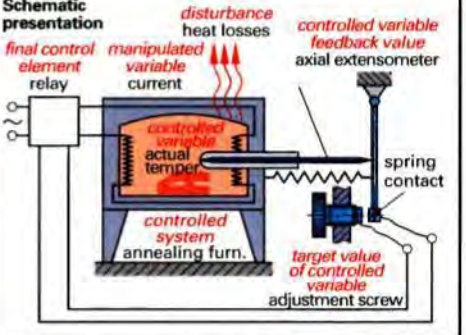
For closed loop control the controlled variable, such as the actual temp. in an annealing furnace, is continuously monitored and compared to the target temp. (reference variable) and, if there are deviations, adjusted to the reference input variable. Closed loop control has a closed action flow.

### Example: Annealing furnace

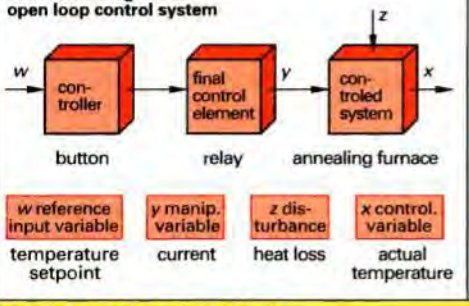
**Schematic presentation**



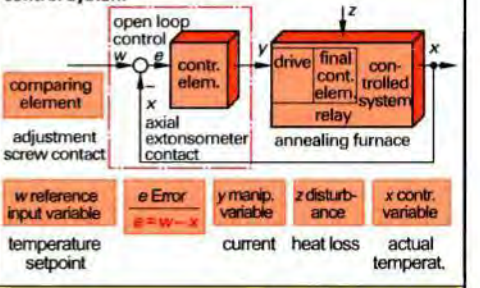

**Schematic presentation**




**Functional diagram of open loop control system**




**Simplified functional diagram of closed loop control system**



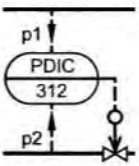

## Application-based code letters

cf. DIN 19227-1 (1993-10)

**Designation example:** PDIC

| First letters | | Supplementary letters | | Succeeding letters | |
|---|---|---|---|---|---|
| D | density | D | difference | A | error indication |
| E | electrical parameters | F | ratio | C | automatic closed loop control |
| F | flow, throughput | J | control point query | H | upper limit value |
| G | distance, position, length | Q | sum, integral | I | display |
| H | manual input/intervention | | | L | lower limit value |
| K | time | | | R | registration |
| L | status (e.g. level) | | | | |
| M | humidity | | | | |
| P | pressure | | | | |
| Q | quality parameters | | | | |
| R | radiation parameters | | | | |
| S | speed, rotational speed | | | | |
| T | temperature | | | | |
| W | weight, mass | | | | |

**Example:** Differential pressure closed loop control




Explanation: P pressure
D difference
I display
C automatic closed loop control

In plain language: Pressure differential closed loop control with display of pressure difference

# Symbols

cf. DIN 19227-1 (1993-10)

## Location of output & user control

- Local, general
- or
- Process control room
- Local control console
- Local, implemented by process control system
- Local, implemented by process computer

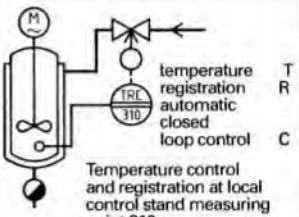
## Effect on the controlled system

- Servo motor, general
- Servo motor; the setting for minimal mass flow or flow of energy is set during loss of auxiliary power.
- Servo motor; the setting for maximum mass flow or flow of energy is set during loss of auxiliary power.
- Servo motor; the final control device remains in the most recently acquired setting during loss of auxiliary power.

## Measuring point, control point

- Reference line
- Measuring point, sensor
- Final control element, control point

## Example




Temperature control and registration at local control stand measuring point 310

# Solution based symbols for devices

cf. DIN 19227-2 (1991-02)

## Sensors

- T
- or
- T
- Sensor for temperature, general
- P
- Sensor for pressure
- L
- Sensor for level with float
- W
- Sensor for weight, scales; indicating

## Controllers

- Controller, general
- PID
- Two-point controller with switching output and PID behavior
- Three-point controller with switching output

## Adapters

- P / A
- Pressure transducer with pneumatic signal output

## Final controlling & user control elements

- M
- Valve actuator with motor drive
- Valve actuator with solenoid drive
- Adjuster for electric signal

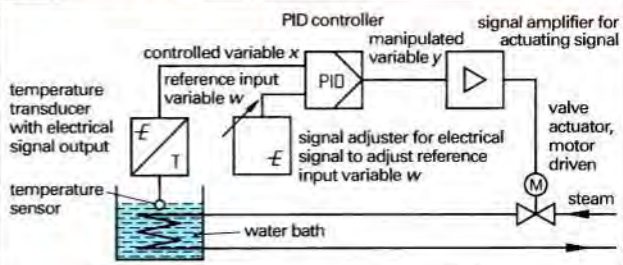
## Signal designators

- Signal, electrical
- Signal, pneumatic
- Analog signal
- Digital signal

## Output devices

- Basic symbol, general display
- 6
- Printer, analog, no. of channels as a numeral
- Monitor

## Example: Temperature controller

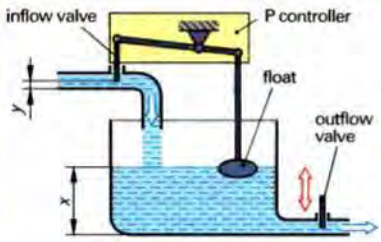
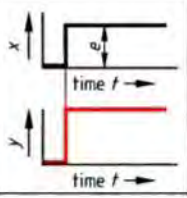
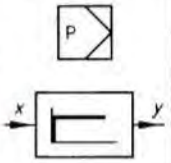
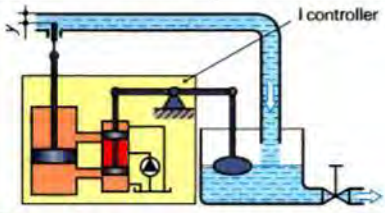
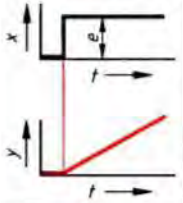
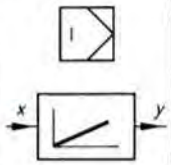
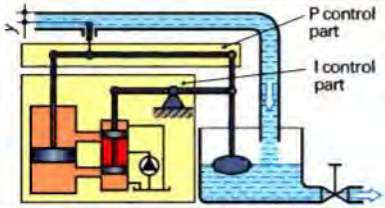
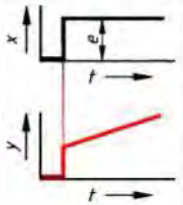
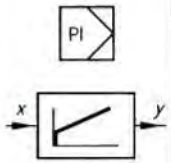
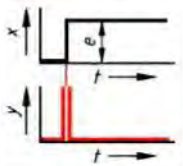
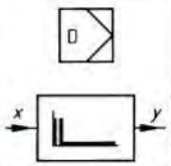
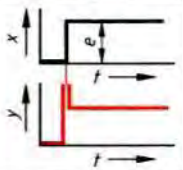
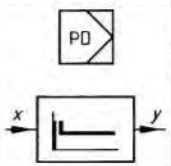
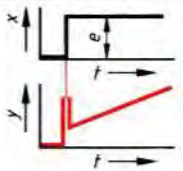
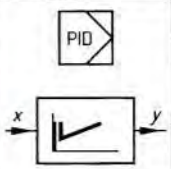


# Analog controllers

## Analog (continuous) controllers

cf. DIN 19225 (1981-12) and DIN 19226-2 (1994-02)

In analog controllers the manipulated variable $y$ may assume any desired value within the control range.

| Controller design | Level control example, description | Transition function | Symbol[1] Block representation[2] |
|---|---|---|---|
| **P-controllers** Proportional controllers<br><br>Output variable is proportional to input variable. P-controllers have steady-state errors. |  | $x$ controlled variable — step function[3]<br>$y$ manipulated variable — step response[4]<br>$e$ error<br>  |  |
| **I-controllers** Integral controllers<br><br>I-controllers are slower than P-controllers, but they eliminate all errors. |  |  |  |
| **PI-controllers** Proportional integral controllers<br><br>In PI-controllers a P-controller and a I-controller are connected in parallel. |  |  |  |
| **D-controllers** Derivative controllers | D-controller systems only occur with P- or PI-controller systems, since pure D-controller behavior with constant error does not provide any manipulated variable and therefore no closed loop control. |  |  |
| **PD-controllers** Proportional derivative controllers | PD-controllers are created when a P controller and a D element are connected in parallel.<br>The D part changes the output variable at a rate proportional to the rate of change of the input variable. The P part changes the output variable so that it is proportional to the input variable itself.<br>PD-controllers act quickly. |  |  |
| **PID-controllers** Proportional integral derivative controllers | PID-controllers are created by connecting P, I and D-controllers in parallel.<br>Initially the D part reacts with a large change to the control signal, afterwards this change is reduced to approximately the magnitude of the P element, and finally the effect of the I element causes the response to rise linearly. |  |  |

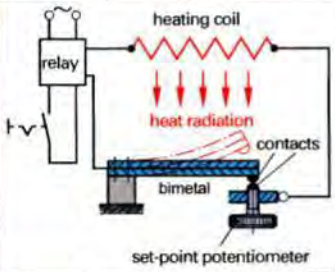
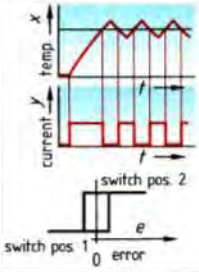
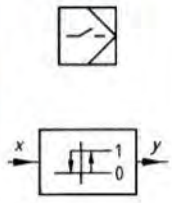
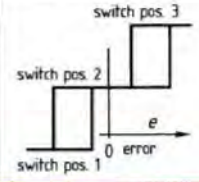
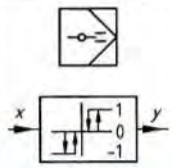
[1] Symbol as per DIN 19227-2
[2] Block representation as per DIN 19226-2
[3] Signal curve at controlled system input
[4] Signal curve at controlled system output

# Discontinuous and digital controllers

## Switching (discontinuous) controllers

cf. DIN 19225 (1981-12) and DIN 19226-2 (1994-02)

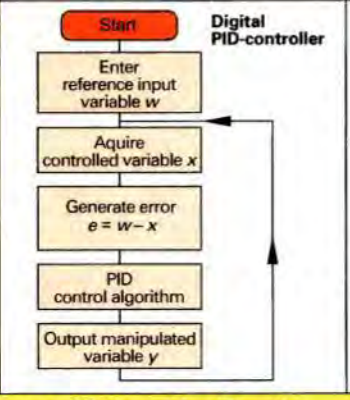
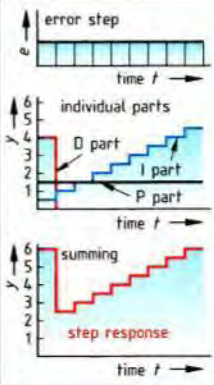
Switching controllers change the manipulated variable $y$ discontinuously by switching in several steps.

| Controller design | Example, description | Transition function, switching behavior | Symbol Block representation |
|---|---|---|---|
| **Two-point controller** |  |  |  |
| **Three-point controller** | **Air conditioning system**<br>In an air conditioning system three temperature ranges are assigned three switch positions:<br>– heating ON<br>– heating/cooling OFF<br>– cooling ON |  |  |

## Digital controllers (software controllers)

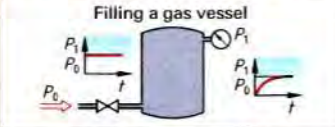
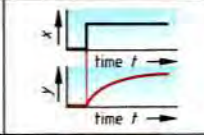
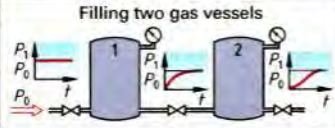
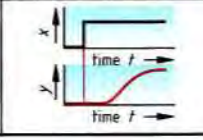
cf. DIN 19225 (1981-12) and DIN 19226-2 (1994-02)

The operating mode of the digital controller is implemented as a computer program.

| Controller design | Example (simplified) | Transient function | Explanation |
|---|---|---|---|
| **Computers**<br>**Programmable Logic Controllers (PLC)**<br>**Microcontrollers**<br>**Microprocessors** |  |  | The computer program has the following tasks:<br>– generate error $e$<br>– calculate the manipulated variable $y$ based on programmed control algorithms<br>At the step response all P, D and I-parts are summed.<br>Sampling of analog signals and their conversion to digital values and internal program flow causes a time delay of the controlled variable $x$ (similar to a T-controlled system). |

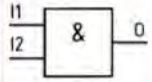
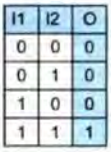
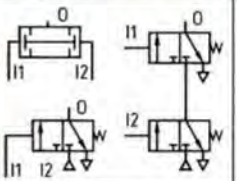
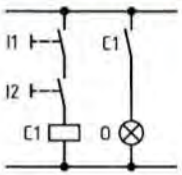
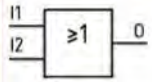
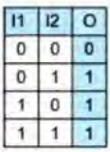
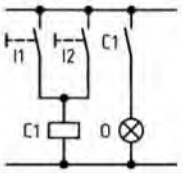
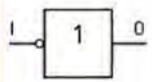
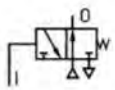
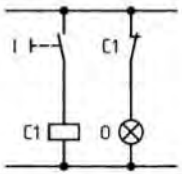
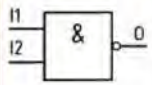
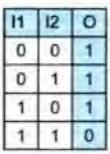
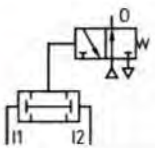
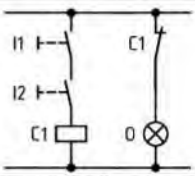
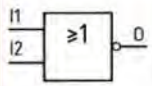
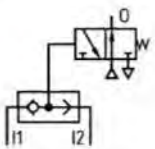
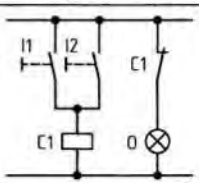
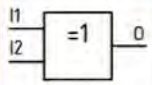
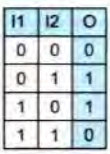
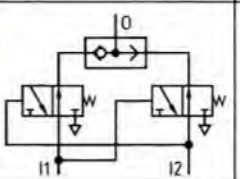
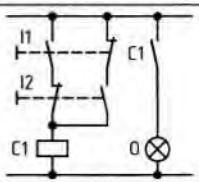
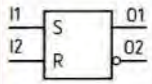
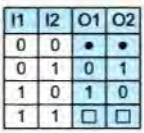
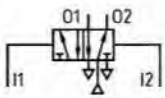
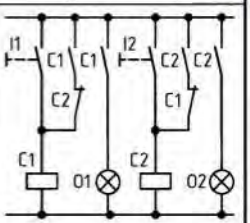
## P-controlled systems with time delay (T part)

cf. DIN 19226-2 (1994-02)

| Controller design | Example | Transient function | Explanation |
|---|---|---|---|
| **P-controlled system with delay 1st order (P-$T_1$ controlled system)** |  |  | If the pressure vessel is filled by a flow of gas, pressure $p_1$ in the vessel gradually reaches the pressure of the gas flow. |
| **P-controlled system with delay 2nd order (P-$T_2$ controlled system)** |  |  | If two vessels are connected in series, pressure $p_2$ increases in the second vessel slower than pressure $p_1$ in the first vessel. |

# Binary logic

cf. DIN EN 60617-12 (1999-04)

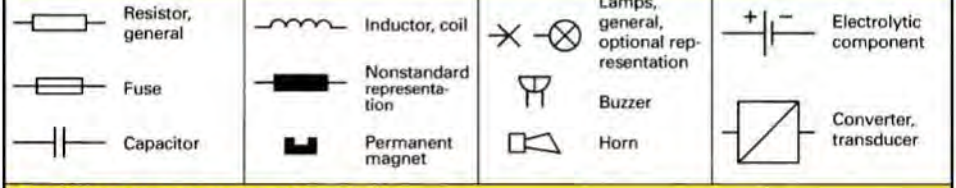
| Function | Circuit symbols Logical equation | Function table | Technical implementation pneumatic | Technical implementation electric |
|---|---|---|---|---|
| **AND** |  $O = I1 \wedge I2$ |  |  |  |
| **OR** |  $O = I1 \vee I2$ |  |  |  |
| **NOT** |  $O = \overline{I}$ |  |  |  |
| **NOT AND** (NAND) |  $O = \overline{I1 \wedge I2}$ |  |  |  |
| **NOT-OR** (NOR) |  $O = \overline{I1 \vee I2}$ |  |  |  |
| **Exclusive OR** (XOR) |  $O = (I1 \wedge \overline{I2}) \vee (\overline{I1} \wedge I2)$ |  |  |  |
| **Memory** (RS flip-flop) |  S set R reset |  • state unchanged condition □ indeterminate state |  |  |

I = inputs O = outputs, e.g. lamps C = relays, contacts

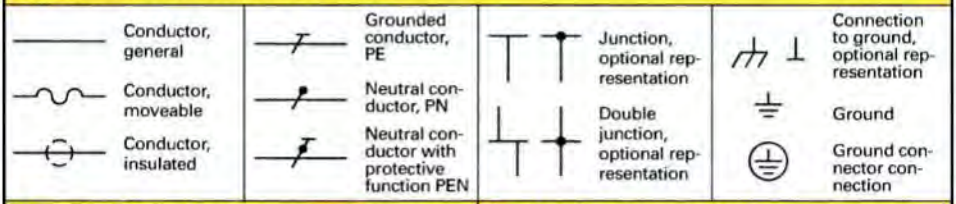
# Circuit symbols

cf. DIN EN 60617-1 to -12 (1999-04)

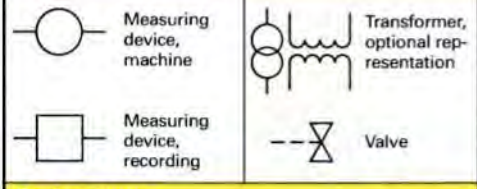
## General circuit symbols



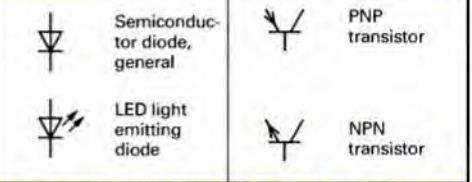

## Conductors, connectors and terminals



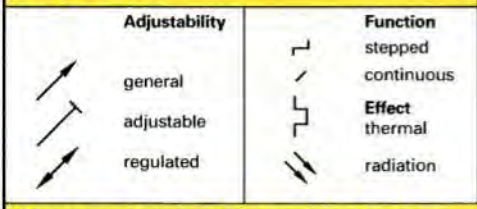

## Devices and machines



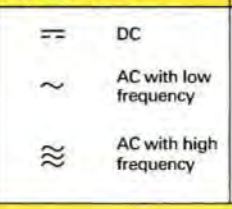

## Semiconductor components



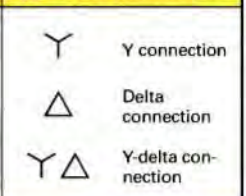

## Designations



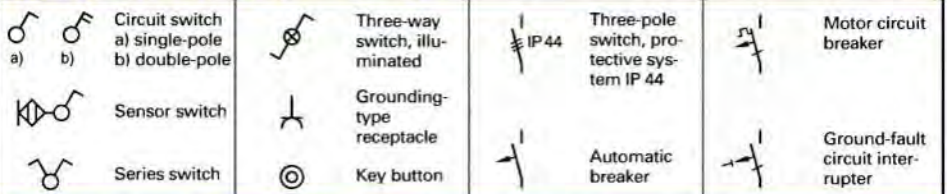

## Types of current



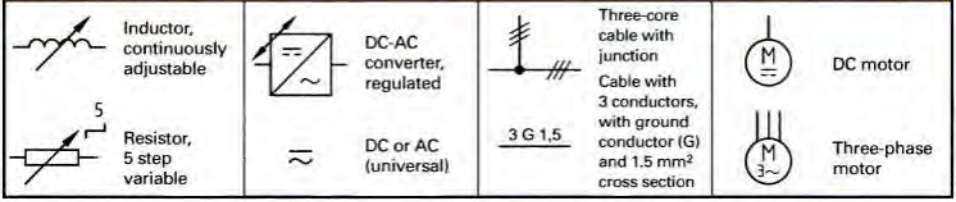

## Types of connections




## Circuit symbols in wiring system drawings



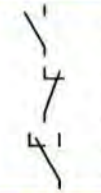

## Application examples



# Circuit symbols

cf. DIN EN 60617-1 to -12 (1999-04)

## Relay contacts



NO contact, normally open

NC contact, normally closed

Single pole double throw

## Actuation types

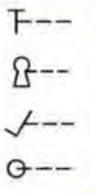


Manual, general

By pressing

By pulling

By turning

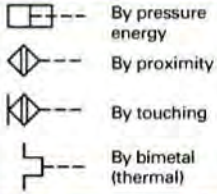


By tilting

By key

By pedal

By coil



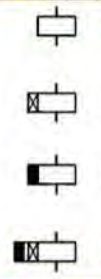
By pressure energy

By proximity

By touching

By bimetal (thermal)

## Electromech. relays



Relay coil, general

Timer on delay

Timer off delay

Timer on off delay

## Switch behavior



Lock, prevents automatic return

a) Delayed action (parachute effect) for movement

b)

a) to the right
b) to the left

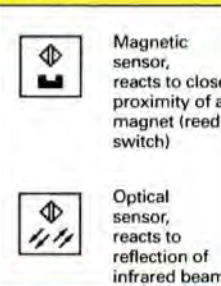
Symbol for "actuated state"

## Sensors (Block representation)



Capacitive sensor, reacts to proximity of all substances

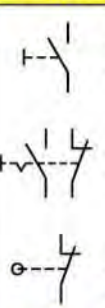
Inductive sensor, reacts to proximity of metals



Magnetic sensor, reacts to close proximity of a magnet (reed switch)

Optical sensor, reacts to reflection of infrared beam

## Examples of switch applications



NO contact manually

Double pole single throw

NC contact with roller actuation



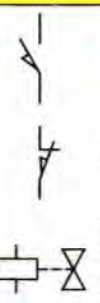
a) b)

a) NC contact
b) NO contact
Representation in actuated condition

a) b)

NO contact
a) closes
b) delayed opening when actuated

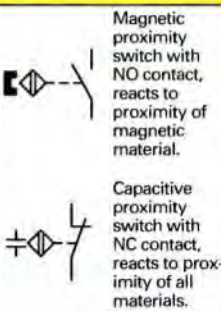
Emergency palm button



Limit switch, NO contact

Limit switch, NC contact

Valve with electromagnetic actuation

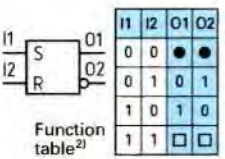


Magnetic proximity switch with NO contact, reacts to proximity of magnetic material.

Capacitive proximity switch with NC contact, reacts to proximity of all materials.

## Flip-flop elements

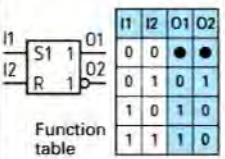
### RS[1] flip-flop




| I1 | I2 | O1 | O2 |
|---|---|---|---|
| 0 | 0 | ● | ● |
| 0 | 1 | 0 | 1 |
| 1 | 0 | 1 | 0 |
| 1 | 1 | □ | □ |

Function table[2]

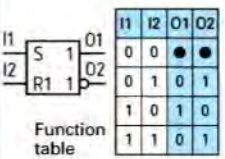
### RS flip-flop set dominant




| I1 | I2 | O1 | O2 |
|---|---|---|---|
| 0 | 0 | ● | ● |
| 0 | 1 | 0 | 1 |
| 1 | 0 | 1 | 0 |
| 1 | 1 | 1 | 0 |

Function table

### RS flip-flop reset dominant

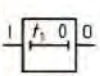



| I1 | I2 | O1 | O2 |
|---|---|---|---|
| 0 | 0 | ● | ● |
| 0 | 1 | 0 | 1 |
| 1 | 0 | 1 | 0 |
| 1 | 1 | 0 | 1 |

Function table

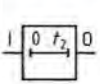
## Delay elements

### With rise-delay time




When a signal is applied to input I, output O assumes value 1 after time $t_1$ elapses.

### With turn-off delay




With loss of a signal at input I, output O takes the value 0 after completion of time $t_2$.

Flip-flops are integrated circuits which store signal conditions.

1) R = reset
S = set

2) ● unchanged state
□ indeterminate state

The numeral 1 after an R or S input indicates that the logical state of this input is dominant.

If a signal simultaneously lies at inputs I1 and I2 (I1 = 1 and I2 = 1) the following applies:

Input without the numeral 1 (R for set dominant, S for reset dominant RS flip-flop) is always set to logical state 0.

# Designations in circuit plans*

## Designation of devices in circuit diagrams

cf. DIN EN 61346-2 (2000-12)

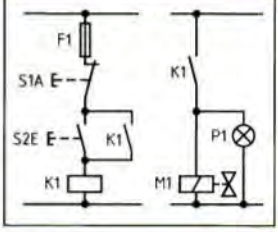
**Example:** S 2 E

- S: **Type of device**
- 2: **Sequential number**
- E: **Device function**

| Code letters for type (selection) | |
|---|---|
| B | Sensor, proximity switch |
| F | Fuse |
| K | Switch relay, timed relay |
| Q | Circuit breaker, contactor |
| M | Solenoid valve, solenoid |
| P | Indicator light, horn |
| R | Resistor |
| S | Control switch, push-button switch |

| Code letters for function (not standardized) | |
|---|---|
| A | Function OFF |
| B | Direction of movement |
| E | Function ON |
| G | Test |
| K | Jog operation |
| S | Save, set |
| R | Clear, reset |

Example of circuit diagram



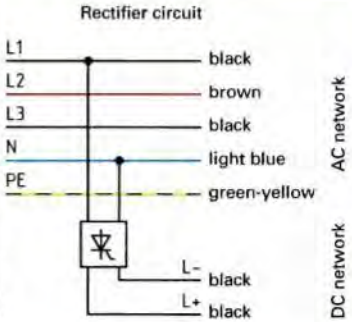

## Designation of wires and connections

cf. DIN EN 60446 (1999-10) and DIN EN 60445 (2000-08)

**Insulated wires**

| Type of wire | | Code letters | Designation: Wire color | Designation: Symbols |
|---|---|---|---|---|
| DC network | positive | L+ | black[1] | + |
| | negative | L– | black[1] | – |
| | neutral wire | M | light blue | |
| AC network | Phase conductor 1 | L1 | black[1] | |
| | Phase conductor 2 | L2 | black[1] | |
| | Phase conductor 3 | L3 | black[1] | |
| | neutral wire | N | light blue | |
| Ground wire | | PE | green-yellow | |
| PEN wire (neutral wire with ground function, PE + N) | | PEN | green-yellow[2] | |
| Ground | | E | black[1] | |

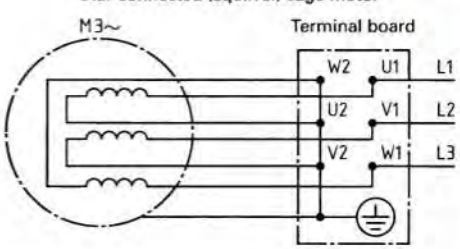
Example




**Device connections**

| Connections for | Designation |
|---|---|
| Phase conductor 1 | U |
| Phase conductor 2 | V |
| Phase conductor 3 | W |

Example




1) Color is unspecified. Black is recommended, brown to differentiate. Green-yellow may not be used.

2) PEN-wires have a continuous green-yellow conductor color. To avoid confusion with PE wires, PEN wires are additionally marked with light blue on the ends of the wires, e.g. with a wire clip or adhesive tape.

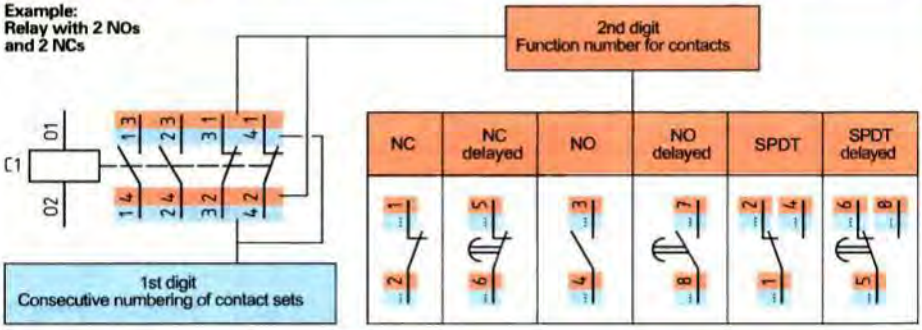
*) According to European Standards

# Circuit diagrams

cf. DIN EN 61082 (1998-09)

## Connector markings on relays

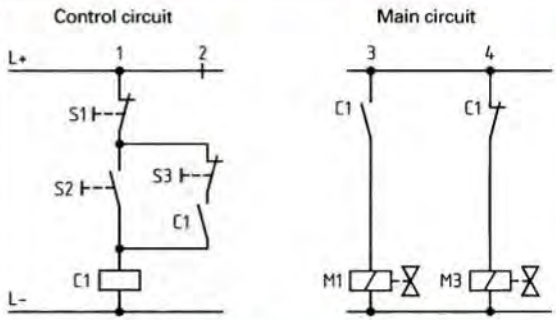
**Example:**
**Relay with 2 NOs and 2 NCs**




## Designing circuit diagrams

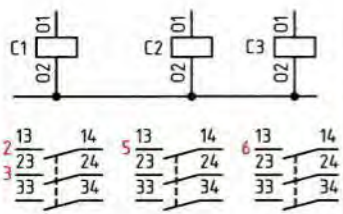
### Current sections and distribution of electric circuits

- Every electrical device is shown with a vertical current section regardless of the actual spatial arrangement of the elements.
- Current sections are numbered sequentially from left to right.
- The **control circuit** contains devices for signal input and signal processing.
- The **main circuit** contains the necessary final control elements for the working elements.
- The spatially shared devices, e.g. relay coil and relay contact, are not represented.

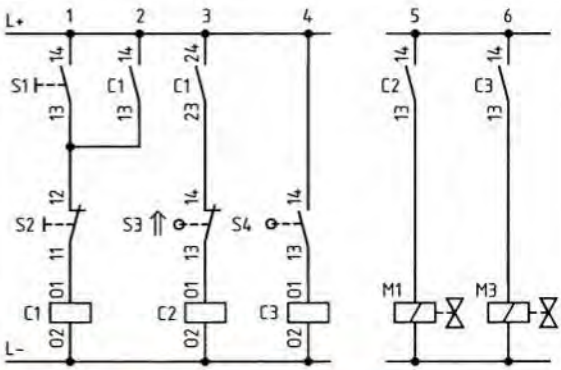



### Designation of devices

- Contacts and the associated relay coils are marked with the same code numeral.
  **Example:** Current sections **1**, **2** and **3**
- 2 NO contacts belong to relay coil **C1**, both marked as **C1**. They are used to latch the relay coil.
- All contacts of a relay are entered as a complete contact set or as a table under the current path of the relay. Both representations indicate the current section on which a contact is located.




**Representation as contact set**




| Contacts C1 | Section |
|---|---|
| 13 - 14 | 2 |
| 23 - 24 | 3 |

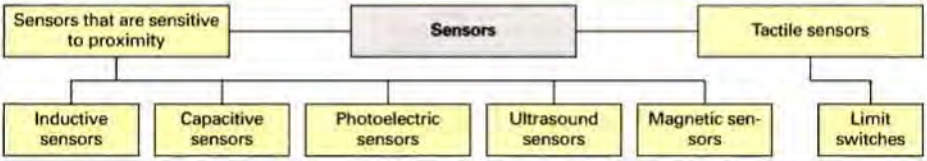
| Contacts C2 | Section |
|---|---|
| 13 - 14 | 5 |

| Contacts C3 | Section |
|---|---|
| 13 - 14 | 6 |

**Representation as table**

# Sensors

## Sensors (selection)




## Characteristics of sensors

| Sensor type | Symbol | Principle | Advantages | Disadvantages | Object distance |
|---|---|---|---|---|---|
| Inductive |  | Triggers if an object interferes with the alternating magnetic leakage field of the sensor | High degree of protection (IP67), very high switch point precision, dirt tolerant | Only objects with high electrical conductivity, unsuitable where there is greater accumulation of metal chips | 1 mm to 150 mm |
| Capacitive |  | Triggers if an object interferes with the alternating electric leakage field of the sensor | High degree of protection (IP67), detects all materials; dirt tolerant | Small object distances, larger design than comparable inductive sensors | 20 mm to 40 mm |
| Photo-electric |  | Triggers if an object returns the infrared field of the sensor | Detects all materials, large distances | Sensitive to dirt, smoke and secondary light, auxiliary power necessary | approx. 2 m |
| Ultra-sound |  | Evaluates transit times of reflected ultrasonic pulses to determine the distance to an object | Tolerant to dust, dirt and light; detects very small objects at large distances | Slow, use only with standard pressure, not in areas subject to explosion hazards and no high-frequency noise | 60 mm to 6 m |
| Magnetic |  | A permanent magnet actuates a proximity switch (reed contact) using two contact springs | Suitable in rough environment, high service life, suitable for switches in high frequency circuits | Risk of contact welding; suppresses the current peaks of RC modules | – |
| Mechanical |  | Triggered by manual actuation or lever system | Low price, robust, small, unaffected by interference fields, no auxiliary power necessary | Contact chatter, not allowed in food and chemical industries | – |

## Designation of proximity sensors

cf. DIN EN 60947-5-2 (2004-11)

**Example:** U 1 A30 A F 2 N

| Type of detection | Mechanical mounting conditions | Design and size | Circuit element function | Type of output | Type of connection | NAMUR function |
|---|---|---|---|---|---|---|
| I inductive<br>C capacitive<br>U ultrasound<br>D photoelectric diffuse reflected luminous beam<br>M magnetic<br>R photoelectric reflected luminous beam<br>T photoelectric direct luminous beam | 1 flush mounting possible<br>2 flush mounting not possible<br>3 unspecified | FORM<br>A cylindrical threaded sleeve<br>B smooth cylindrical sleeve<br>C rectangular with square cross-section<br>D square, with rectangular cross-section<br>SIZE<br>(2 digits)<br>for diameter or side length | A NO contact<br>B NC contact<br>C single pole double throw<br>P programmable by user<br>S other | P PNP output, 3 or 4 DC connections<br>N NPN output, 3 or 4 DC connections<br>D 2 DC connections[1]<br>F 2 AC connections[2]<br>U 2 AC or DC connections<br>S other | 1 integrated connection line<br>2 plug connection<br>3 screw connection<br>4 ⋮ 8 unused<br>9 other type of connection | N NAMUR[3] function<br>Note:<br>NAMUR sensors are 2 wire sensors that are connected to an external switching amplifier |

[1] DC = Direct Current
[2] AC = Alternating Current
[3] NAMUR = **N**ormenarbeitsgemeinschaft für **M**ess- und **R**egelungstechnik (Standardization Association for Measurement and Control)

# Safety precautions*

## Safety precautions against electrical shock

cf. DIN VDE 0 100-410 (2003-06)

| Protection against direct and indirect contact | Protection against electric shock under normal conditions: against direct contact | Protection against electric shock under fault conditions: for indirect contact |
|---|---|---|
| Protection by:<br>– Safety Extra Low Voltage (SELV)<br>– Protective Extra Low Voltage (PELV)<br>– Functional Extra Low Voltage FELV | Protection by:<br>– protective insulation of active parts, e.g. cable<br>– coating as insulation, e.g. housings on electr. devices<br>– distance, e.g. protective hoods, housings of machine screen<br>– barriers, e.g. protective screen, enclosure | Protection by:<br>– automatic disconnect or warning, e.g. residual current protective device<br>– potential equalization<br>– non-conductive areas; e.g. by insulating coverings<br>– protective insulation, e.g. housings encapsulated with insulating material |

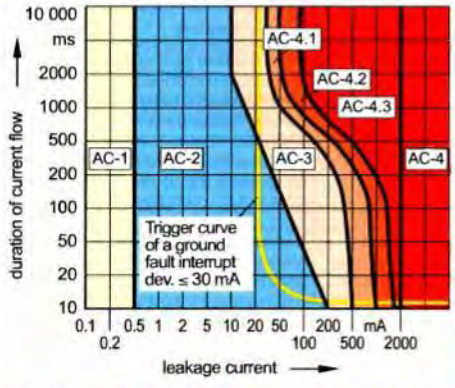
⇑ ⇑

Additional protection by residual current circuit breaker GFI's: Ground Fault Interrupter

## Effects of alternating current

vgl. IEC 60479-1 (1994)

Safety curves for AC 50 Hz from hand to hand or from hand to foot for adults




| Zone | Physical effects |
|---|---|
| AC-1 | normally no effect |
| AC-2 | normally no damaging physical effects |
| AC-3 | usually no organic damage, difficulty breathing (> 2 s), muscle cramps |
| AC-4.1 | 5% probability of ventricular fibrillation |
| AC-4.2 | up to 50% probability of ventricular fibrillation |
| AC-4.3 | over 50% probability of ventricular fibrillation |
| AC-4 | cardiac arrest, cessation of breathing, and extreme burns (increasing with exposure time and current level) |

## Automatic fuses and wire cross-sectional areas

cf. DIN VDE 0 1000-430 (1991-11)

| Rated current of fuse $I_n$ in A | Color code of fuse | Minimum cross-sectional area in mm² for Cu wires by method of installation | | | | | | | | Rated current of fuse $I_n$ in A | Color code of fuse | Minimum cross-sectional area in mm² for Cu wires by method of installation | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | A1 | | B1 | | B2 | | C | | | | A1 | | B1 | | B2 | | C | |
| | | and number of loaded strands | | | | | | | | | | and number of loaded strands | | | | | | | |
| | | 2 | 3 | 3 | 3 | 2 | 3 | 2 | 3 | | | 2 | 3 | 3 | 3 | 2 | 3 | 2 | 3 |
| 10 (13) | red | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 25 | yellow | 4 | 4 | 2.5 | 4 | 4 | 4 | 2.5 | 2.5 |
| 16 | gray | 1.5 | 2.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 35 | black | 6 | 6 | 6 | 6 | 6 | 6 | 4 | 4 |
| 20 | blue | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 1.5 | 2.5 | 50 | white | 10 | 16 | 10 | 10 | 10 | 10 | 10 | 10 |

## Method of installation of cables and insulated wires

cf. DIN VDE 0 298-4 (2003-08)

| | | | | | |
|---|---|---|---|---|---|
| A1 |  | Installation in thermally insulated walls, in electrical conduit | B2 |  | Installation in electrical conduit or in the wall, in cable channels or behind base boards |
| B1 |  | Installation in electrical conduit or in the wall or in cable channels | C |  | Installation directly on or in the wall |

*) According to European Standards

# Safety precautions*

## Protective systems for electrical devices

cf. DIN EN 60529 (2000-09)

**Example:** IP 3 4 C M

- IP: Protective system designation IP (International Protection)
- 3: 1st code numeral for protection of device[1] against penetration of solid foreign objects
- 4: 2nd code number for protection of the device[1] against water with damaging effect
- C: Additional code letters[2]
- M: Supplementary letters

| Code no | 1st code no. Protection against accidental contact | 1st code no. Protection from foreign objects | Symbol |
|---|---|---|---|
| 0 | No protection | No protection | |
| 1 | Protected against contact by back of the hand | Protected against penetration by foreign objects $d \geq 50$ mm | |
| 2 | Protected against contact with finger $d = 12$ mm | Protected against penetration by foreign objects $d \geq 12.5$ mm | |
| 3 | Protected against contact with a tool $d = 2.5$ mm | Protected against penetration by foreign objects $d \geq 2.5$ mm | |
| 4 | Protected against contact with a wire $d = 1$ mm | Protected against penetration by foreign objects $d \geq 1$ mm | |
| 5 | Protected against contact with a wire $d = 1$ mm | Protected from dust |  |
| 6 | Protected against contact with a wire $d = 1$ mm | Dust proof |  |

| Code no | 2nd code number Water protection | Symbol |
|---|---|---|
| 0 | No protection | None |
| 1 | Protected against vertical drips |  |
| 2 | Protected against drips if device is inclined 15° |  |
| 3 | Protected against water spray impacting device at 60° |  |
| 4 | Protected against water spray from all directions |  |
| 5 | Protected against water jets from all directions |  |
| 6 | Protected against strong water jets from all directions |  |
| 7 | Protected against temporary submersion in water |  |
| 8 | Protected against continual submersion in water |  ...kPa |

| Additional letters | |
|---|---|
| A | Protected against contact by back of the hand |
| B | Protected against contact with finger $d = 12$ mm, 80 mm long |
| C | Protected against contact with a tool $d = 2.5$ mm, 100 mm long |
| D | Protected against contact with a wire $d = 1$ mm, 100 mm long |
| **Supplementary letters** | |
| H | Equipment for high voltage |
| M | Tested on water intake in running machine |
| S | Tested on water intake on idle machine |
| W | Suitable for specific weather conditions |

[1] If a code number is not given, the letter X is used in its place, e.g. IP X6 or IP 3X

[2] Is only given if the protection is greater than the 1st code number.

## Electric equipment for explosive areas

cf. DIN EN 13237 (2003-01)

**Example:** EEx de II/B T2

- EEx: Symbol for explosion protection
- de: Type of protection
- II/B: Electrical devices group
- T2: Temperature class

| Code | Type of protection | Group II A | Group II B | Group II C |
|---|---|---|---|---|
| o | oil immersion | Risk of explosion by occurrence of the following gases: | | |
| p | pressurized enclosure | methane, propane, butane, propylene, benzene, toluol, naphthalene, turpentine, petroleum, gasoline, fuel oil, diesel oil, carbon monoxide, methanol, metaldehyde, acetone, acids, chloride | ethylene, acryl nitrite, hydrogen cyanide, dimethylether, propylene oxide, coke oven gas, tetrafluoroethylene | hydrogen, acetylene, carbon bisulphide, ethyl nitrite |
| q | sand filling | | | |
| d | flameproof enclosure | | | |
| e | increased safety | | | |
| i | inherent safety | | | |

| Code | Surface temperature |
|---|---|
| T1 | 450°C |
| T2 | 300°C |
| T3 | 200°C |
| T4 | 135°C |
| T5 | 100°C |
| T6 | 85°C |

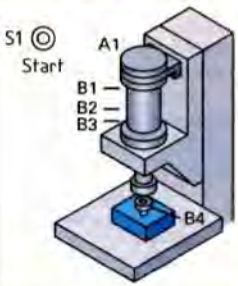
*) According to European Standards

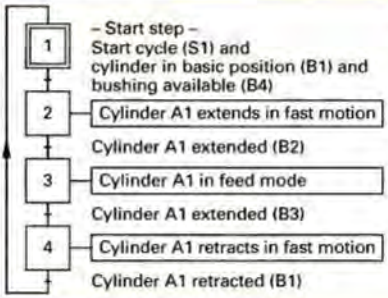
# Function charts for sequential controls (GRAFCET)[1)]

cf. DIN EN 60848 (2002-12)

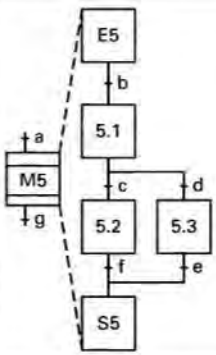
The function chart in accordance with GRAFCET is a graphical design language for sequential control. However, it does not make any statement about the type of devices used, the direction of lines and the installation of electrical equipment. Only the general representation via symbols is obligatory; dimensions and other details are left to the user.

## Example: hydraulic press with sequential control



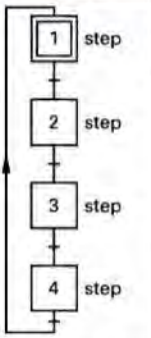
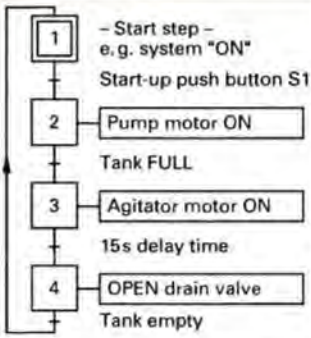
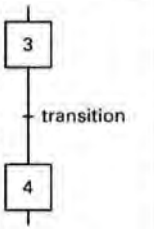
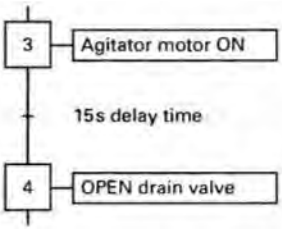
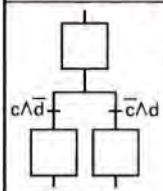
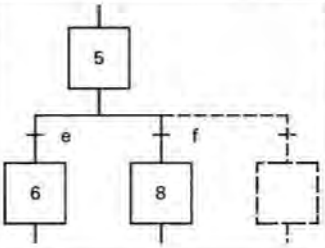
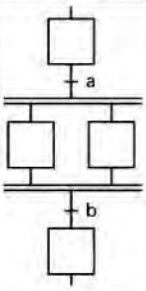
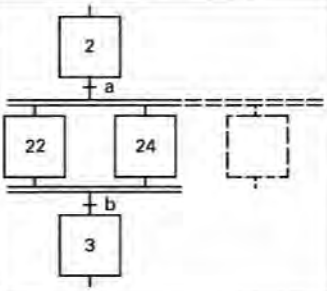




The ram of a hydraulic press forces bushings into a plate. When the cylinder is in its end position (B1) and a bushing is available (B4), the cylinder extends in fast motion. The sensor B2 switches to feed mode. As soon as the bushing is forced in (B3) the cylinder retracts in fast motion.

| Symbol | Explanation | Examples | Explanation |
|---|---|---|---|
| **Steps** | **Closed cycle** (step chain) | | |
|  | Continuous action | Cylinder A1 retracts in fast motion | This action is only valid as long as the corresponding step is active. |
|  | Stored with rising edge | Solenoid valve M2 ON M2:=1 | When the step is activated, the value 1 is assigned to the solenoid valve M2. This action remains active also after the reset of the step. |
|  | Stored with falling edge | Signal light M5 ON M5:=1 | When the step is activated, the value 1 is assigned to the signal light P5 only after the reset of the step. |
|  | Step |  5 | The number must be in the upper center of the step field |
|  1 | Start step |  1 | Start step with step number 1 |
|  | Set step<br>It displays which steps are set for a definite condition of the process |  | Steps that are active at a particular time can be marked with a dot. |
|  M | Macro step<br>Individual representation of a detailed part of a sequential control |  E5 b 5.1 a M5 c d 5.2 5.3 g f e S5 | Macro step M5, shown in its detailed structure:<br>– The release of transition a activates the access step E5 of the macro step M5.<br>– The activation of the exit step S5 releases transition g.<br>– The release of transition g deactivates step S5. |
|  * | Inclusive step<br>This step contains several steps that are referred to as included steps. | | |
|  * | Inclusive start step<br>This step contains several steps that are referred to as included steps. | | |

1) GRAFCET French: **GRA**phe **F**onctionnel de **C**ommande **E**tape **T**ransition.
English: specification language for function charts of sequential controls

## Basic designs of sequential charts cf. DIN EN 60848 (2002-12)

| Symbol | Explanation | Examples | Explanation |
|---|---|---|---|
| **Sequential chart** | | | |
|  | A sequential chart consists of a series of steps placed one after another. Steps and transitions alternate. |  | 1. Sequential charts enforce a step structure developed from top to bottom.<br>2. Within the sequence, only one step can be active at a time.<br>3. The start step describes the initial condition of the system.<br>4. After execution of the last step and release of the transition, a feedback loop returns the system to the start step. |
| **Transistions** | | | |
|  | The transition is composed of<br>• a dash and<br>• a text describing the transition<br>Transitions can be represented by:<br>• text statements<br>• Boolean algebra (equation)<br>• graphical symbols |  | 1. Step 3 is active, i.e. the agitator motor is ON.<br>2. If the condition for the release of the transition (the agitator runs for 15 sec.) is satisfied, step 4 is set.<br>3. Step 4 resets step 3, i.e. the ON signal for the agitator motor is no longer active. The motor is shut down.<br>4. The drain valve opens. |
| **Sequence selection** (alternative branch) | | | |
|  <br>Example: sequence branch | A sequence branches to several sequences starting at a single or several steps.<br>A difference is made between:<br>• sequence branch<br>• sequence junction |  | Sequence branch:<br>The sequence occurs if step 5 is set<br>a) branching to step 6 if the condition for the release of transition "e" is satisfied, (e=1) **or**<br>b) branching to step 8 if the condition for the release of transition "f" is satisfied (f=1). |
| **Simultaneous sequences** (parallel branch) | | | |
|  | A sequence branches to multiple sequences that are simultaneously activated but run independently of each other.<br>The next individual step is carried out only after all branches are processed. |  | A sequence from step 2 to steps 22, 24 etc. only occurs if,<br>a) step 2 is set **and**<br>b) the condition for the release of the common transition "a" is satisfied (a=1). |

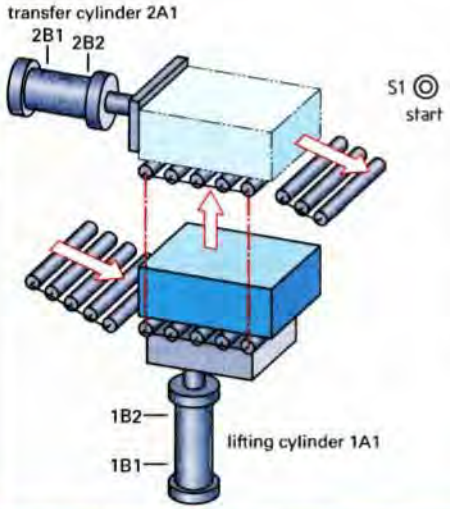
# Function charts for sequential controls, Examples

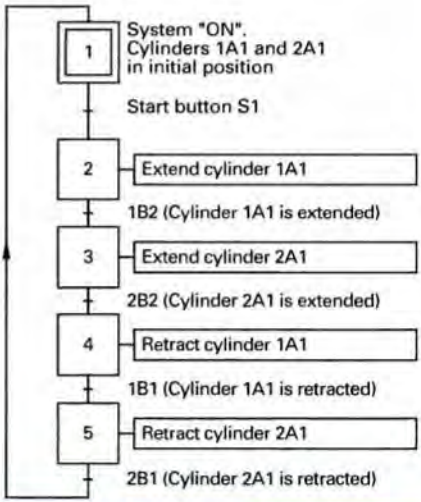
cf. DIN EN 60848 (2002-12)

## Example: Lifting device

Workpieces are lifted by a lifting cylinder and pushed onto a roller conveyor by a transfer cylinder.

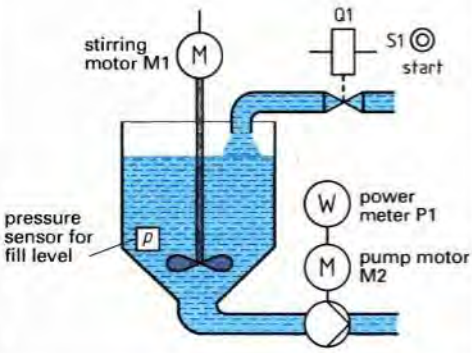
Actuating the main valve and start button S1 causes the lifting cylinder 1A1 to extend, lifting the workpiece and activating the limit switch 1B2 in the end position. This causes transfer cylinder 2A1 to extend, pushing the workpiece onto the roller conveyor and activating limit switch 2B2. Cylinder 1A1 returns to its initial position, actuates 1B1 thereby causing cylinder 2A1 to be retracted.

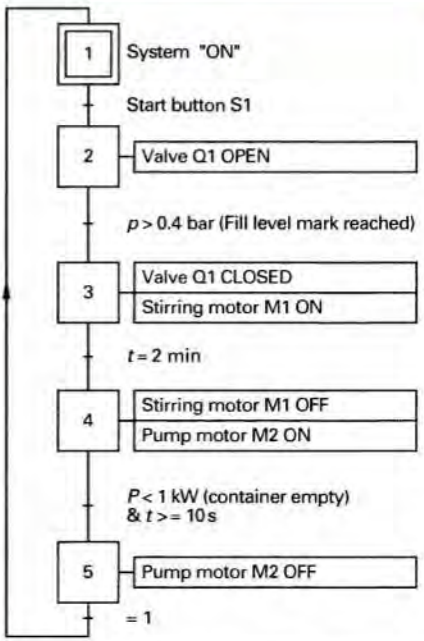



## Example: Stirring machine control

Paint flows into a mixing tank, is stirred there and then pumped back out. Opening valve Q1 causes the paint to fill to a level mark. Afterwards motor M1 is turned on and the paint is stirred 2 minutes. After shutoff of stirring motor M1 and activation of pump motor M2 (running time at least 10 sec), the container is pumped empty. Shutoff criterion for pump motor M2 is drop of motor power below 1 kW (container is empty).

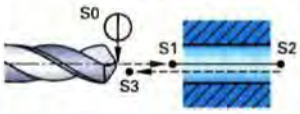


# Function diagrams

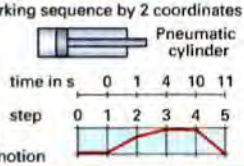
Path diagram — **Function diagram** — State diagram

Simple motion sequences




S0: signal element ON
S1: fast motion up to S1
S2: feed up to S2
S3: fast reverse motion up to S3

Description of a working sequence by 2 coordinates




Step 1: idle position
Step 2: fast forward motion
Step 3: feed
Step 4: end position
Step 5: fast reverse motion

## Symbols of a function diagram

### Movements and functions

| Paths and movements | Function lines | Path and movement limits |
|---|---|---|
| Straight line working movement | Idle and initial position of subassemblies | Path limits general |
| Straight line idle movement | For all conditions deviating from the idle or initial position | Path limits using signal elements |

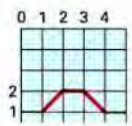
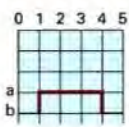
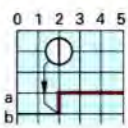
### Signal elements

| Manual actuation | Mechanical actuation | Hydraulic or pneumatic actuation |
|---|---|---|
| ON | Limit switch actuated in end position | p 6 bar — Pressure switch set to 6 bar |
| OFF | Limit switch actuated over longer path length | t 2 s — Time element set to 2 sec. |
| ON/OFF | | |
| JOG MODE | | |
| AUTOMATIC MODE ON | | |

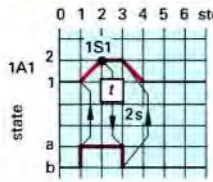
### Signal combinations

| | | |
|---|---|---|
| The signal line begins at the signal output and ends at the point where a change of state is introduced. | The signal branch is marked with a dot. | AND state: marked with a slash<br>OR state: marked with a dot |

## Execution of a function diagram (state diagram)

| Cylinder | Valve with two switch positions | Signal element activated manually |
|---|---|---|
|  |  |  |
| Step 1: move from initial position 1 to position 2<br>Step 2: remain in position<br>Step 3: move from position 2 to initial position 1 | Step 1: switch from initial position b to position a<br>Step 2 and 3: remain in position<br>Step 4: switch from position a to initial position a | Step 2: switch on; control element switches from b to a |

### Example: Final control element mechanically activated




Step 1: Final control element switches directional control valve from b to a and causes extension of cylinder 1A1.

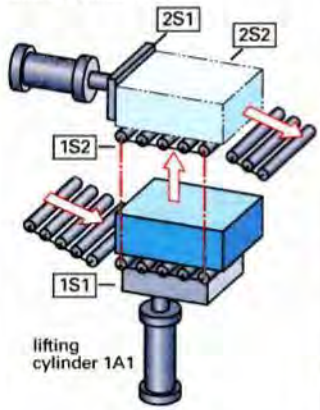
Step 2: Cylinder actuates signal element 1S1
Signal element 1S1 controls timer element
Timer runs out (2 sec).

Step 3: Timer element controls directional control valve from a to b
Cylinder 1A1 retracts to initial state.

# Function diagrams, Example

## Example: Pneumatically controlled lifting device

### Layout

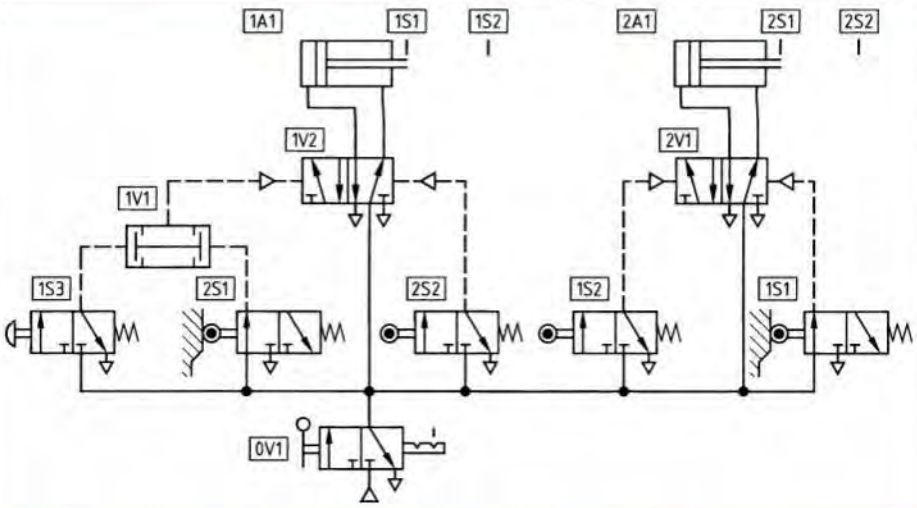



### Function diagram

| Components | | | Step |
|---|---|---|---|
| Name | No. | Posit./ condit. | $x_1$ $x_2$ $x_3$ 1 2 3 4 5 |
| Main pneumatic valve | 0V1 | a | |
| | | b | |
| Cylinder (vertic. stroke) | 1A1 | 2 | |
| | | 1 | |
| 5/2 directional control valve | 1V2 | a | |
| | | b | |
| Cylinder (horiz. stroke) | 2A1 | 2 | |
| | | 1 | |
| 5/2 directional control valve (DCV) | 2V1 | a | |
| | | b | |



### Pneumatic circuit diagram




### Parts list

| Designations | Name | Designations | Name |
|---|---|---|---|
| 1A1 | Cylinder, double acting | 1S1 | 3/2 DCV, roller activated |
| 2A1 | Cylinder, double acting | 1S2 | 3/2 DCV, roller activated |
| 0V1 | 3/2 DCV with detent, manually activated | 1S3 | 3/2 DCV, activated by push button |
| 1V1 | Two pressure valve | 2S1 | 3/2 DCV, roller activated |
| 1V2 | 5/2 DCV, pressure activated | 2S2 | 3/2 DCV, roller activated |
| 2V1 | 5/2 DCV, pressure activated | | |

# Circuit symbols

cf. DIN ISO 1219-1 (1996-03)

## Function elements

- Hydraulic fluid flow
- Compressed air flow
- Direction of flow
- Direction of rotation
- Adjustability
- Spring
- Flow restriction

## Power transmission

- Hydraulic pressure source
- Pneumatic press. source
- Working line
- Control line
- Leakage current line
- Enclosure around subassemblies
- Line junction
- Line crossing
- Quick coupling
- Exhaust without connection
- Exhaust with connection
- Muffler
- Tank
- Air receiver
- Hydraulic accumulator
- Service unit (FRL)
- Filter or screen
- Water separator
- Air dryer
- Lubricator

## Pumps, compressors, motors

- Fixed displacement hydraulic pump, unidirectional
- Variable displacement hydraulic pump, bidirectional
- Compressor, unidirectional
- Fixed displacement hydraulic motor, unidirectional
- Fixed displacement pneumatic motor, unidirectional
- Variable displacement hydraulic motor, bidirectional
- Variable displacement pneumatic motor, bidirectional
- Hydraulic oscillating drive
- Pneumatic oscillating drive
- Electric motor

## Single-acting cylinders

- Single-acting cylinder, return stroke by undefined power source (simplified:)
- Single-acting cylinder, return stroke by integrated spring (simplified:)

## Double-acting cylinders

- Double-acting cylinder with one-sided piston rod (simplified:)
- Double-acting cylinder with one-sided piston rod and two-sided adjustable end cushion (simplified:)

## Check, and/or valves

- Check valve, unloaded
- Check valve, spring loaded
- Shuttle valve (OR function)
- Quick exhaust valve
- Pilot operated check valve
- One-way flow control valve
- Dual-pressure valve (AND function)

## Pressure valves

- Pressure relief valves
- Sequence valve
- 2-way pressure regulator, direct-acting
- Pressure switch, emits electrical signal for a preset pressure

## Flow control valves

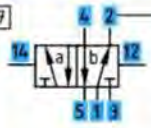
- Adjustable throttle valve
- Adjustable 2-way flow-control valve
- Adjustable 3-way flow-control valve, relief opening to tank

# Circuit symbols

## Connection designations and codes for directional control valves

cf. DIN ISO 1219-1 (1996-03)
DIN ISO 5599 (2005-12)

**Example:**
**5/2 directional control valve with connection designation**




Designator

**Code designation**

**5 / 2 – directional control valve 6 V 7**

| Number of connections | Number of switch positions | Circuit number | Part designation | Part number |
|---|---|---|---|---|

**Switch positions[1]**

| | |
|---|---|
| a b | Valve with 2 positions |
| a 0 b | Valve with 3 positions |

[1] Number of rectangles ≙ Number of positions

**Part designation**

| | |
|---|---|
| P | pumps and compressors |
| A | drives |
| M | drive motors |
| S | signal pick-up |
| V | valves |
| Z | all other parts |

**Connection designations for pneumatic and hydraulic equipment**

| Connection | as per DIN with numbers | obsolete: with letters[1][2] |
|---|---|---|
| Inflow, pressure port | 1 | P |
| Working ports | 2, 4, 6 | A, B, C |
| Vent, drain | 3, 5, 7 | R, S, T |
| Leakage oil port | – | L |
| Control ports[3] | 10, 11, 12, 14 | X, Y, Z |

[1] Letters are still frequently used in hydraulic circuit diagrams.
[2] The sequence of the letters does not necessarily correspond to the number sequence.
[3] A pulse at control port 12, for example, connects ports 1 and 2.

## Designs of directional control valves

### 2/ directional control valves

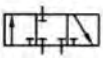

2/2 DCV, normally closed


2/2 DCV, normally open

### 3/ directional control valves

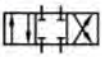

3/2 DCV, normally closed

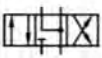

3/2 DCV, normally open


3/3 DCV, NC in middle position

### 4/ directional control valves

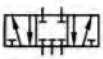

4/2 directional control valve


4/3 DCV. NC in middle pos.

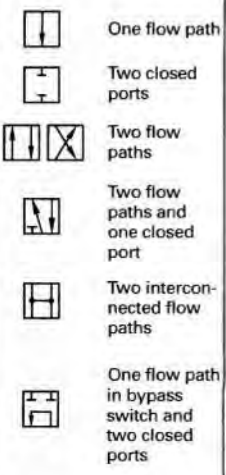

4/3 DCV, with float in middle position

### 5/ directional control valves


5/2 directional control valve

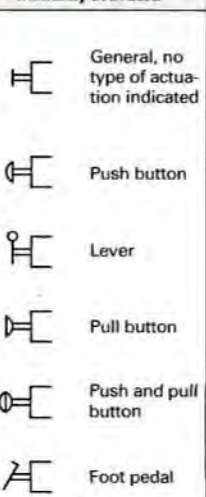

5/3 DCV, NC in middle position

## Flow paths

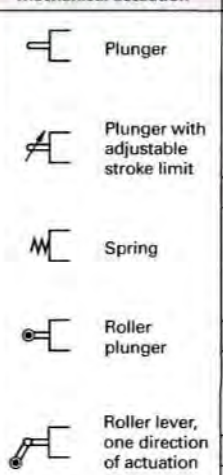



## Actuation of directional control valves

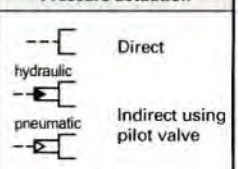
### Manually activated



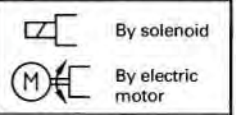

### Mechanical actuation



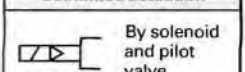

### Pressure actuation



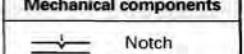

### Electrical actuation




### Combined actuation


By solenoid and pilot valve

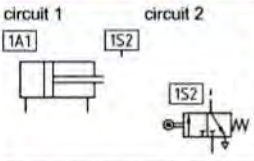
### Mechanical components


Notch

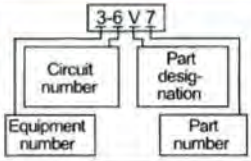
# Circuit diagrams

cf. DIN ISO 1219-2 (1996-11)

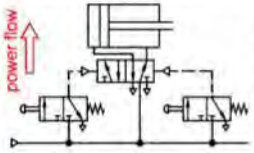
## Designing a circuit plan



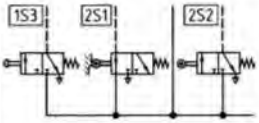

The circuit is subdivided into subcircuits with related control functions.
The actual spatial arrangement of the components is not considered.



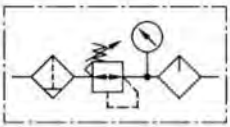

If the circuit diagram is made of several units, the unit number must be given, beginning with numeral 1.



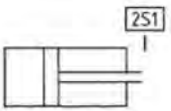

Components are arranged from bottom to top in the direction of power flow and from left to right.



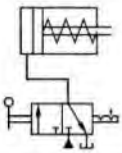

Similar components or subassemblies are shown at the same height within a circuit.



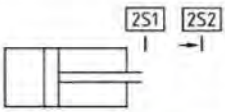
Subassemblies such as throttle check valves or service units (FRL) are enclosed by a dash-dot line.



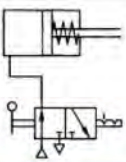

Devices actuated by drives, e.g. limit switches, are represented at their point of activation by a dash and their designator.



Hydraulic components are shown in their initial positions in the equipment before pressure is applied.




For roller plunger valves operating on one side only, a directional arrow is also placed at the dash.

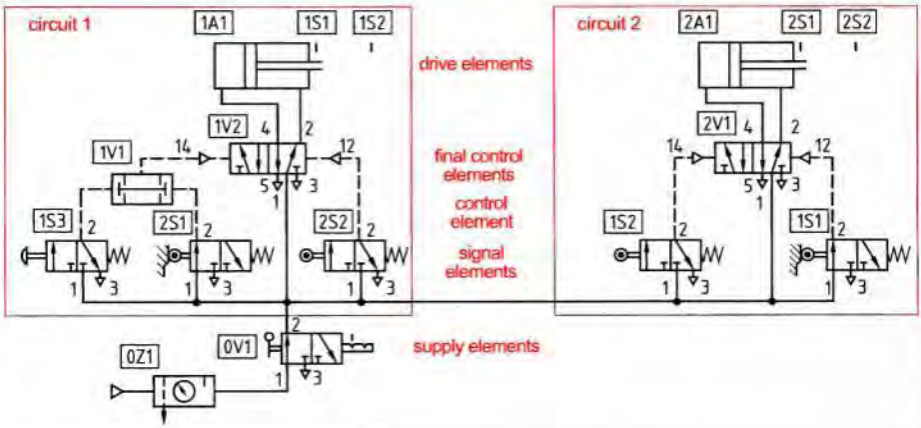


Pneumatic components are shown in their initial positions in the equipment before pressure is applied.

**Components of a circuit**

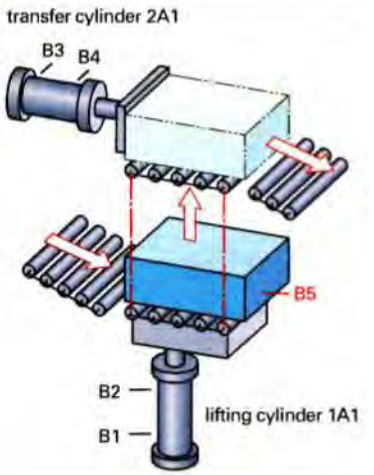
| | |
|---|---|
| Drive elements<br>Actuators | Motors, cylinders, valves<br>Valves for controlling drive elements |
| Control elements<br>Signal elements | Valves for signal combination<br>Components used to trigger a switching action |
| Supply elements | Service unit (FRL), main valve |

## Example: Pneumatic circuit diagram with two cylinders (lifting device)

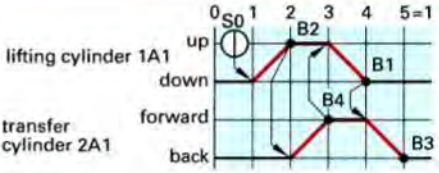


# Electropneumatic controls

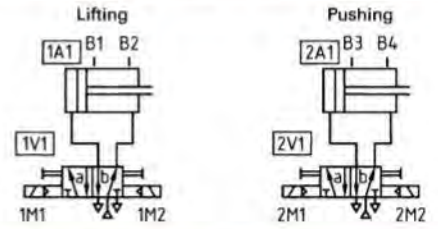
## Layout



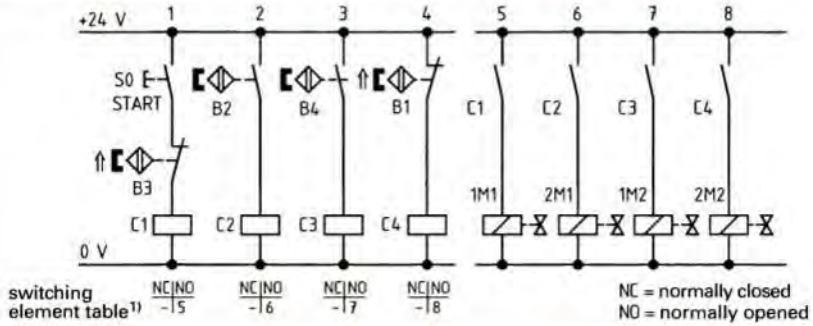

## Function diagram



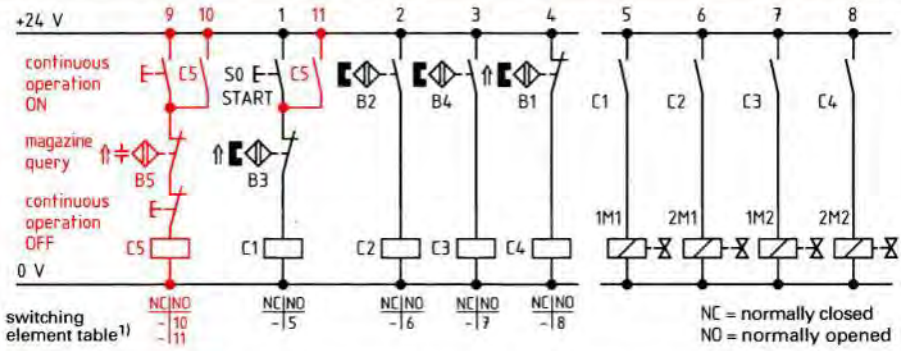

## Pneumatic circuit diagram




## Circuit diagram




## Circuit diagram with the additional functions – magazine query and continuous operation

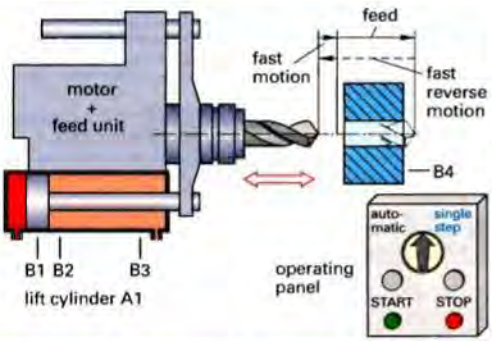



**Example for relay K5:** Relay K5 has a normally open switch in section 10 and a normally open switch in section 11.

1) The switching element table is similar to the contact table (pg. 354) and is often used in practice. However it is not standardized. The table indicates the section in which a NC or NO relay contact can be found.

# Sequence control of a feed unit via PLC according to GRAFCET

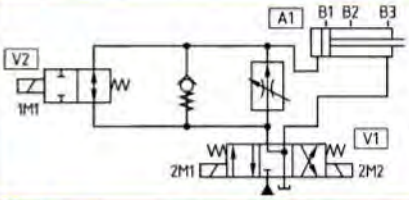
## Technological scheme



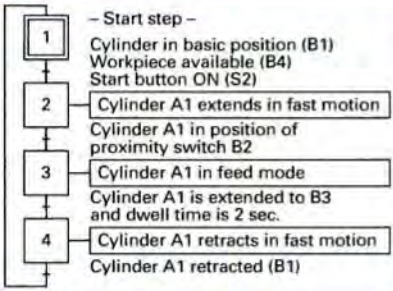

## Description

The hydraulic cylinder extends in fast motion and is switched into feed mode by switch B2. In the fully extended position, the proximity switch B3 switches to fast reverse after a time delay of 2 seconds.

## Description




## Function chart and GRAFCET



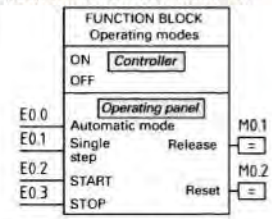

## Allocation list

| Components and action | Component designation | Address | Remarks |
|---|---|---|---|
| Mode switch AUTOMATIC/STEP | S0/S1 | E0.0/E0.1 | NO contact/ NC contact |
| Push button START | S2 | E0.2 | NO contact |
| Push button STOP | S3 | E0.3 | NC contact |
| Proximity switch | B1-B4 | E0.4-E0.7 | NO contact |
| Solenoid valve Q11 Cylinder in feed mode | 1M1 | A1.0 | – |
| Solenoid valve Q12 Extend cylinder | 2M1 | A1.1 | – |
| Solenoid valve Q14 Retract cylinder | 2M2 | A1.2 | – |

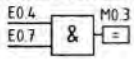
## Function block language FBL

**Operating modes**

**Network 1:** Function block FB1

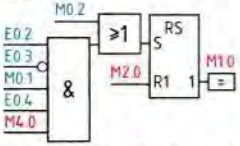



**Network 2:** Basic position



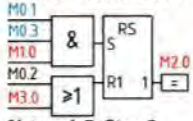

**Step chain**

**Network 3: Step 1**
Start step

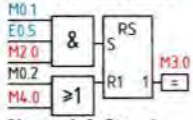



Color marking: step flag in red
Transition in blue

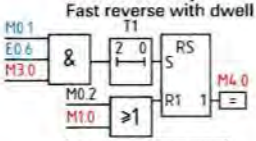
**Network 4: Step 2**
Extend in fast motion




**Network 5: Step 3**
Extend in feed mode

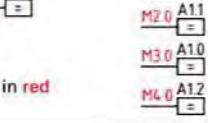



**Network 6: Step 4**
Fast reverse with dwell time




**Command output**

**Networks 7 to 9**




## Instruction list IL

```
Network 1
CALL FB1

Network 2
Basic position
U E0.4
U E0.7
S M0.3

Network 3
Step 1:
Start step
U E0.2
UN E0.3
U M0.1
U E0.4
U M4.0
O M0.2
S M1.0
U M2.0
R M1.0

Network 4
Step 2:
Fast extension
U M0.1
U M0.3
U M1.0
S M2.0
O M0.2
O M3.0
R M2.0

Network 5
Step 3:
Feed mode
U M0.1
U E0.5
U M2.0
S M3.0
U M0.2
O M4.0
R M3.0

Network 6
Step 4:
Fast reverse
U M0.1
U E0.6
U M3.0
= T1
U T1
S M4.0
U M0.2
O M1.0
R M4.0

Network 7 to 9
Steps 5 to 7:
Command output
U M2.0
= A1.1
U M3.0
= A1.0
U M4.0
= A1.2
PE
```

# Hydraulic fluids

## Mineral oil based hydraulic oils

cf. DIN 51524-1 to -3 (2006-04)

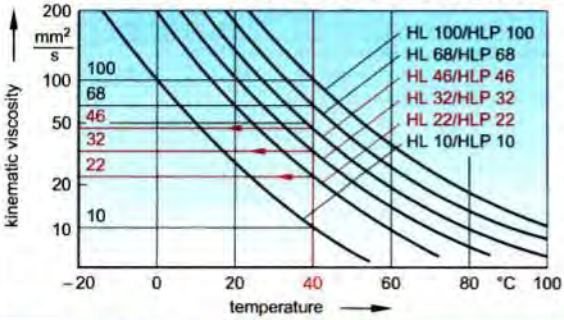
| Type | Standard | Effect of the ingredients | | Applications |
|---|---|---|---|---|
| HL | DIN 51524-1 | Increase in corrosion resistance + Increase in aging resistance | – | Hydraulic units up to 200 bar, with high temperature requirements |
| HLP | DIN 51524-2 ) | | + Reduction of wear due to scoring in mixed friction area | Hydraulic units with hydro pumps and hydro motors above 200 bar operating pressure and with high temperature requirements |
| HVLP | DIN 51524-3 | | + Reduction of wear due to scoring in mixed friction area<br>+ Improvement of viscosity-temperature behavior | |

| Properties | | HL 10 HLP 10 | HL 22 HLP 22 | HL 32 HLP 32 | HL 46 HLP 46 | HL 68 HLP 68 | HL 100 HLP 100 |
|---|---|---|---|---|---|---|---|
| Kinematic viscosity in mm²/s | at –20 °C | 600 | – | – | – | – | – |
| | at 0 °C | 90 | 300 | 420 | 780 | 1400 | 2560 |
| | at 40 °C | 9–11 | 19.8–24.2 | 28.8–35.2 | 41.4–50.6 | 61.2–74.8 | 90–110 |
| | at 100 °C | 2.4 | 4.1 | 5.0 | 6.1 | 7.8 | 9.9 |
| Pour point[1] equal to or lower than | | 30 °C | –21 °C | –18 °C | –15 °C | –12 °C | –12 °C |
| Flash point above | | 125 °C | 165 °C | 175 °C | 185 °C | 195 °C | 205 °C |

[1] The pour point is the temperature at which hydraulic oil still flows under the force of gravity.

⇒ **Hydraulic oil DIN 51524 – HLP 46**: Hydraulic oil of type HLP, kinematic viscosity = 46 mm²/s at 40 °C

### Viscosity-temperature behavior of HL and HLP hydraulic oils




**Example of reading from diagram:**
A gear pump operates at an average operating temperature of 40 °C. During operation the allowable kinematic viscosity of the hydraulic oil is allowed to fluctuate between 20 to 50 mm²/sec.

According to the diagram there are 6 hydraulic oils that would be suitable:

- HL 22/HLP 22
- HL 32/HLP 32
- HL 46/HLP 46

## Non-flammable hydraulic fluids

| Type | ISO Viscosity classes | Suitability for temperatures °C | Characteristics | Applications |
|---|---|---|---|---|
| HFC | 15, 22, 32, 46, 68, 100 | –20 to +60 | Aqueous monomer and/or polymer solutions, good wear protection | Mining, printing machines, welding machines, forging presses |
| HFD | | –20 to +150 | Water free synthetic liquids, good resistance to aging, lubricating property through wide temperature range | Hydraulic equipment with high operating temperatures |

## Biodegradable hydraulic fluids

cf. VDMA 24569 (1994-03)

| Hydraulic fluid | Suitability and properties: Low temperature flowability | High temperature oxidation stability | Rust protection | Compatibility with inner coatings | Seal compatibility | Cost effectiveness | Fluid life |
|---|---|---|---|---|---|---|---|
| Unsaturated esters | ◐ | ◐ | ● | ◔ | ◕ | ◐ | ◕ |
| Saturated esters | ● | ● | ● | ◕ | ◕ | ◔ | ● |
| Polyglycol oils | ● | ● | ◔ | ◔ | ◕ | ◐ | ◕ |

Suitability: ● very good ◕ good ◐ average ◔ limited/poor

# Pneumatic cylinders

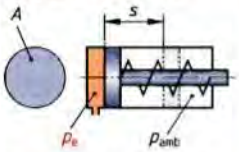
## Dimensions and piston forces

| Piston diameter | | 12 | 16 | 20 | 25 | 32 | 40 | 50 | 63 | 80 | 100 | 125 | 160 | 200 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Piston rod diameter (mm) | | 6 | 8 | 8 | 10 | 12 | 16 | 20 | 20 | 25 | 25 | 32 | 40 | 40 |
| Coupling thread | | M5 | M5 | G1/8 | G1/8 | G1/8 | G1/8 | G1/4 | G3/8 | G3/8 | G1/2 | G1/2 | G3/4 | G3/4 |
| Pushing force[1] at $p_e$ = 6 bar in N | single-act. cyl.[2] | 50 | 96 | 151 | 241 | 375 | 644 | 968 | 1560 | 2530 | 4010 | – | – | – |
| | double-act. cyl. | 58 | 106 | 164 | 259 | 422 | 665 | 1040 | 1650 | 2660 | 4150 | 6480 | 10600 | 16600 |
| Pulling force[1] at $p_e$ = 6 bar in N | double-act. cyl. | 54 | 79 | 137 | 216 | 364 | 560 | 870 | 1480 | 2400 | 3890 | 6060 | 9960 | 15900 |
| Stroke in mm | single-act. cyl. | 10, 25, 50 | | | | | 25, 50, 80, 100 | | | | | – | | |
| | double-act. cyl. | to 160 | to 200 | to 320 | 10, 25, 50, 80, 100, 160, 200, 250, 320, 400, 500 | | | | | | | | | |

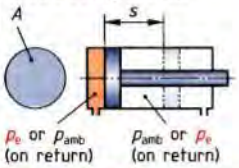
[1] For a cylinder efficiency $\eta = 0.88$ [2] The return force of the spring is considered.

## Calculating air consumption

**Single-acting cylinder**




**Double-acting cylinder**




$Q$ air consumption
$p_e$ gage pressure in cylinder
$p_{amb}$ ambient air pressure
$n$ number of strokes
$A$ piston surface area
$q$ specific air consumption per cm piston stroke
$s$ piston stroke

**Example:**

Single-acting cylinder with $d$ = 50 mm; $s$ = 100 mm; $p_e$ = 6 bar; $n$ = 120/min; $p_{amb}$ = 1 bar; air consumption $Q$ in l/min?

$$Q = A \cdot s \cdot n \cdot \frac{p_e + p_{amb}}{p_{amb}}$$

$$= \frac{\pi \cdot (5\,\text{cm})^2}{4} \cdot 10\,\text{cm} \cdot 120\,\frac{1}{\text{min}} \cdot \frac{(6+1)\,\text{bar}}{1\,\text{bar}}$$

$$= 164\,934\,\frac{\text{cm}^3}{\text{min}} \approx \mathbf{165}\,\frac{\text{l}}{\textbf{min}}$$

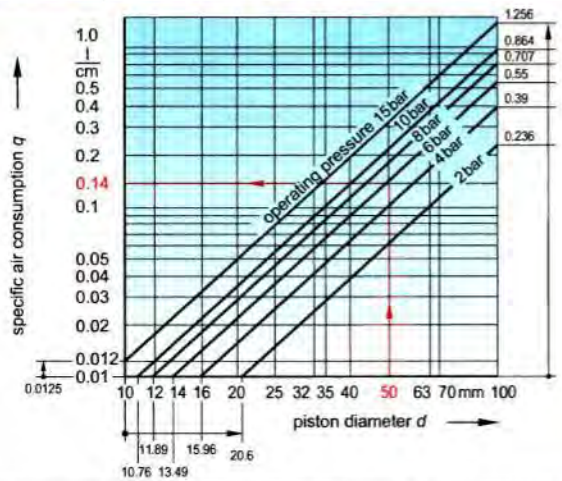
**Air consumption[1] Single-acting cylinder**

$$Q = A \cdot s \cdot n \cdot \frac{p_e + p_{amb}}{p_{amb}}$$

**Air consumption[1] Double-acting cylinder**

$$Q \approx 2 \cdot A \cdot s \cdot n \cdot \frac{p_e + p_{amb}}{p_{amb}}$$

## Air consumption taken from diagram




**Air consumption[1] Single-acting cylinder**

$$Q = q \cdot s \cdot n$$

**Air consumption[1] Double-acting cylinder**

$$Q \approx 2 \cdot q \cdot s \cdot n$$

**Example:**

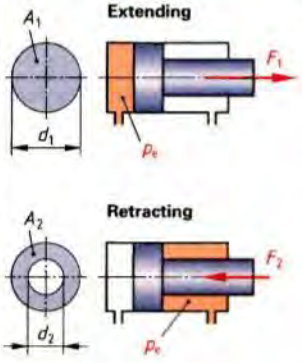
Calculate the air consumption of a single-acting cylinder of $d$ = 50 mm, $s$ = 100 mm and $n$ = 120/min from the diagram for $p_e$ = 6 bar.
According to the diagram the piston stroke is $q$ = 0.14 l/cm.

$Q = q \cdot s \cdot n =$
$= 0.14\,\text{l/cm} \cdot 10\,\text{cm} \cdot 120/\text{min}$
$= \mathbf{168\,l/min}$

[1] When it fills dead space, actual air consumption may be up to 25% greater. Dead spaces include compressed air lines between the directional control valve and the cylinder and unused space in the end position of the piston. The cross-sectional area of the piston rod is not taken into consideration.

# Force calculation

## Piston forces




$p_e$ gage pressure
$A_1$, $A_2$ piston areas
$F_1$ piston force when extending
$F_2$ piston force when retracting
$d_1$ piston diameter
$d_2$ piston rod diameter
$\eta$ efficiency

**Example:**

Hydraulic cylinder with $d_1 = 100$ mm; $d_2 = 70$ mm; $\eta = 0.85$ and $p_e = 60$ bar.
What are the effective piston forces?

**Extending:**

$$F_1 = p_e \cdot A_1 \cdot \eta = 600 \frac{\text{N}}{\text{cm}^2} \cdot \frac{\pi \cdot (10\text{ cm})^2}{4} \cdot 0.85$$

$$= \mathbf{40\,055\ N}$$

**Retracting:**

$$F_2 = p_e \cdot A_2 \cdot \eta$$

$$= 600 \frac{\text{N}}{\text{cm}^2} \cdot \frac{\pi \cdot [(10\text{ cm})^2 - (7\text{ cm})^2]}{4} \cdot 0.85$$

$$= \mathbf{20\,428\ N}$$

**Effective piston force**

$$F = p_e \cdot A \cdot \eta$$

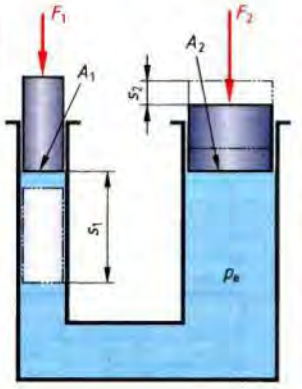
**Pressure units**

$$1\text{ Pa} = 1 \frac{\text{N}}{\text{m}^2} = 10^{-5}\text{ bar}$$

$$1\text{ bar} = 10 \frac{\text{N}}{\text{cm}^2} = 0.1 \frac{\text{N}}{\text{mm}^2}$$

1 mbar = 100 Pa = 1 hPa

## Hydraulic press




In confined liquids or gases, pressure is distributed uniformly in all directions.

$F_1$ force on pressure piston
$F_2$ force on working piston
$A_1$ area of pressure piston
$A_2$ area of working piston
$s_1$ travel of pressure piston
$s_2$ travel of working piston
$i$ hydraulic transmission ratio

**Example:**

$F_1 = 200$ N; $A_1 = 5$ cm²; $A_2 = 500$ cm²; $s_2 = 30$ mm; $F_2 = ?$; $s_1 = ?$; $i = ?$

$$F_2 = \frac{F_1 \cdot A_2}{A_1} = \frac{200\text{ N} \cdot 500\text{ cm}^2}{5\text{ cm}^2} = 20\,000\text{ N} = \mathbf{20\ kN}$$

$$s_1 = \frac{s_2 \cdot A_2}{A_1} = \frac{30\text{ mm} \cdot 500\text{ cm}^2}{5\text{ cm}^2} = \mathbf{3000\ mm}$$

$$i = \frac{F_1}{F_2} = \frac{200\text{ N}}{20\,000\text{ N}} = \mathbf{\frac{1}{100}}$$

**Displaced volume**

$$A_1 \cdot s_1 = A_2 \cdot s_2$$

**Work on both pistons**

$$F_1 \cdot s_1 = F_2 \cdot s_2$$

**Ratios: forces, areas, travel**

$$\frac{F_2}{F_1} = \frac{A_2}{A_1} = \frac{s_1}{s_2}$$

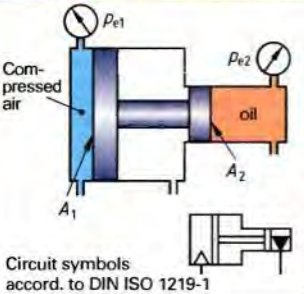
**Transmission ratio**

$$i = \frac{F_1}{F_2}$$

$$i = \frac{s_2}{s_1}$$

$$i = \frac{A_1}{A_2}$$

## Pressure intensifier




$A_1$, $A_2$ piston surface areas
$p_{e1}$ gage pressure at piston area $A_1$
$p_{e1}$ gage pressure at piston area $A_2$
$\eta$ efficiency of pressure intensifier

**Example:**

$A_1 = 200$ cm²; $A_2 = 5$ cm²; $\eta = 0.88$; $p_{e1} = 7$ bar = 70 N/cm²; $p_{e2} = ?$

$$p_{e2} = p_{e1} \cdot \frac{A_1}{A_2} \cdot \eta = 70 \frac{\text{N}}{\text{cm}^2} \cdot \frac{200\text{ cm}^2}{5\text{ cm}^2} \cdot 0.88$$

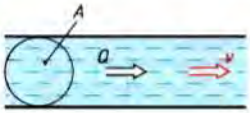
$$= 2464\text{ N/cm}^2 = \mathbf{246.4\ bar}$$

**Gage pressure**

$$p_{e2} = p_{e1} \cdot \frac{A_1}{A_2} \cdot \eta$$

# Speeds, Power

## Flow rates




$Q$, $Q_1$, $Q_2$ volume flow rates
$A$, $A_1$, $A_2$ cross-sectional areas
$v$, $v_1$, $v_2$ flow rates

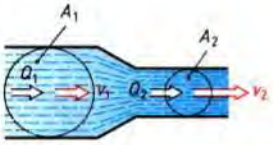
**Continuity equation**

In a pipeline of variable cross-section the volume flow rate $Q$ is constant throughout all cross-sections over time $t$.

**Volume flow rate**

$$Q = A \cdot v$$

$$Q_1 = Q_2$$




**Example:**

Pipeline with $A_1 = 19.6\ cm^2$; $A_2 = 8.04\ cm^2$ and $Q = 120\ l/min$; $v_1 = ?$; $v_2 = ?$

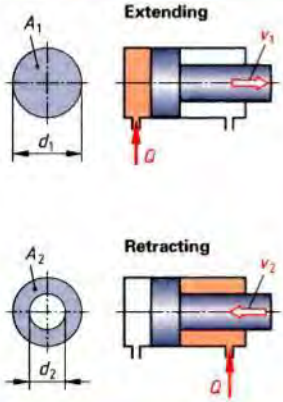
$$v_1 = \frac{Q}{A_1} = \frac{120\,000\ cm^3/min}{19.6\ cm^2} = 6122\ \frac{cm}{min} = \mathbf{1.02\ \frac{m}{s}}$$

$$v_2 = \frac{v_1 \cdot A_1}{A_2} = \frac{1.02\ m/s \cdot 19.6\ cm^2}{8.04\ cm^2} = \mathbf{2.49\ \frac{m}{s}}$$

**Ratio of flow rates**

$$\frac{v_1}{v_2} = \frac{A_2}{A_1}$$

## Piston speeds




$Q$ volume flow rate
$A_1$, $A_2$ effective piston areas
$v_1$, $v_2$ piston speeds

**Example:**

Hydraulic cylinder with piston diameter
$d_1 = 50$ mm; piston rod diameter
$d_2 = 32$ mm and $Q = 12$ l/min.
How high are the piston speeds?

**Extending:**

$$v_1 = \frac{Q}{A_1} = \frac{12\,000\ cm^3/min}{\frac{\pi \cdot (5\ cm)^2}{4}} = 611\ \frac{cm}{min} = \mathbf{6.11\ \frac{m}{min}}$$

**Retracting:**

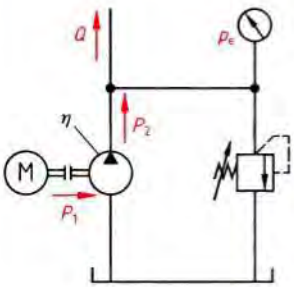
$$v_2 = \frac{Q}{A_2} = \frac{12\,000\ cm^3/min}{\frac{\pi \cdot (5\ cm)^2}{4} - \frac{\pi \cdot (3.2\ cm)^2}{4}}$$

$$= 1035\ \frac{cm}{min} = \mathbf{10.35\ \frac{m}{min}}$$

**Piston speed**

$$v = \frac{Q}{A}$$

## Power of pumps and cylinders




$P_1$ input power on pump drive shaft
$P_2$ output power on pump outlet
$Q$ volume flow rate
$p_e$ gage pressure
$\eta$ efficiency of the pump
$M$ torque
$n$ rotational speed
9550 conversion factor
600 conversion factor

**Example:**

Pump with $Q = 40$ l/min; $p_e = 125$ bar; $\eta = 0.84$; $P_1 = ?$; $P_2 = ?$

$$P_2 = \frac{Q \cdot p_e}{600} = \frac{40 \cdot 125}{600}\ kW = \mathbf{8.333\ kW}$$

$$P_1 = \frac{P_2}{\eta} = \frac{8.333}{0.84}\ kW = \mathbf{9.920\ kW}$$

**Input power**

$$P_1 = \frac{M \cdot n}{9550}$$

**Output power**

$$P_2 = \frac{Q \cdot p_e}{600}$$

**Efficiency**

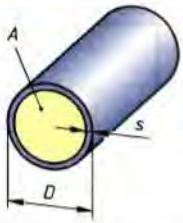
$$\eta = \frac{P_2}{P_1}$$

**Formulae for input and output power with:**
$P$ in kW, $M$ in N · m, $n$ in 1/min, $Q$ in l/min, $p_e$ in bar

# Tubes

## Seamless precision steel tubes for hydraulic and pneumatic lines (selection)

cf. DIN EN 10305-1 (2003-02)




| | | | | |
|---|---|---|---|---|
| Materials | E235 (St37.4), E355 (St52.4) according to DIN 1630 | | | |
| Mechanical properties | Material | Tensile strength $R_m$ N/mm² | Yield strength $R_e$ N/mm² | Elongation at fracture $EL$ % |
| | E235 | 340 to 480 | 235 | 25 |
| | E355 | 490 to 630 | 355 | 22 |
| | Good cold workability, surface phosphatized or electroplated and chromed | | | |
| Applications | For lines in hydraulic or pneumatic systems at maximal rated pressures up to 500 bar | | | |

**Delivery type:** Normal manufactured length: 6 m, normalized. Tubes have a surface quality of $Ra \leq 4$ µm.

⇒ **Tube HPL-E235-NBK-20 x 2:** Seamless precision steel tube for hydraulic and pneumatic applications, made of E235, normalized, bright-drawn, outside diameter 20 mm, wall thickness 2 mm

| Outside diameter $D$ mm | Wall thickness $s$ mm | Flow sectional area $A$ cm² | Outside diameter $D$ mm | Wall thickness $s$ mm | Flow sectional area $A$ cm² | Outside diameter $D$ mm | Wall thickness $s$ mm | Flow sectional area $A$ cm² |
|---|---|---|---|---|---|---|---|---|
| 4 | 0.8 | 0.05 | 20 | 2.0 | 2.01 | 38 | 2.5 | 8.55 |
| 4 | 1.0 | 0.01 | 20 | 2.5 | 1.77 | 38 | 4.0 | 7.07 |
| 5 | 0.8 | 0.10 | 20 | 3.0 | 1.54 | 38 | 5.0 | 6.16 |
| 5 | 1.0 | 0.07 | 20 | 4.0 | 1.13 | 38 | 7.0 | 4.52 |
| 6 | 1.0 | 0.13 | 22 | 1.0 | 3.14 | 38 | 10.0 | 2.55 |
| 6 | 1.5 | 0.07 | 22 | 2.0 | 2.54 | 42 | 2.0 | 11.34 |
| 8 | 1.0 | 0.28 | 22 | 3.0 | 2.01 | 42 | 5.0 | 8.04 |
| 8 | 1.5 | 0.20 | 22 | 3.5 | 1.77 | 42 | 8.0 | 5.31 |
| 8 | 2.0 | 0.13 | 25 | 1.5 | 3.80 | 50 | 4.0 | 13.85 |
| 10 | 1.0 | 0.50 | 25 | 2.5 | 3.14 | 50 | 5.0 | 12.57 |
| 10 | 1.5 | 0.39 | 25 | 3.0 | 2.84 | 50 | 8.0 | 9.08 |
| 10 | 2.0 | 0.28 | 25 | 3.5 | 2.55 | 50 | 10.0 | 7.07 |
| 12 | 1.0 | 0.79 | 25 | 4.5 | 2.01 | 50 | 13.0 | 4.52 |
| 12 | 1.5 | 0.64 | 25 | 6.0 | 1.33 | 55 | 4.0 | 17.35 |
| 12 | 2.0 | 0.50 | 28 | 1.5 | 4.91 | 55 | 6.0 | 14.52 |
| 14 | 1.0 | 1.13 | 28 | 2.0 | 4.52 | 55 | 8.0 | 11.95 |
| 14 | 1.5 | 0.95 | 28 | 3.0 | 3.80 | 55 | 10.0 | 9.62 |
| 14 | 2.0 | 0.79 | 28 | 3.5 | 3.46 | 60 | 5.0 | 19.64 |
| 15 | 1.0 | 1.33 | 28 | 4.0 | 3.14 | 60 | 8.0 | 15.21 |
| 15 | 1.5 | 1.13 | 30 | 2.0 | 5.31 | 60 | 10.0 | 12.57 |
| 15 | 2.5 | 0.79 | 30 | 2.5 | 4.91 | 60 | 12.5 | 9.62 |
| 16 | 1.0 | 1.54 | 30 | 3.0 | 4.52 | 70 | 5.0 | 28.27 |
| 16 | 2.0 | 1.13 | 30 | 5.0 | 3.14 | 70 | 8.0 | 22.90 |
| 16 | 3.0 | 0.79 | 30 | 6.0 | 2.55 | 70 | 10.0 | 19.64 |
| 16 | 3.5 | 0.64 | 35 | 2.5 | 7.07 | 70 | 12.5 | 15.90 |
| 18 | 1.0 | 2.01 | 35 | 3.5 | 6.16 | 80 | 6.0 | 36.32 |
| 18 | 1.5 | 1.77 | 35 | 4.0 | 5.73 | 80 | 8.0 | 32.17 |
| 18 | 2.0 | 1.54 | 35 | 5.0 | 4.91 | 80 | 10.0 | 28.27 |
| 18 | 3.0 | 1.13 | 35 | 6.0 | 4.16 | 80 | 12.5 | 23.76 |

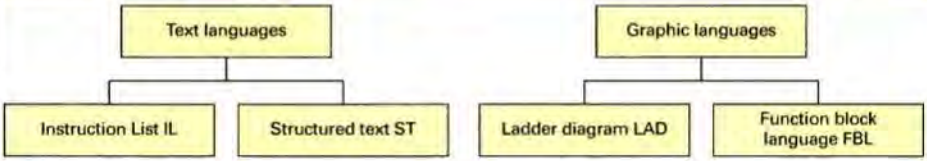
**Rated pressure** depending on wall thickness

| Outside diameter $D$ in mm | Rated pressure $p$ in bar | | | | | |
|---|---|---|---|---|---|---|
| | 64 | 100 | 160 | 250 | 320 | 400 |
| | Wall thickness $s$ in mm | | | | | |
| 6 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.5 |
| 8 | 1.0 | 1.0 | 1.0 | 1.5 | 1.5 | 2.0 |
| 10 | 1.0 | 1.0 | 1.0 | 1.5 | 1.5 | 2.0 |
| 12 | 1.0 | 1.0 | 1.5 | 2.0 | 2.0 | 2.5 |
| 16 | 1.5 | 1.5 | 1.5 | 2.0 | 2.5 | 3.0 |
| 20 | 1.5 | 1.5 | 2.0 | 2.5 | 3.0 | 4.0 |
| 25 | 2.0 | 2.0 | 2.5 | 3.0 | 4.0 | 5.0 |
| 30 | 2.5 | 2.5 | 3.0 | 4.0 | 5.0 | 6.0 |
| 38 | 3.0 | 3.0 | 4.0 | 5.0 | 6.0 | 8.0 |
| 50 | 4.0 | 4.0 | 5.0 | 6.0 | 8.0 | 10.0 |

# Programming languages

## PLC programming languages (overview)

cf. DIN EN 61131 (2003-12)




## Common elements of all PLC languages (selection)

**Delimiters** (selection)

cf. DIN EN 61131 (2003-12)

| Symbol | Use |
|---|---|
| (**) | At beginning and end of comment |
| + | Leading prefix for decimal numbers<br>Addition operator (ST) |
| – | Leading prefix for decimal numbers<br>Year-month-day separator<br>Subtraction, negative operator (ST)<br>Horizontal line (LAD and FBL) |
| := | Initialization operator<br>Assignment operator (ST) |
| # | Base number and time literal separator |
| ' | Beginning and end of character strings |
| $ | Beginning of special characters in strings |
| . | Whole number/fraction separator<br>Separator for hierarchal addresses and structured elements |
| e *or* E | Real-exponent delimiter |

| Symbol | Use |
|---|---|
| : | Step names and variable/type separators<br>Statement label separators (ST)<br>Network label separators (LAD and FBL) |
| ( ) | Instruction lists modifier/operator (ST)<br>Function arguments (ST)<br>Delimiter for FBL input lists (ST) |
| ; | Separator for type declaration<br>Separator for statements (ST) |
| " | Separator for areas<br>Separator for CASE areas (ST) |
| , | Bulleted lists, initial values and field index separators, operand lists, function argument lists and CASE value lists separators (ST) |
| % | Direct representation prefix[1] |
| I *or* ! | Vertical lines (LD) |

**Individual element variables for storage locations**

| Variable | Meaning | Variable | Meaning | Example (AWL) |
|---|---|---|---|---|
| I | storage location input | B | byte size (8 bit) | **ST %QB5**[1]:<br>Stores current result in byte size in output storage location 5 |
| Q | storage location output | W | word size (16 bit) | |
| M | storage location tag | D | double word size (32 bit) | |
| X | (individual) bit size | L | long word size (64 bit) | |

**Operators**

| Name | Symbol | Meaning |
|---|---|---|
| ADD | + | addition |
| SUB | – | subtraction |
| MUL | * | multiplication |
| DIV | / | division |
| AND | & | Boolean AND |
| OR | ≥ 1 | Boolean OR |
| XOR | = 1 | Boolean exclusive OR |
| NOT | ⊐ | negation |
| S | ----[3] | sets Boolean operator to "1" |
| R | ----[3] | sets Boolean operator to "0" |
| GT | > | comparison: greater than |
| GE | >= | comparison: greater than or equal to |
| EQ | = | comparison: equal to |
| NE | <> | comparison: not equal to |
| LE | <= | comparison: less than or equal to |
| LT | < | comparison: less than |

**Elementary data types**

| Key word | Data type | Bits |
|---|---|---|
| BOOL | Boolean | 1 |
| SINT | short whole number | 8 |
| INT | whole number | 16 |
| DINT | double whole number | 32 |
| LINT | long whole number | 64 |
| REAL | real number | 32 |
| LREAL | long real number | 64 |
| STRING | variable long number sequence | –[4] |
| TIME | duration | –[4] |
| DATE | date | –[4] |
| BYTE | bit sequence of length 8 | 8 |
| WORD | bit sequence of length 16 | 16 |
| DWORD | bit sequence of length 32 | 32 |
| LWORD | bit sequence of length 64 | 64 |

[1] Directly represented individual element variables have a leading % symbol.
[2] This symbol is not allowed as operator in text language.
[3] No symbol
[4] Manufacturer specific

# Programming languages

## Ladder diagram (LD)

cf. DIN EN 61131 (2003-12)

A ladder diagram represents the flow in an electromechanical relay system.

| Symbol | Description |
|---|---|
| **Lines and blocks** | |
| — | Horizontal line |
| \| | Vertical line |
| ┼ | Line junction |
| ─┤├─ | Crossing without connection |
| ... 1) | Blocks with connection lines |
| ├ | Left power rail |
| ┤ | Right power rail |
| **Contacts** | |
| ... 1) ┤ ├ | NO contact logic condition "1" |
| ... 1) ┤/├ | NC contact logic condition "0" |
| ... 1) ┤P├ | Contact for sensing rising edge, signal from "0" to "1" |
| ... 1) ┤N├ | Contact for sensing falling edge, signal from "1" to "0" |
| **Coils** | |
| ... 1) —( )— | Coil output energize |
| ... 1) —(/)— | Coil output deenergize |
| ... 1) —(S)— | Latching coil, stores an operation |
| ... 1) —(R)— | Unlatching coil |
| ... 1) —(P)— | Coil for sensing positive slopes, signal from "0" to "1" |
| ... 1) —(N)— | Coil for sensing negative slopes, signal from "0" to "1" |

1) component designator

## Function block language (FBL)

cf. DIN EN 61131 (2003-12)

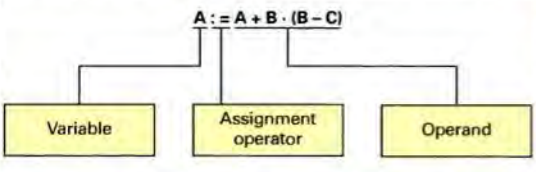
Function block language consists of individual function blocks with statistical data. They are useful in implementing frequently recurring functions.

| Symbol | Description |
|---|---|
| | Elements are rectangular or square. Input parameters are placed on the left side and output parameters on the right side. |
| FB 1.2 ADD | The block's functionality is entered as a name or symbol within the block. The block designator is located above the block. |
| AND OR OR | Elements must be interconnected by horizontal and vertical signal flow lines. |
| | Negation of Boolean signals is shown by a circle on the input or output. |

## Structured text (ST)

cf. DIN EN 61131 (2003-12)

Structured text is a high level language and builds on the syntax of ISO-PASCAL.




| Statement | Type |
|---|---|
| := | assignment |
| IF | conditional statement |
| CASE | selection statement |
| FOR | repeat statement |
| WHILE | repeat statement |
| REPEAT | repeat statement |
| EXIT | leaving a repeated statement |

## Comparison of Function Block Language (FBL) and Structured text (ST)

| Function blocks (examples) | Structured text (examples) |
|---|---|
| B, C, D → ADD → A *or* B, C, D → + → A | A:= ADD (B, C, D) *or* A:= B + C + D |
| F, G, H → AND → E *or* F, G, H → & → E | E:= AND (F, G, H) *or* E:= F & G & H |

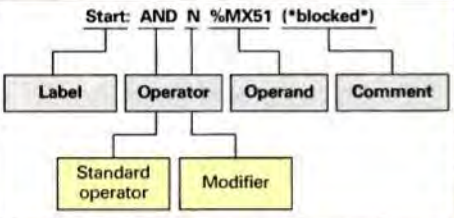
# Programming languages

## Instruction list (IL)

cf. DIN EN 61131 (2003-12)

Instruction list is a machine-oriented textual programming language, similar to assembly language.

**Structure of an instruction**




| Operator modifiers | |
|---|---|
| N | Boolean negation of the operand. |
| C | Statement is only executed if the evaluated result is a Boolean 1. |
| , | Separates multiple. |
| ( | Evaluation of the operator is deferred until ")" appears. |

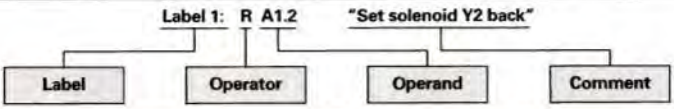
**Standard operators**

| Operator | Modifier | Meaning |
|---|---|---|
| LD | N | setting an operand |
| ST | N | storing on operand addresses |
| S | – | sets Boolean operator to 1 |
| R | – | sets Boolean operator back to 0 |
| AND | N,( | Boolean AND |
| & | N,( | Boolean AND |
| OR | N,( | Boolean OR |
| XOR | N,( | Boolean exclusive OR |
| ADD | ( | addition |
| SUB | ( | subtraction |
| MUL | ( | multiplication |
| DIV | ( | division |
| GT | ( | comparison: > |
| GE | ( | comparison: >= |
| EQ | ( | comparison: = |
| NE | ( | comparison: <> |
| LE | ( | comparison: <= |
| LT | ( | comparison: < |
| JMP | C,N | jump to label |
| CAL | C,N | call of a function block |
| RET | C,N | jump back |
| ) | – | processing of deferred operations |

## Information list (IL) according to VDI[1)]

cf. VDI 2880 (1985-09)

**Structure of an instruction**




| Operators for program organization | |
|---|---|
| L | load |
| ( | open parenthesis |
| ) | closed parenthesis |
| NOP | null operation |
| SP | unconditional jump |
| SPB | conditional jump |
| BA | call of a block |
| BAB | conditional call of a block |
| BE | block end |
| " | comment beginning |
| " | comment end |
| PE | program end |

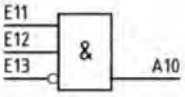
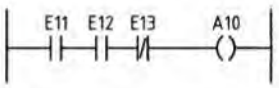
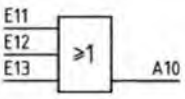
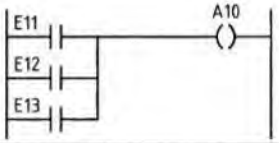
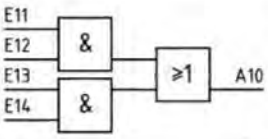
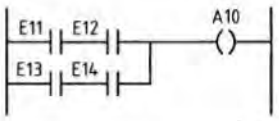
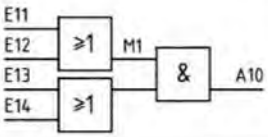
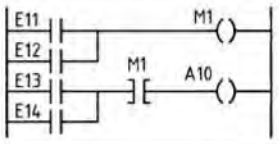
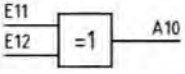
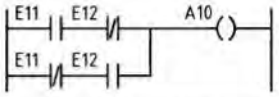
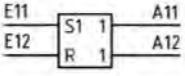
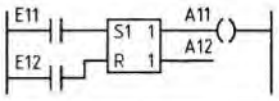
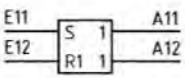
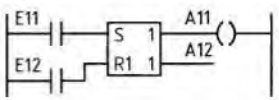
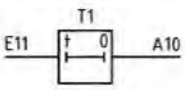
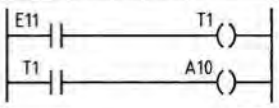
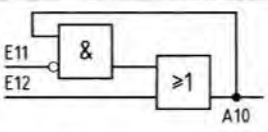
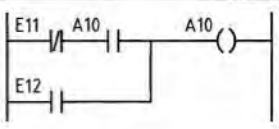
| Operators for signal processing | |
|---|---|
| U | AND operation |
| O | OR operation |
| N | negation |
| UN | NAND operation |
| ON | NOR operation |
| = | assignment |
| ADD | addition |
| SUB | subtraction |
| MUL | multiplication |
| DIV | division |
| S | set |
| R | reset |

| Operators | |
|---|---|
| ZV | count forwards |
| ZR | count backwards |
| XO | exclusive OR |
| **Operand** | |
| E | input |
| A | output |
| M | tag |
| K | constant |
| T | timer |
| Z | counter |
| P | program block |
| F | function block |

1) In practice, many more PLC controls exist which are programmed according to the VDI guidelines.

# Programming languages

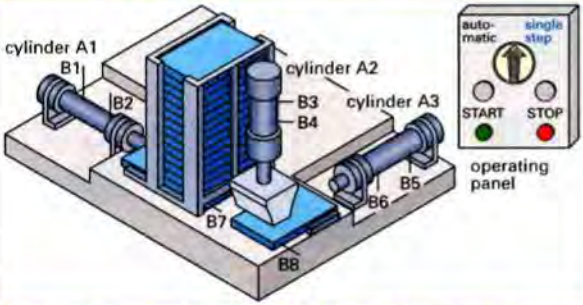
## Comparison of the most commonly used PLC programming languages

| Functions as components of programs | Instruction list (IL) according to VDI | Function block language (FBL) | Ladder diagram (LD) |
|---|---|---|---|
| **AND** with 3 inputs | U E11<br>U E12<br>UN E13<br>= A10 |  |  |
| **OR** with 3 inputs | U E11<br>O E12<br>O E13<br>= A10 |  |  |
| **AND** before **OR** | U E11<br>U E12<br>O<br>U E13<br>U E14<br>= A10 |  |  |
| **OR** before **AND** with intermediate tag | U E11<br>O E12<br>= M1<br>U E13<br>O E14<br>U M1<br>= A10 |  |  |
| Exclusive **OR** (XOR) | U E11<br>UN E12<br>O (UN E11<br>U E12)<br>= A10 |  |  |
| **RS flip-flop Set dominant** | U E12[1]<br>R A11<br>U E11<br>S A11 |  |  |
| **RS flip-flop Reset dominant** | U E11[1]<br>S A11<br>U E12<br>R A11 |  |  |
| **Turn on delay** | U E11<br>= T1<br>U T1<br>= A10 |  |  |
| **Latch,** ON (E 12) dominating | U E12<br>O A10<br>UN E11<br>= A10 |  |  |

[1] The following applies to flip-flops: If S = 1 and R = 1, the last function programmed in the IL dominates.

# PLC controlled embossing machine tool

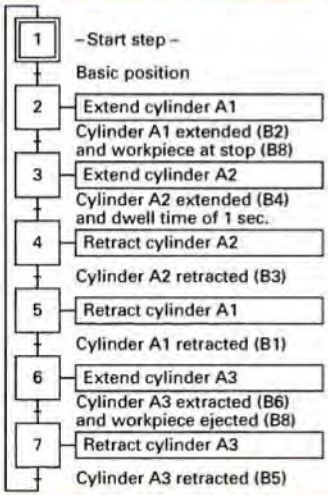
## Technological scheme




## Description

Workpieces are to be fitted with a workpiece number on an embossing machine tool. The sensor B7 detects whether workpieces are still available in the stacker. The pneumatic cylinder A1 pushes the workpiece out of the stacker into the working position. After this, the embossing cylinder A2 extends and embosses the workpiece. After a delay time of 1 sec., first the embossing cylinder A2 and then the pushing cylinder A1 are retracted. Cylinder A3 serves as an ejector of the embossed workpiece. Sensor B8 detects whether the workpiece was actually ejected.

## Function chart in accordance with GRAFCET



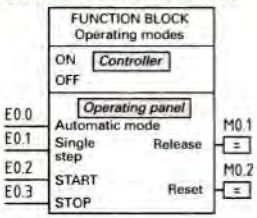

## Allocation list

| Component and action | Component designation | Address | Remarks |
|---|---|---|---|
| Mode switch AUTOMATIC/STEP | S0/S1 | E0.0/E0.1 | NO contact/ NC contact |
| Push button START | S2 | E0.2 | NO contact |
| Push button STOP | S3 | E0.3 | NC contact |
| Proximity switch | B1-B4<br>B5-B8 | E0.4-E0.7<br>E1.0-E1.3 | NO contact |
| Solenoid valve (with cyl. A1) | 1M1 und 1M2 | A0.0/A0.1 | – |
| Solenoid valve (with cyl. A2) | 2M1 und 2M2 | A0.2/A0.3 | – |
| Solenoid valve (with cyl. A3) | 3M1 und 3M2 | A0.4/A0.5 | – |

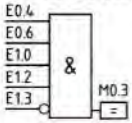
## Function block language (FBL)

**Operating modes**

**Network 1:** Function block FB1



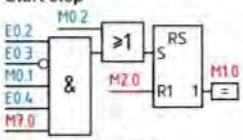

**Network 2:** Basic position



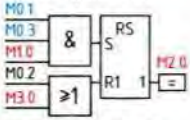

Color marking: step flag in red
Transition in blue

**Step chain**

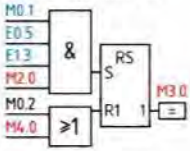
**Network 3: Step 1**
Start step



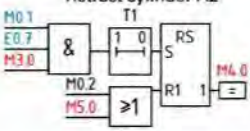

**Network 4: Step 2**
Extend cylinder A1



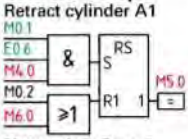

**Network 5: Step 3**
Extend cylinder A2



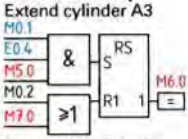

**Network 6: Step 4**
Retract cylinder A2



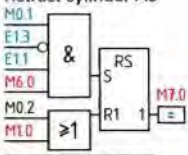

**Network 7: Step 5**
Retract cylinder A1




**Network 8: Step 6**
Extend cylinder A3

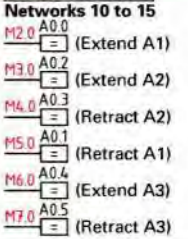



**Network 9: Step 7**
Retract cylinder A3




**Command output**

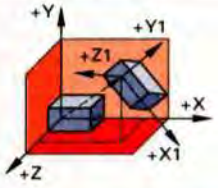
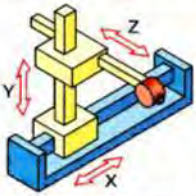
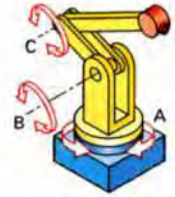
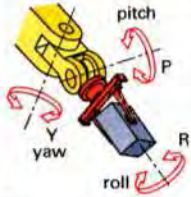
**Networks 10 to 15**



# Coordinate systems and axes

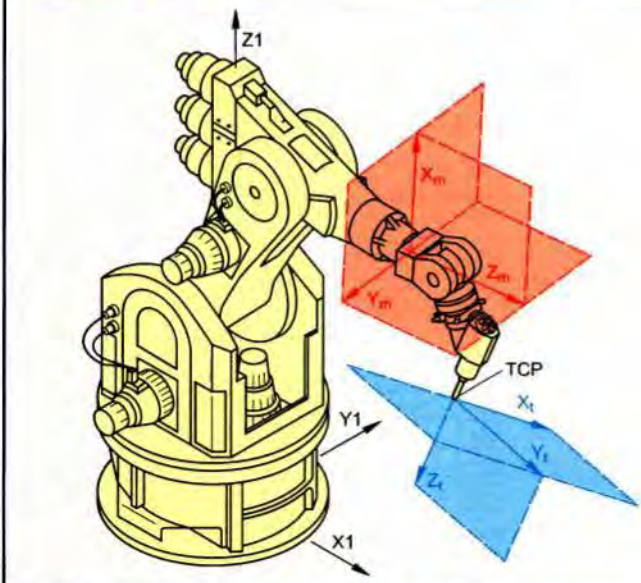
cf. DIN EN ISO 9787 (2000-07)

## Robot axes

| Coordinate system | Robot main axes for positioning | | Robot auxiliary axes for orientation |
|---|---|---|---|
|  |  |  |  |
| To manipulate workpieces or tools in space, the following are necessary:<br>• 3 degrees of freedom for positioning and<br>• 3 degrees of freedom for orientation | To reach a desired point in space, 3 robot main axes are necessary. | | 3 robot auxiliary axes for spatial orientation<br>• R (roll)<br>• P (pitch)<br>• Y (yaw) |
| | Cartesian robots | Articulated arm robots | |
| | 3 translation axes (T axes) designated X, Y and Z | 3 rotational axes (R-axes) designated A, B and C | |

## Coordinate systems

cf. DIN EN ISO 9787 (2000-07)




**Base coordinate system**

The base coordinate system references
- the level mounting surface for the X-Y plane
- the center of the robot for the Z axis

**Flange coordinate system**

The flange coordinate system references the end surface of the terminating main axis of the robot.

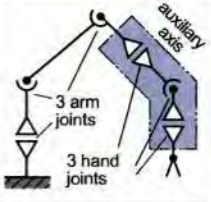
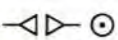
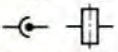
**Tool coordinate system**

The origin of the tool coordinate system lies at the tool center point *TCP* (*T*ool *C*enter *P*oint).

The speed of the tool center point is referred to as the robot speed and the path of tool travel as the robot trajectory.

## Symbols for representing robots (selection)

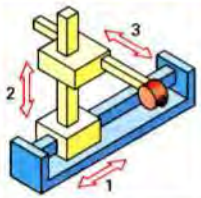
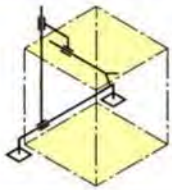
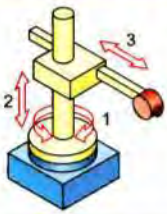
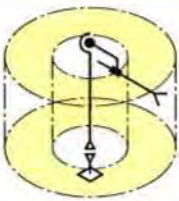
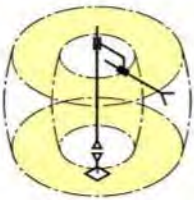
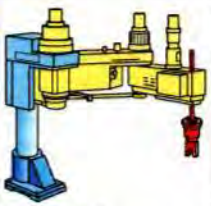
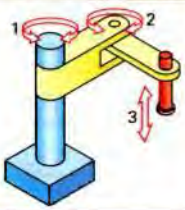
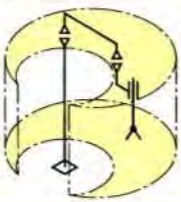
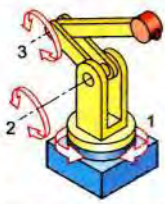
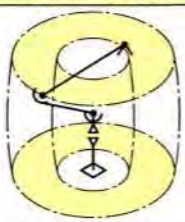
cf. VDI 2861 (1988-06)

| Designation | Symbol | Designation | Symbol | Example RRR robots |
|---|---|---|---|---|
| **Translation axis (T-axis)[1]** | | **Rotation axis (R-axis)[2]** | |  |
| Translation aligned (telescoping) |  | Rotation aligned |  | |
| Translation out of alignment |  | Rotation out of alignment |  | |
| Gripper |  | Auxiliary axis (e.g. for roll, pitch and yaw) |  | |

[1] Translation = straight line motion [2] Rotation = rotational motion

# Robot designs

cf. DIN EN ISO 9787 (2000-07)

| Mechanical structure[1] | Kinematics[2] and working space | Examples of design types | Characteristics, areas of application |
|---|---|---|---|
| Cartesian robots | TTT-Kinematics |  Gantry robot | Main axes:<br>• 3 translational<br>Areas of application:<br>• large working space, therefore often in overhead gantry<br>• tool and workpiece feed in production cells<br>• sheet processing with laser beam and water jet cutting<br>• palletizing |
|  |  | | |
| Cylindrical robots | RTT-Kinematics |  Base robot | Main axes:<br>• 1 rotational<br>• 2 translational<br>Areas of application:<br>• suitable for heavy masses<br>• handling of heavy forged and cast parts<br>• transport of pallets and tool cartridges<br>• pick and place |
|  |  | | |
| Polar robot 1 | RRT-Kinematics |  Vertical swivel arm robot | Main axes:<br>• 2 rotational<br>• 1 translational<br>Areas of application:<br>• telescoping type axis 3, consequently deeper working space<br>• point and simple path welding, e.g. on car bodies<br>• pick and place with die casting machines |
|  |  | | |
| Polar robot 2<br>Type: SCARA[3] robot | RRT-Kinematics |  Horizontal swivel arm robot | Main axes:<br>• 2 rotational as horizontal revolute joint<br>• 1 translational<br>Areas of application:<br>• primarily in vertical assembly area<br>• point and simple path welding<br>• pick and place work |
|  |  | | |
| Articulated arm robots | RRR-Kinematics |  Vertical swivel arm robot | Main axes:<br>• 3 rotational<br>Areas of application:<br>• handling and assembly area<br>• complex path welding<br>• painting work<br>• adhesive bonding<br>• low space requirement yet large working space |
|  |  | | |

1) Axes are designated with numbers, where axis 1 is the axis of the first motion.
2) R = rotational axis; T = translational axis (Designations "R" and "T" are not standardized.)
3) SCARA = Selective Compliance Assembly Robot Arm

# Grippers, Job safety

## Gripper

cf. DIN EN ISO 14539 (2002-12) and VDI 2740 (1995-04)

**Gripper**

- **mechanical**
- **pneumatic**
  - suction gripper
  - articulated finger gripper
- **magnetic**
  - electromagnets
  - permanent magnets
- **adhesive**
  - velcro fastener gripper

### Finger grippers

| Linear grippers | Characteristics |
|---|---|
|  | 1 degree of movement |
| Flat gripper<br>  | 3 degrees of movement |
| Spatial gripper<br>  | 6 degrees of movement |

### Jaw grippers

| Scissors grippers | Characteristics |
|---|---|
|  | Both gripper fingers turn about an axis fixed in the frame.<br>Frequently used grippers. |
| Parallel gripper<br>  | Both gripper fingers are pushed parallel to each other opposite to the gripper housing. |

### Clamp grippers

| Spring loaded | Characteristics |
|---|---|
|  | Clamping force is created by a spring.<br>Opening of the gripper by pressure. |
| Weight loaded<br>  | Clamping force created by the own weight of the gripping object.<br>Opening of the gripper by pressure. |

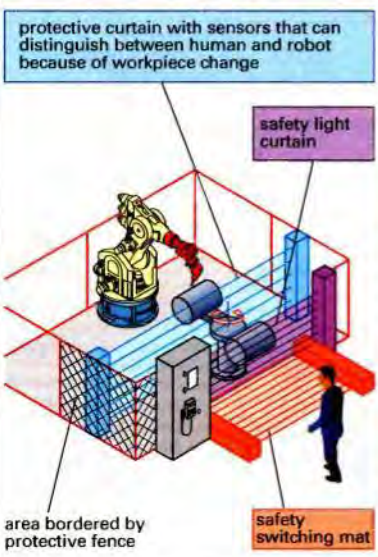
### Needle grippers



Used in textile industry. Four nail plates are extended by a tapered plug and grip the fabric.

## Work safety for handling and robot systems*

cf. DIN EN ISO 10218-1 (2007-02) & VDI 2854 (1991-06)




| Concepts | Explanations |
|---|---|
| Maximum space | Area encompassing:<br>• moving parts of robot<br>• tool flange<br>• workpiece |
| Restricted space | A portion of the maximum space which should not be entered in case of an eventual breakdown of the robot system |
| Separating safeguards | Containment fences, coverings, permanent encasements, locking devices (DIN EN 1088) |
| Protective systems with contactless activation | Hazardous area security: light curtains and light barriers<br>Area monitoring: laser scanners<br>Access security: light grills and light barriers |
| **Important safety relevant standards** | |
| DIN EN 292 | Safety stand. for machines, basic terminology |
| DIN EN 61496 | Safety standards for machines, contactless activation of safety systems |
| DIN EN 418 | Safety standards for machines, emergency OFF systems |
| DIN EN 294 | Safety around machines, safe distances |
| DIN EN 457 | Acoustical hazard signals |
| CSA Z 434-03 | Industrial Robots and Robot systems |
| ANSI R 15.06 | American Standard for Industrial Robots |

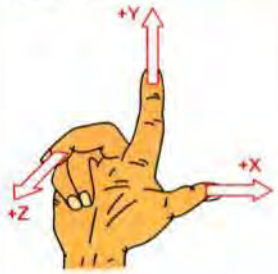
*) According to European Standards

# Coordinate axes

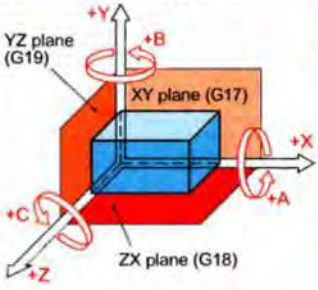
cf. DIN 66217 (1975-12)

## Coordinate system

**Right hand rule**




**Cartesian coordinate system**




Coordinate axes X, Y and Z are perpendicular to each other.

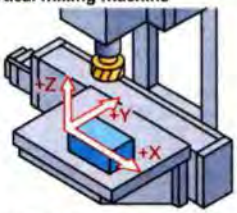
This arrangement can be represented by thumb, index finger and middle finger of the right hand.

Axes of rotation A, B and C are assigned to coordinate axes X, Y and Z.

When looking down one axis in the positive direction, the positive direction of rotation is clockwise.

## Coordinate axes in programming

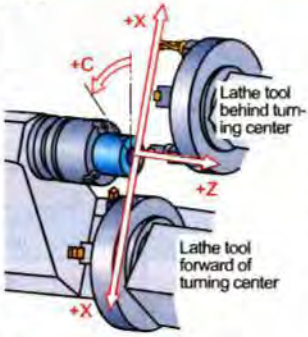
**Vertical milling machine**




**Horizontal milling machine**




**Lathe**




**Example:**
2-carriage lathe with programmable main spindle

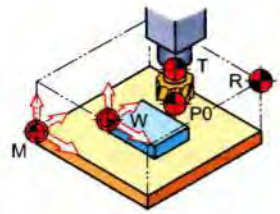
Coordinate axes and the resulting directions of motion are aligned to the main slideways of the CNC machine and are essentially relative to the clamped workpiece with its workpiece zero point.

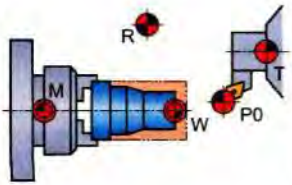
Positive directions of motion always result in greater coordinate values on the workpiece.

The Z axis always runs in the direction of the main spindle.

To simplify programming it is assumed that the workpiece remains motionless and only the tool moves.

## Reference points




M

**Machine zero point M**
Origin of the machine coordinate system and is set by the machine manufacturer.

P0

**Program zero point P0**
Indicates the coordinates of the point at which the tool is located before start of the program.

R

**Reference point R**
Origin of incremental position measurement system with a distance to the machine zero point set by the machine manufacturer.

T[1)]

**Tool holder reference point T**
Lies central to the limiting face of the tool holder. On milling machines this is the abutting surface of the tool spindle, on lathes the abutting face of the tool holder on revolver.

[1)] not standardized

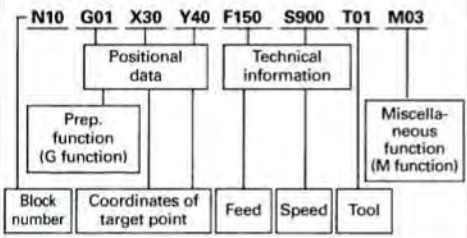
W

**Workpiece zero reference point W**
Origin of the workpiece coordinate system and is set by the programmer based on engineering principles.

# Program structure

## Tasks of the control program

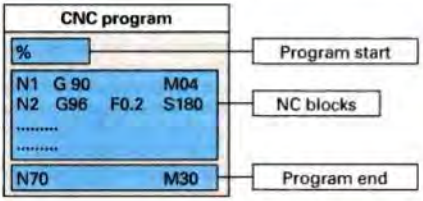
### Block structure



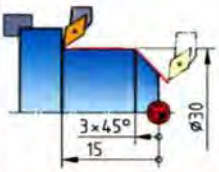

**Explanation of words:**

N10 block number 10
G01 feed, linear interpolation
X30 coordinate of target point in X direction
Y40 coordinate of target point in Y direction
F150 feed 150 mm/min
S900 speed of main spindle 900/min
T01 tool no. 1
M03 spindle clockwise

### Program structure




**Example:**




**CNC program**

```
% 01
N1 G90          M04
N2 G96  F0.2    S180
N3 G00  X20     Z2
N4 G01  X30     Z-3
N5              Z-15
N6 G00  X200    Z200
N7              M30
```

## Preparatory functions

| Prep. functions | Effective-ness | Meaning | Prep. functions | Effective-ness | Meaning |
|---|---|---|---|---|---|
| G00 | ● | Positioning at rapid rate | G53 | ● | Cancel shift |
| G01 | ● | Linear interpolation | G54–G59 | ● | Shift 1––Shift 6 |
| G02 | ● | Circle interpolation clockwise | | | |
| G03 | ● | Circle interpol. counterclockwise | G74 | ● | Approach reference point |
| G04 | ● | Dwell time predetermined | G80 | ● | Cancel fixed cycle |
| G09 | ● | Exact stop | G81–G89 | ● | Fixed cycle 1––Fixed cycle 9 |
| G17 | ● | Plane selection XY | | | |
| G18 | ● | Plane selection ZX | G90 | ● | Absolute dimensional notation |
| G19 | ● | Plane selection YZ | G91 | ● | Incremental dimensional notation |
| G33 | ● | Thread cutting, constant pitch | G94 | ● | Feed rate in mm/min |
| G40 | ● | Cancel tool offset | G95 | ● | Feed in mm |
| G41 | ● | Cutter compensation, left | G96 | ● | Constant cutting speed |
| G42 | ● | Cutter compensation, right | G97 | ● | Spindle speed in 1/min |

● modal: Preparatory functions that remain effective until they are overwritten by a similar type of condition.

● non-modal: Preparatory functions that are only effective in the block in which they are programmed.

## Universal miscellaneous functions (m-functions, selection)

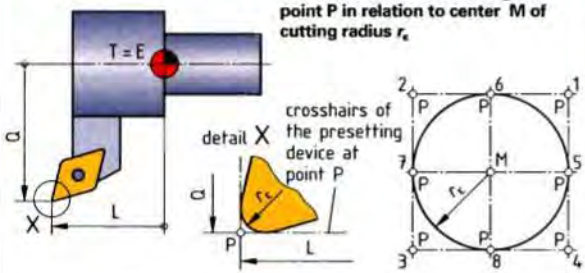
cf. DIN 66025-2 (1988-09)

| | | | | | |
|---|---|---|---|---|---|
| M00 | Programmed stop | M04 | Spindle counterclockwise | M07 | Cooling lubricant ON |
| M02 | Program end | M05 | Spindle stop | M09 | Cooling lubricant OFF |
| M03 | Spindle clockwise | M06 | Tool change | M30 | Program end with reset |

# Tool offset and Cutter compensation

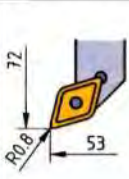
## Turning

### Tool offset

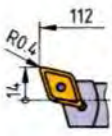



**Positional codes[1] for cutting tool point P in relation to center M of cutting radius $r_\varepsilon$**

Q transverse offset of X axis
L longitudinal correction of Z axis
$r_\varepsilon$ cutting radius
1–8 positional code digits
T tool holder reference point
E tool reference point
M center of cutting radius $r_\varepsilon$
P tool cutting point
[1] not standardized



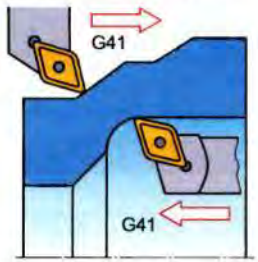

| Offset memory | |
|---|---|
| Q | 72 |
| L | 53 |
| $r_\varepsilon$ | 0.8 |
| Positional digit | 3 |



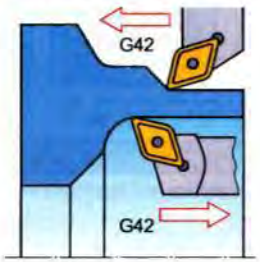

| Offset memory | |
|---|---|
| Q | 14 |
| L | 112 |
| $r_\varepsilon$ | 0.4 |
| Positional digit | 2 |

### Cutter compensation

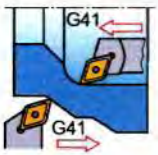
**G41 Lathe tool left**

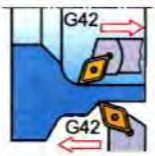



**G42 Lathe tool right**



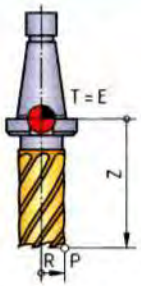

**Lathe tool forward of spindle axis**




For layout of lathe tool in front of center according to DIN 66217: Because of the different perspective in the X-Z plane, the cutter compensation would be opposite for the user looking down on the workpiece and for programming.

## Milling

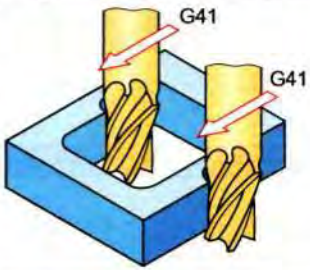



Z tool length
R tool radius
T tool holder reference point
E tool reference point
P tool cutting point

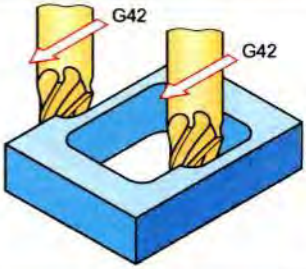



| Offset memory | |
|---|---|
| Z | 126 |
| R | 10 |

**G41 Milling cutter left**




**G42 Milling cutter right**



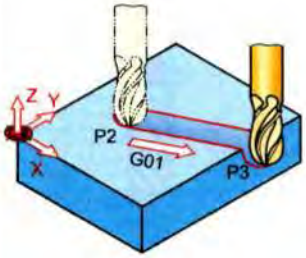

Cutter compensations G41 and G42 may be canceled with function G40.

# Program structure of CNC machines according to DIN

## Machining motion for vertical milling machines

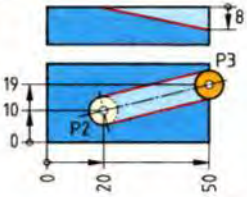
cf. DIN 66025-2 (1983-01)

### G01 Linear motion




**Designation and machining example:**

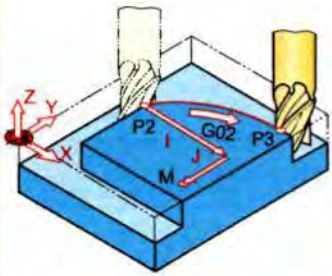
| N30 | G01 | X50 | Y19 | Z-8 |
|---|---|---|---|---|
| | Linear interpolation, machining motion in programmed feed | Coordinates of target point | | |
| | | in X direction | in Y direction | in Z direction |




**CNC program**

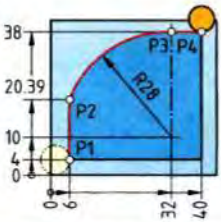
```
N...
N10  G00  X20  Y10  Z1   (P1)
N20  G01       Z0   (P2)
N30       X50  Y19  Z-8  (P3)
N...
```

### G02 Clockwise circular movement




**Designation and machining example:**

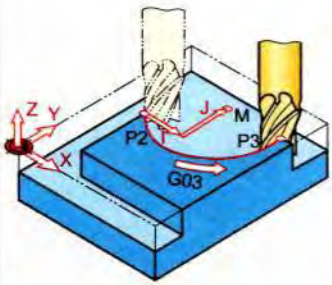
| N40 | G02 | X32 | Y38 | I26 | J-10.39 |
|---|---|---|---|---|---|
| | Clockwise circular interpolation, machining motion in programmed feed | Coordinates of circle endpoint | | Incremental input of the center point relative to circle starting point | |
| | | in X direction | in Y direction | in X direction | in Y direction |




**CNC program**

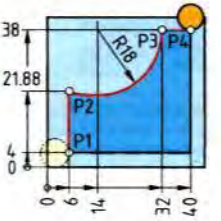
```
N...
N10  G41
N20  G01  X6   Y4          (P1)
N30            Y20.39      (P2)
N40  G02  X32  Y38  I26  J-10.39  (P3)
N50  G01  X40              (P4)
N...
```

### G03 Counterclockwise circular movement




**Designation and machining example:**

| N40 | G03 | X32 | Y38 | I8 | J16.12 |
|---|---|---|---|---|---|
| | Counterclockwise circle interpolation, machining motion in programmed feed | Coordinate of circle endpoint | | Incremental input of the center point relative to circle starting point | |
| | | in X direction | in Y direction | in X direction | in Y direction |




**CNC program**

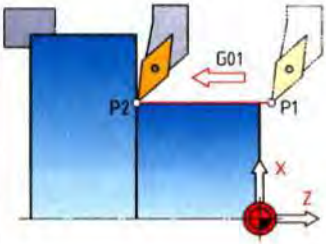
```
N...
N10  G41
N20  G01  X6   Y4          (P1)
N30            Y21.88      (P2)
N40  G03  X32  Y38  I8  J16.12  (P3)
N50  G01  X40              (P4)
N...
```

# Program structure of CNC machines according to DIN

## Machining motions of lathes

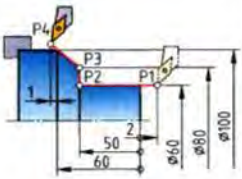
cf. DIN 66025-2 (1983-01)

### G01 Linear movement




**Designation and machining example:**

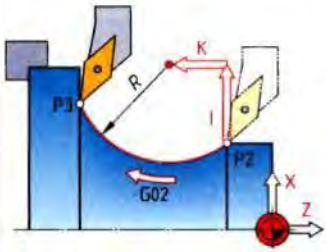
| N20 | G01 | X60 | Z-50 |
|---|---|---|---|
| | Linear interpolation, machining motion in programmed feed | Coordinates of target point | |
| | | in X direction | in Z direction |




**CNC program**

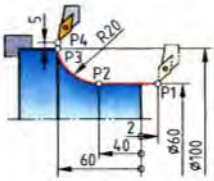
| | | | | |
|---|---|---|---|---|
| N... | | | | |
| N10 | G00 | X60 | Z2 | (P1) |
| N20 | G01 | | Z-50 | (P2) |
| N30 | | X 80 | | (P3) |
| N40 | | X102 | Z-61 | (P4) |
| N... | | | | |

### G02 Clockwise circular movement




**Designation and machining example:**

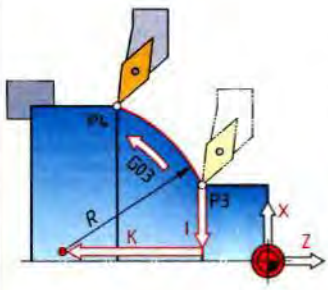
| N30 | G02 | X100 | Z-60 | I20 | K0 |
|---|---|---|---|---|---|
| | Clockwise circular interpolation, machining motion in programmed feed | Coordinates of circle endpoint | | Incremental input of center point relative to circle starting point | |
| | | in X direction | in Z direction | in X direction | in Z direction |




**CNC program**

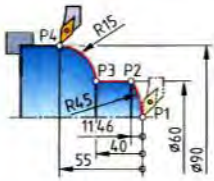
| | | | | | | |
|---|---|---|---|---|---|---|
| N... | | | | | | |
| N10 | G00 | X60 | Z2 | | | (P1) |
| N20 | G01 | | Z-40 | | | (P2) |
| N30 | G02 | X100 | Z-60 | I20 | K0 | (P3) |
| N40 | G01 | X110 | | | | (P4) |
| N... | | | | | | |

### G03 Counterclockwise circular movement




**Designation and machining example:**

| N40 | G03 | X90 | Z-55 | I0 | K-15 |
|---|---|---|---|---|---|
| | Counterclockwise circle interpolation, machining motion in programmed feed | Coordinates of circle endpoint | | Incremental input of center point relative to circle starting point | |
| | | in X direction | in Z direction | in X direction | in Z direction |




**CNC program**

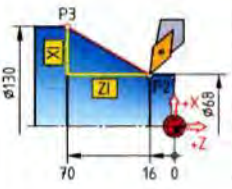
| | | | | | | |
|---|---|---|---|---|---|---|
| N... | | | | | | |
| N10 | G01 | X0 | Z0 | | | (P1) |
| N20 | G03 | X60 | Z-11.46 | I0 | K-45 | (P2) |
| N30 | G01 | | Z-40 | | | (P3) |
| N40 | G03 | X90 | Z-55 | I0 | K-15 | (P4) |
| N... | | | | | | |

# Program structure of CNC machines according to PAL[1)]

## Linear interpolation with G1 for lathes and milling machines

### Turning

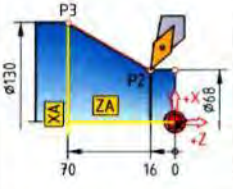
#### Incremental programming with XI, YI and ZI coordinates in NC programs with G90




**NC program**

```
N10...
N15 G90
N20...
N25 G1  X68 Z-16    ;P2
N30 G1  XI31 ZI-54  ;P3
N35...
```

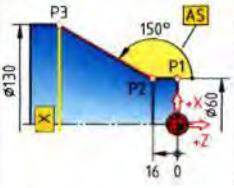
#### Absolute programming with XA, YA and ZA coordinates in NC programs with G91




**NC program**

```
N10...
N15 G91
N20...
N25 G1  X68 Z-16      ;P2
N30 G1  XA130 ZA-70   ;P3
N35...
```

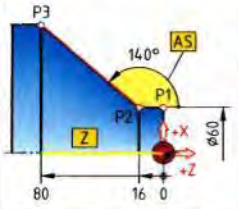
#### Start angle AS with coordinate value X




**NC program**

```
N10...
N15
N20...
N25 G1  X60 Z-16    ;P2
N30  AS150 X130     ;P3
N35...
```

#### Start angle AS with coordinate value Z

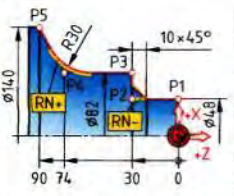



**NC program**

```
N10...
N15 G90
N20...
N25 G1  X60 Z-16    ;P2
N30 G1  AS140 Z-80  ;P3
N35...
```

#### Transition elements radius RN+ and phase RN–

The radius RN+ and the phase RN– are transition elements between two contour elements (circles, straight lines)

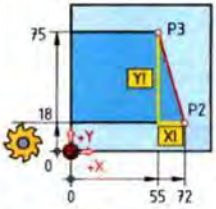



**NC program**

```
N10...
N15 G90
N20 G0  X48 Z0      ;P1
N25 G1  Z-30  RN–10 ;P2
N30 G1  X82         ;P3
N35 G1  Z-74  RN+30 ;P4
N40 G1  X140 Z-90   ;P5
```

### Milling

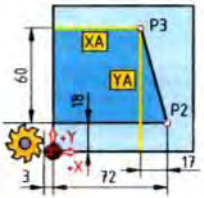
#### Incremental programming with XI, YI and ZI coordinates in NC programs with G90




**NC program**

```
N10...
N15 G42
N20 G0  X...
N25 G1  X72          ;P2
N30 G1  XI-17 YI57   ;P3
N35...
```

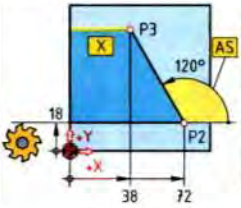
#### Absolute programming with XA, YA and ZA coordinates in NC programs with G91




**NC program**

```
N10...
N15 G42 G0 X-16 Y18
N20 G91
N25 G1  X88          ;P2
N30 G1  XA55 YA78    ;P3
N35...
```

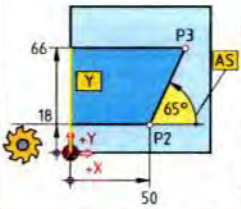
#### Start angle AS with coordinate value X




**NC program**

```
N10...
N15 G42
N20 G0  X...  Y18
N25 G1  X72          ;P2
N30 G1  AS120 X38    ;P3
N35...
```

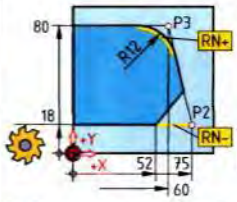
#### Start angle AS with coordinate value Z




**NC program**

```
N10...
N15 G42
N20 G0  X...  Y18
N25 G1  X50          ;P2
N30 G1  AS65 Y66     ;P3
N35...
```

#### Transition elements radius RN+ and phase RN–




**NC program**

```
N10...
N15 G42
N20 G0 X... Y18
N25 G1 X75 RN–23     ;P2
N30 G1 X60 Y80 RN+12 ;P3
N35...
```

1) Prüfungsaufgaben- und Lehrmittelentwicklungsstelle (PAL) (Institute for the development of training and testing material)

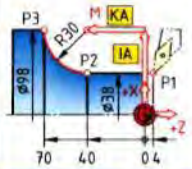
# Program structure of CNC machines according to PAL

## Circular interpolation for lathes and milling machines

### Turning

**Circular interpolation with absolute center point coordinates**

**Block structure:**
G90
G1 X.. Z.. ;P2
G2 X.. Z.. IA.. KA.. ;P3

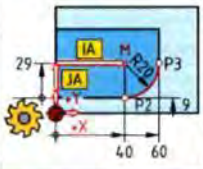



**NC program**

```
N10 ...
N15 G90
N20 G0  X38 Z4          ;P1
N25 G1  Z-40            ;P2
N30 G2 X98 Z-70 IA49 KA-40 ;P3
N35 ...
```

### Milling

**Block structure:**
G90
G1 X.. Z.. ;P2
G2 X.. Z.. IA.. JA.. ;P3




**NC program**

```
N10 ...
N15 G90
N20 G0  X... Y9         ;P1
N25 G1  X40             ;P2
N30 G3 X60 Y29 IA40 JA29 ;P3
N35 ...
```

## Selection criteria for multiple solutions

When using the radius R or the aperture angle AO, several arc solutions may result. The programmer can select the desired arc by defining an arc or a start angle with the help of the two addresses O and/or R and H.

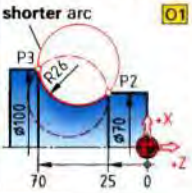
**Selection of the arc length using the address O or R**

**Block structure:**
G1 X.. Z.. ;P2
G2 X.. Z.. R.. O.. ;P3

*or:*

**Block structure:**
G1 X.. Z.. ;P2
G2 X.. Z.. R+.. ;P3

shorter arc O1




**NC program**

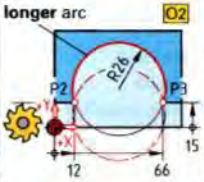
```
N10 ...
N15 G90
N20...
N25 G1 X70 Z-25          ;P2
N30 G2 X100 Z-70 R26 O1  ;P3
or:
N30 G2 X100 Z-70 R+26    ;P3
```

**Block structure:**
G1 X.. Z.. ;P2
G2 X.. Z.. R.. O.. ;P3

*or:*

**Block structure:**
G1 X.. Z.. ;P2
G2 X.. Z.. R-.. ;P3

longer arc O2



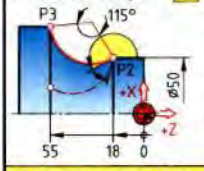

**NC program**

```
N10 ...
N15 G90
N20...
N25 G1 X12 Y15           ;P2
N30 G2 X66 Y15 R26 O2    ;P3
or:
N30 G2 X66 Y15 R-26      ;P3
```

**Selection of the start angle using the address H**

**Block structure:**
G1 X.. Z..
G2 Z.. R.. AO.. H.. ;P2 ;P3

smaller start angle H1

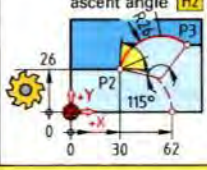



**NC program**

```
N10 ...
N15 G90
N20...
N25 G1 X50 Z-18          ;P2
N30 G2 Z-55 R26 AO115 H1 ;P3
```

**Block structure:**
G90
G1 X.. Z.. ;P2
G2 X.. R.. AO.. H.. ;P3

larger ascent angle H2




**NC program**

```
N10 ...
N15 G90
N20...
N25 G1 X30 Y26           ;P2
N30 G2 Z62 R26 AO115 H2  ;P3
```

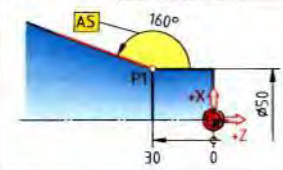
## Contour routing for lathes (selection)

Where open contour routing is concerned, the starting point as well as the target point may still be undefined. The control system calculates the starting and end point of the open element on the basis of the specified addresses.

### G61 Open line section

**Block structure:**
G1 X.. Z..
G61 AS..

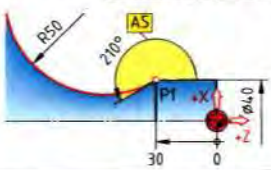
```
N15 G1  X50 Z-30 ;P1
N20 G61 AS160
```




### G62/G63 Open arc

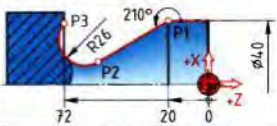
**Block structure:**
G1 X.. Z..
G62 AS.. R..

```
N15 G1  X40 Z-30 ;P1
N20 G62 AS210 R50
```




### Three-point routing

```
N15 ...
N20 G1  X40 Z-20  ;P1
N20 G61 AS210     ;P2
N30 G62 Z-72 R+26 ;P3
```



# Program structure of CNC machines according to PAL

## PAL functions for lathes and milling machines

**Programming coordinates and interpolation parameters**

| | |
|---|---|
| XA, YA, ZA | Absolute input of coordinate values relative to the workpiece zero point |
| XI, YI, ZI | Incremental input of coordinate values relative to the current tool position |
| IA, KA | Absolute input of the interpolation parameters relative to the workpiece zero point |

**T-addresses for tool change**

| | |
|---|---|
| T | Tool storage place in the tool revolver or holder |
| TC | Selection of the number of the offset memory |
| TR | Incremental tool radius or cutting edge offset in the selected offset memory |
| TL | Incremental tool length offset in the selected offset memory (milling) |
| TZ | Incremental tool length offset in Z direction in the selected offset memory (turning) |
| TX | Incremental diameter offset in X direction in the selected offset memory (turning) |

**Additional M-functions[1] according to PAL**

| | | | |
|---|---|---|---|
| M13 | Clockwise spindle rotation, coolant ON | M17 | End of sub program |
| M14 | Counter clockwise spindle rotation, coolant ON | M60 | Constant feed |
| M15 | Spindle and coolant OFF | M61 | M60 + corner shaping |

## PAL functions for lathes

**G-functions**

**Types of interpolation**

| | |
|---|---|
| G0 | Rapid travel/motion |
| G1 | Linear interpolation with feed rate |
| G2 | Circular interpolation, clockwise |
| G3 | Circular interpolation, counter clockwise |
| G4 | Dwell time |
| G9 | Exact stop |
| G14 | Travel to configured tool change point |
| G61 | Linear interpolation for contour routing |
| G62 | Circular interpolation for contour routing, clockwise |
| G63 | Circular interpolation for contour routing, counter clockwise |

**Reference points**

| | |
|---|---|
| G50 | Cancellation of incremental zero point shift and rotations |
| G53 | Cancellation of all zero point shifts and rotations |
| G54–G57 | Adjustable absolute zero points |
| G59 | Incremental Cartesian zero point shift and rotation |

**Machining planes and rechucking**

| | |
|---|---|
| G18 | Selection of the plane of rotation |
| G17 | Face machining planes |
| G19 | Shell surface/segment surface machining planes |
| G30 | Rechucking/opposed spindle takeover |

**Dimensions**

| | |
|---|---|
| G70 | Inch input confirmation |
| G71 | Metric input confirmation (mm) |
| G90 | Absolute dimensions |
| G91 | Input of incremental dimensions |

**Cutter compensation**

| | |
|---|---|
| G40 | Cancel tool radius offset TRO |
| G41 | Tool radius offset TRO to the left of the programmed contour |
| G42 | Tool radius offset TRO to the right of the programmed contour |

**Feeds and speeds**

| | |
|---|---|
| G92 | Rotational speed limitation |
| G94 | Feed in mm per minute |
| G95 | Feed in mm per revolution |
| G96 | Constant cutting speed |
| G97 | Constant rotational speed |

**Program features**

| | |
|---|---|
| G22 | Call sub program |
| G23 | Repeat program section |
| G29 | Conditional jumps |

**Cycles**

| | |
|---|---|
| G31 | Thread cycle |
| G32 | Tapping cycle |
| G33 | Thread chasing cycle |
| G80 | Completion of a machining cycle contour description |
| G81 | Longitudinal rough-turning cycle |
| G82 | Rough facing cycle |
| G83 | Rough-turning cycle parallel to the contour |
| G84 | Drilling cycle |
| G85 | Undercut cycle |
| G86 | Radial grooving cycle |
| G87 | Radial contour cutting cycle |
| G88 | Axial grooving cycle |
| G89 | Axial contour cutting cycle |

# Program structure of CNC machines according to PAL

## G-functions for lathes

### G22 Call sub program

**Structure of NC block**
G22 L [H] [/]

**Obligatory addresses:**
L number of the sub program

**Optional addresses:**
H number of repetitions
/ extract level

Main program %900

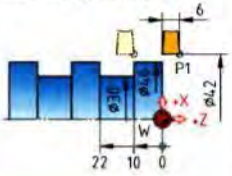
```
N10 G90..
N15 F.. S.. M4
N20 G0 X42 Z6 ;P1
N25 G22 L911 H2
N30..
N35..
N150 M30
```

jump → Sub program L911

```
N10 G91
N15 G0 Z-16
N20 G1 X-6
N25 G1 X6
N30 G0 Z-6
N35 G1 X-6
N40 G1 X6
N45 M17
```

return

**Machining example**




### G23 Repeat program section

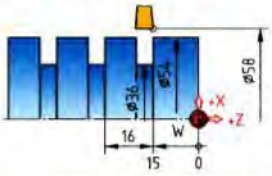
**Structure of NC block**
G23 N N [H]

**Obligatory addresses:**
N start block number of the program section to be repeated
N end block number of the program section to be repeated

**Optional addresses:**
H number of repetitions

```
N10 ..
N15 G0 X58 Z-15 M4
N20 G91
N25 G1 X-11
N30 G1 X11
N35 G0 Z-16
N40 G23 N20 N35 H2
N45 G90
N50 ...
```

**Machining example**




### G14 Travel to tool change point

**Structure of NC block**
G14 [H]

**Optional addresses:**
H0 travel to tool change point simultaneously in all axes
H1 first X axis, then Z axis H2 first Z axis, then X axis



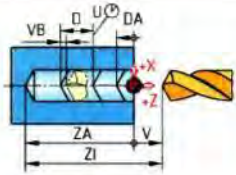

## PAL cycles for lathes

### G84 Drilling cycle

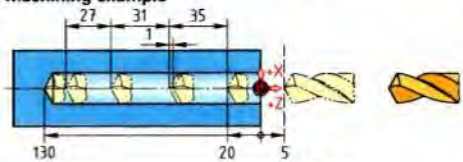
**Structure of NC block**
**G84 ZI/ZA [D] [V] [VB] [DR] [DM] [R] [DA] [U] [O] [FR] [E]**

**Obligatory addresses:**
ZI depth of hole, incremental depth relative to the current tool position
ZA depth of hole, absolute depth

**Optional addresses** (selection):
D pecking amount
(if D is not specified, pecking depth is equal to the final drilling depth)
V safety distance
VB safety distance to the hole bottom
DR reduction value of the pecking amount
DM minimum infeed
R retract level/distance
DA spot-drilling depth
U dwell time at hole bottom
O dwell time selection
O1 in seconds
O2 in revolutions
FR rapid travel reduction in %
E spot-drilling feed




**Machining example**

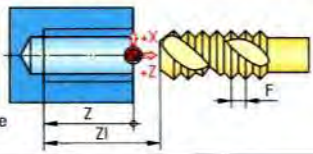



```
N10 G90
N15 G84 Z-130 D30 V5 VB1 DR4 U0.5
N20 ..
```

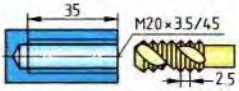
### G32 Tapping cycle

**Structure of NC block**
G32 Z/ZI/ZA F

**Obligatory addresses:**
Z, ZI, ZA thread end point in Z direction
I incremental, A absolute
F pitch of thread




**Machining example**




```
N10 G90
N15 G32 Z-35 F2,5 S.. M..
```

# Program structure of CNC machines according to PAL

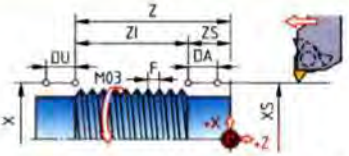
## PAL cycles for lathes

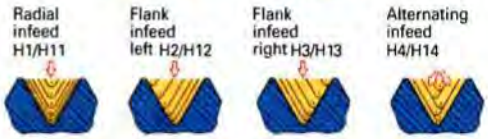
### G31 Thread cycle

**Structure of NC block**
**G31 Z/ZI/ZA X/XI/XA F D [ZS] [XS] [DA] [DU] [Q] [O] [H]**

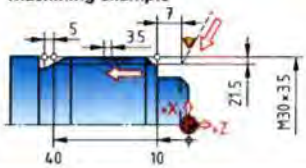
**Obligatory addresses:**
Z, ZI, ZA thread end point in Z direction
Z controlled by G90/G91;
I incremental, A absolute
X, XI, ZI thread end point in X direction;
X controlled by G90/G91,
I incremental, A absolute
F thread pitch
D thread depth

**Optional addresses [..]:**
ZS thread starting point, absolute in Z
XS thread starting point, absolute in X
DA approach
DU overrun
Q number of cuts
O number of idle cycles
H selection of infeed type and residual cuts (RC)
H1 without offset (radial infeed), RC OFF
H2 infeed at left flank, RC OFF
H3 infeed at right flank, RC OFF
H4 alternating infeed, RC OFF
H11 without offset (radial infeed), RC ON
H12 infeed at left flank, RC ON
H13 infeed at right flank, RC ON
H14 alternating infeed, RC ON
Residual cuts 1/2, 1/4, 1/8, 1/8 x (D/Q)




**Machining example**




```
N10 G90
N15 G31 Z-40 X30 F3.5 D2.15 ZS-10 XS30 Q12 O13 H14
N20 ..
```

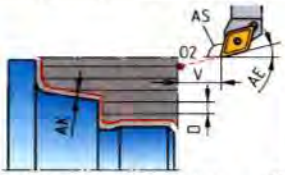
### G81 Longitudinal rough-turning cycle

### G82 Rough facing cycle

**Structure of NC block**
**G81 (or G82) H4 [AK] [AZ] [AX] [AE] [AS] [AV] [O] [Q] [V] [E]**
or
**G81 (or G82) D [H1/H2/H3/H24]**

**Obligatory addresses:**
D infeed

**Optional addresses [..]:**
H type of machining
H1 rough machining, removal below 45°
H2 stepwise angle-cutting along the contour
H3 like H1 with final contour cut
H4 contour finishing
H24 rough-machining with H2 and subsequent finishing
AK contour allowance parallel to the contour
AZ contour allowance in Z direction
AX contour allowance in X direction
AE immersion angle (final angle of the tool)
AS emergence angle (lateral adjustment angle of tool)
AV safety angle reduction for AE and AS
O machining starting point
O1: current tool position
O2: calculated from contour
Q idle step optimization
Q1: optimization OFF
Q2: optimization ON
V safety distance for idle step optimization
G81: in Z direction
G82: in X direction
E immersion feed

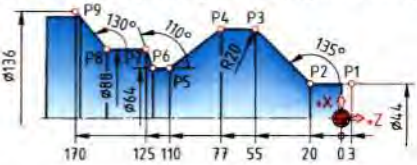



Longitudinal rough turning cycle with G81



Rough facing cycle with G82

**Machining example: longitudinal rough-machining cycle**




```
N10
N15 G81 D3 H3 E0.15 AZ0.1 AX0.5
N20 X44 Z3                      ;P1
N25 G1 Z-20                     ;P2
N30 G1 Z-55 AS135 RN20          ;P3
N35 G1 Z-77 AS180               ;P4
N40 G1 Z-110 X64                ;P5
N45 AS180                       ;P6
N50 AS110 X88 Z-125             ;P7
N55 AS180                       ;P8
N60 AS130 X136 Z-170            ;P9
N65 G80
```

# Program structure of CNC machines according to PAL

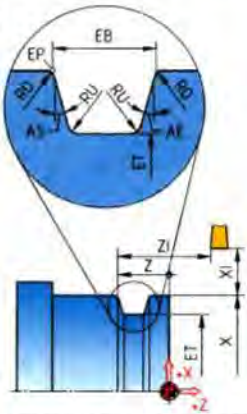
## PAL cycles for lathes

### G86 Radial grooving cycle

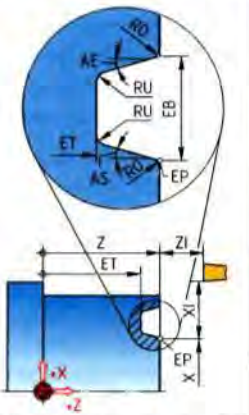
**Structure NC block**
**G86 Z/ZI/ZA X/XI/XA ET [EB] [D] [..]** (selection)
**G88 Z/ZI/ZA X/XI/XA ET [EB] [D] [..]** (selection)

**Obligatory addresses:**
Z, ZI, ZA grooving position in Z direction;
Z controlled by G90/G91,
ZI incremental, ZA absolute
X, XI, XA grooving position in X direction;
X controlled by G90/G91,
XI incremental, XA absolute
ET G86 absolute diameter of grooving depth
G88 absolute grooving depth

**Optional addresses [..]:**
EB grooving width and position
EB+ grooving in direction Z+ relative to the programmed grooving position P
EB– grooving in direction Z– relative to the programmed grooving position P
D pecking amount (if no value is specified, the pecking depth is equal to the groove depth ET)
AS flank angle of grooving at the starting point relative to the grooving direction (X or Z)
AE flank angle of grooving at the end point relative to the grooving direction (X or Z)
RO rounding or chamfering of upper corners
RO+ rounding
RO– chamfer width
RU rounding or chamfering of lower corners
RU+ rounding
RU– chamfer width
AK contour allowance parallel to the contour
AX contour allowance in X direction (contour offset)
EP setpoint definition for groove cutting (position P)
EP1: setpoint in upper corner of the groove
EP2: setpoint in bottom corner of the groove
H type of processing
H1 roughing cut H14 roughing and finishing
H2 plunge turning H24 plunge turning and finishing
H4 finishing
DB infeed in % of the cutting tool width for grooving
V safety distance above groove
E feed rate into solid material

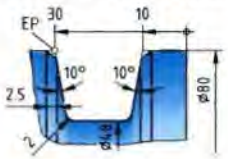


Radial grooving cycle with G86



Axial grooving cycle with G88

**Machining example: radial grooving cycle with G86:**




```
N10 G0 X82 Z-32
N35 G86 Z-30 X80 ET48 EB20 D4 AS10 AE10 RO-2.5 RU2 H14
```

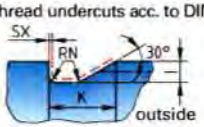
### G85 Undercut and thread undercut cycle

**Structure of NC block**
**G85 Z/ZI/ZA X/XI/XA I/[I] K[K] [RN] [SX] [H] [E]**

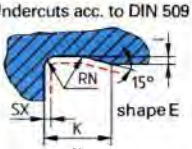
**Obligatory addresses:**
Z, ZI, ZA undercut position in Z direction;
Z controlled by G90/G91,
ZI incremental, ZA absolute
X, XI, XA undercut position in X direction;
X controlled by G90/G91,
XI incremental, XA absolute
I undercut depth; obligatory parameter for DIN 76 (H1)
K undercut length; obligatory parameter for DIN 76 (H1)

**Optional addresses [..]:**
RN corner radius
SX grinding allowance
E feed rate for plunging
H undercut shape
H1 DIN 76 H2 DIN 509 E H2 DIN 509 F

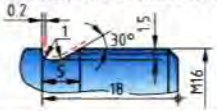
Thread undercuts acc. to DIN 76

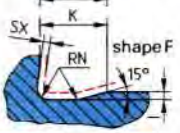



Undercuts acc. to DIN 509




**Machining process with DIN 76**




```
N10 G0 ..
N15 G85 ZA-18 XA16 I1.5 K5 RN1 SX0.2 H1 E0.15
```

Further information on p. 89 and p. 92

### G80 Completion of a contour description in a rough-machining cycle

**Structure of NC block** G80 [ZA] [XA]

**Optional addresses [..]:** ZA absolute Z-coordinate of the machining limit parallel to the X axis
XA absolute Z-coordinate of the machining limit parallel to the Z axis

# Program structure of CNC machines according to PAL

## PAL functions for milling machines

### G-functions

| Types of interpolation, contours | |
|---|---|
| G0 | Rapid motion |
| G1 | Linear interpolation with feed rate |
| G2 | Circular interpolation, clockwise |
| G3 | Circular interpolation, counter clockwise |
| G4 | Dwell time |
| G9 | Exact stop |
| G10 | Rapid motion in polar coordinates |
| G11 | Linear interpolation with polar coordinates |
| G12 | Circular interpolation with polar coordinates, clockwise |
| G13 | Circular interpolation with polar coordinates, counter clockwise |
| G45 | Linear tangential approach to a contour |
| G46 | Linear tangential retraction from a contour |
| G47 | Tangential approach to a contour in a quarter circle |
| G48 | Tangential retraction from a contour in a quarter circle |
| G61 | Linear interpolation for contour routing |
| G62 | Circular interpolation for contour routing, clockwise |
| G63 | Circular interpolation for contour routing, counter clockwise |

| Reference points, rotation, mirror images, scaling | |
|---|---|
| G50 | Cancellation of the incremental zero point shift and rotations |
| G53 | Cancellation of all zero point shifts and rotations |
| G54–G57 | Adjustable absolut zero points |
| G58 | Incremental zero point shift, polar and rotation |
| G59 | Incremental Cartesian zero point shift and rotation |
| G66 | Mirror image across the X or Y axis, mirror image off |
| G67 | Scaling (enlarging or reducing or cancellation) |

| Plane selection, dimensions | |
|---|---|
| G17–G19 | Plane selection, 2½ D processing |
| G70 | Inch input confirmation |
| G71 | Metric input confirmation (mm) |
| G90 | Input of absolute dimensions |
| G91 | Input of incremental dimensions |

| Tool offsets | |
|---|---|
| G40 | Cancel cutter compensation |
| G41–G42 | Cutter compensation left<br>Cutter compensation right |

| Feeds and speeds | |
|---|---|
| G94 | Feed in mm per minute |
| G95 | Feed in mm per revolution |
| G96 | Constant cutting speed |
| G97 | Constant spindle speed |

| Program features | |
|---|---|
| G22 | Call sub program |
| G23 | Repeat program section |
| G29 | Conditional jumps |

| Fixed cycles | |
|---|---|
| G34 | Start-up of the contour pocket cycle |
| G35 | Rough-machining technology of the contour pocket cycle |
| G36 | Residual material technology of the contour pocket cycle |
| G37 | Finishing technology of the contour pocket cycle |
| G38 | Contour description of the contour pocket cycle |
| G80 | Completion of the G38 cycle |
| G39 | Call contour pocket cycle with material removal either parallel to the contour or in meanders |
| G72 | Rectangular pocket milling cycle |
| G73 | Circular pocket and spigot milling cycle |
| G74 | Slot milling cycle |
| G75 | Circular slot milling cycle |
| G81 | Drilling cycle |
| G82 | Deep drilling cycle with pecking |
| G83 | Deep drilling cycle with pecking and full retraction |
| G84 | Tapping cycle |
| G85 | Reaming cycle |
| G86 | Boring cycle |
| G87 | Plunge milling cycle |
| G88 | Internal thread milling cycle |
| G89 | External thread milling cycle |
| G76 | Multiple cycle call on a straight line (line of holes) |
| G77 | Multiple cycle call on a pitch circle (line of holes) |
| G78 | Cycle call at a particular point (polar coordinates) |
| G79 | Cycle call at a particular point (Cartesian coordinates) |

# Program structure of CNC machines according to PAL

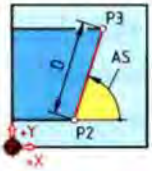
## PAL cycles for milling machines

### G1 Linear interpolation with feed rate

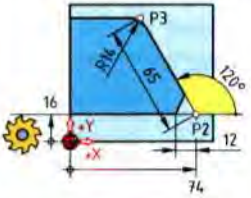
**Structure of NC block**
**G1 [X/XI/XA] [Y/YI/YA] [Z/ZI/ZA] [D] [AS] .. (selection)**

**Obligatory addresses:**
X, XI, XA X coordinate of the target point
Y, YI, YA Y coordinate of the target point
Z, ZI, ZA Z coordinate of the target point

**Optional addresses [..]:**
D length of travel distance
AS ascent angle relative to the X axis
RN transition element to the next contour element
RN+ rounding radius RN– chamfer width
H selection among two solutions via angle criterion
H1 small ascent angle H2 greater ascent angle
TC selection of the offset memory number
TR incremental change of the tool radius value
TL incremental change of the tool length offset




**Machining example**



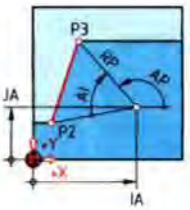

```
N10 ...
N15 G1 X74 Y16 RN-12      ;P2
N20 G1 D65 AS120 RN+14    ;P3
```

### G11 Linear interpolation with polar coordinates

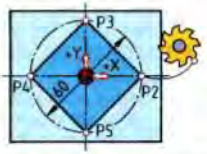
**Structure of NC block**
**G11 RP AP/AI [J/JA] [Z/ZI/ZA] [RN] .. (Auswahl)**

**Obligatory addresses:**
RP polar radius
AP polar angle relative to the positive X axis
AI incremental polar angle

**Optional addresses [..]:**
I, IA X coordinate of the polar center
J, JA Y coordinate of the polar center
Z, ZI, ZA infeed in Z direction
RN transition to the next contour element
RN+ rounding radius RN– chamfer width
TC selection of the offset memory number
TR incremental change of the tool radius value
TL incremental change of the tool length offset




**Machining example**

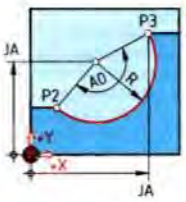



```
N15 G42 G47 R20 X30 Y0 Z-3   ;P2
N20 G11 IA0 JA0 RP30 AP90    ;P3
N25 G11 IA0 JA0 RP30 AP180   ;P4
N30 G11 IA0 JA0 RP30 AP270   ;P5
N35 G11 IA0 JA0 RP30 AP0     ;P2
```

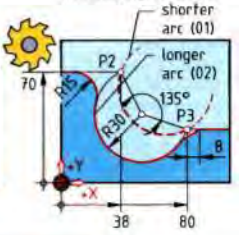
### G2/G3 Circular interpolation with Cartesian coordinates

**Structure of NC block**
**G2 [X/XI/XA] [Y/YI/YA] [Z/ZI/ZA] {(I/IA [J/JA]) / ([I/IA] J/JA) / R / A0 [RN] [O] [F] [S] [M]**
**G3 [X/XI/XA] .... ....**

**Optional addresses [...]:**
X, XI, XA X coordinate of the target point
Y, YI, YA Y coordinate of the target point
Z, ZI, ZA Z coordinate of the target point
I, IA, J, JA center point coordinates
R radius of arc and
selection of solution via arc length criterion
R+ shorter arc R– longer arc
AO aperture angle
RN transition element
RN+ rounding radius RN– chamfer width
O selection of solution via arc length criterion
O1 shorter arc O2 longer arc




**Machining example**



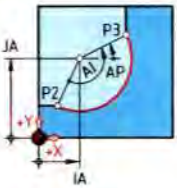

```
N10 ...
N15 G1 X38 Y70 RN+15      ;P2
N20 G3 XA80 R30 AO135 RN-8 O2 ;P3
```

### G12/G13 Circular interpolation with polar coordinates

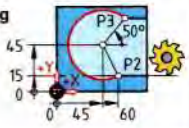
**Structure of NC block**
**G12 AP/AI [I/IA] [J/JA] [Z/ZI/ZA] [RN] [F] [S] [M]**
**G13 AP/AI [I/IA] [J/JA] [Z/ZI/ZA] [RN] [F] [S] [M]**

**Obligatory addresses:**
AP polar angle of target point
AI incremental polar angle

**Optional addresses [...]:**
I, IA X coordinate of polar center
J, JA Y coordinate of the polar center
RN+ rounding radius RN– chamfer width




**Machining example**




```
N15 G1 X60 Y15      ;P2
N20 G12 IA45 JA45 AP50 ;P3
```

# Program structure of CNC machines according to PAL

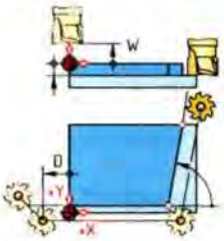
## PAL functions for milling machines

### G45 Linear tangential approach to the contour

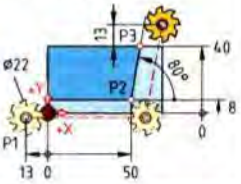
**Structure of NC block**
**G41/G42 G45 D [X/XI/XA] [Y/YI/YA] [Z/ZI/ZA] [W] [E] [F] [S] [M]**
**G46 G40 D [Z/ZI/ZA] [W] [F] [S] [M]**

**Obligatory addresses:**
with G45: D distance to the first contour point, unsigned
with G46: D length of the retracting motion, unsigned

**Optional addresses [..]:**
X, XI, XA X coordinate of the first contour point
Y, YI, YA Y coordinate of the first contour point
Z, ZI, ZA with G45: infeed at approach point in the Z axis
with G46: retracting motion at the end point in the Z axis
W absolute position in fast motion in the infeed axis
E feed rate for plunging




**Machining example**




```
N10 ...
N15 G42 G45 X0 Y8 D13   ;P1
N20 G1 X50              ;P2
N25 G1 Y40 AS80         ;P3
N30 G40 G46 D13         ;P4
```

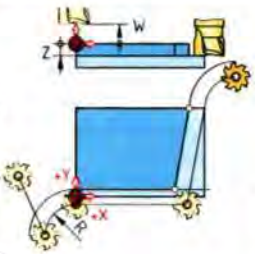
### G47 Tangential approach to the contour in a quarter circle

### G48 Tangential retraction from the contour in a quarter circle

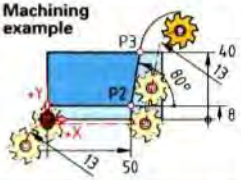
**Structure of NC block**
**G41/G42 G47 R [X/XI/XA] [Y/YI/YA] [Z/ZI/ZA] [W] [E] [F] [S] [M]**
**G48 G40 R [Z/ZI/ZA] [W] [F] [S] [M]**

**Obligatory addresses:**
with G47: R radius of the approach motion relative to the center path of the cutter
with G48: R radius of the retracting motion relative to the center path of the cutter

**Optional addresses [..]:**
X, XI, XA X coordinate of the first contour point
Y, YI, YA Y coordinate of the first contour point
Z, ZI, ZA infeed at the approach point in the Z axis
W absolute position in fast motion in the infeed axis
E feed rate for plunging




**Machining example**

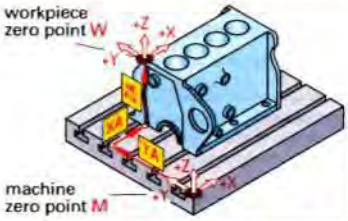



```
N10 ...
N15 G42 G47 X0 Y8 R13   ;P1
N20 G1 X50              ;P2
N25 G1 Y40 AS80         ;P3
N30 G40 G48 R13         ;P4
```

### G54–G57 Adjustable absolute zero point shift

**Structure of NC block**
**G54** *or* **G55** *or* **G56** *or* **G57**

**Explanatory notes:**
The workpiece zero point W is determined by the commands G54 to G57 and has a defined distance to the machine zero point. The operator enters the shift values into the zero point register of the controller before starting the program. The zero point is always specified in absolute coordinates (XA, YA, ZA) relative to the machine zero point.




```
N10 ...
N15 G54 ;W
N20
```

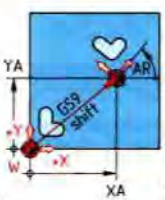
### G59 Incremental zero point shift and rotation

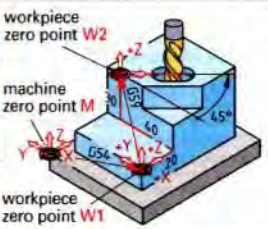
**Structure of NC block**
**G59 [XA] [YA] [ZA] [AR]**

**Optional addresses [..]:**
XA absolute X coordinate of the new workpiece zero point
YA absolute Y coordinate of the new workpiece zero point
ZA absolute Z coordinate of the new workpiece zero point
AR angle of rotation of the new coordinate system relative to the X axis

**Explanatory notes:**
If the coordinate system of the workpiece is rotated in its current position, only the angle of rotation is specified:
**N... G59 AR–**

The zero point shift launched via G54...G57 is reset by:
**N... G50**




```
N10 ..
N15 G54                 ;W1
N20 G59 X20 Y40 Z30 AR45 ;W2
```

# Program structure of CNC machines according to PAL

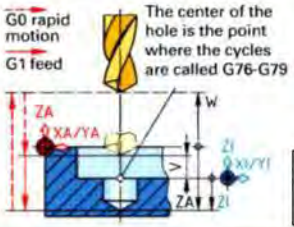
## PAL cycles for milling machines

### G81 Drilling cycle

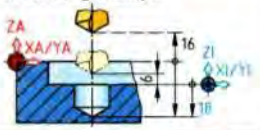
**Structure of NC block**
**G81 ZI/ZA V [W] [F] [S] [M]**

**Obligatory addresses:**
ZI depth of bore in the feed axis
ZA absolute depth of bore relative to the coordinate system of the workpiece
V safety distance from the top edge of the hole

**Optional addresses [..]:**
W retract level relative to the coordinate system of the workpiece




**Machining example**




```
N10 ...
N15 G81 ZI-18 V6 W15
N20 G79 X.. Y.. Z.. ;cycle call
```

### G82 Deep drilling cycle with pecking

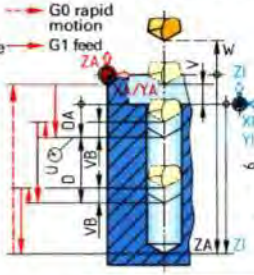
**Structure of NC block**
**G82 ZI/ZA D V [W] [VB] [DR] [DM]**
**[U] [O] [DA] [E] [F] [S] [M]**
**G83 ZI/ZA D V [W] [VB] [DR] [DM]**
**[U] [O] [DA] [E] [FR] [F] [S] [M]**

**Obligatory addresses:**
ZI/ZA depth of bore in the feed axis
ZI incremental depth from the top edge of the hole
ZA absolute depth in workpiece coordinates
D pecking amount
V safety distance above the top edge of the hole

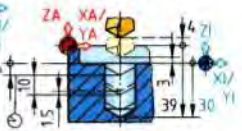
**Optional addresses [..]:**
W retract level relative to the coordinate system of the workpiece
VB retract distance to the current hole bottom
DR reduction value of the last pecking amount
DM minimum pecking amount (unsigned)
U dwell time at hole bottom (relative to pecking)
O unit of the dwell time
O1 dwell time in seconds
O2 dwell time in number of revolutions
DA incremental spot-drilling depth of the first infeed
E spot-drilling feed rate

### G83 Deep drilling cycle with pecking and full retraction

G83 has the following features:
– the same addresses as G82
– retracts to the safety distance V for chip removal
and in addition
FR rapid motion reduction in %




**Machining example**



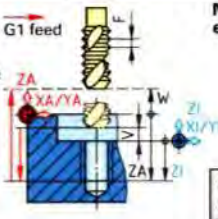

```
N10 ...
N15 G82 ZI-30 D10 V3 W4 VB1.5 DR3 U1 O1 DA6
N20 G79 X.. Y.. Z.. ;cycle call
```

### G84 Tapping cycle

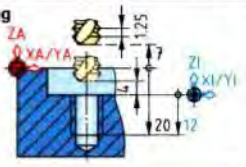
**Structure of NC block**
**G84 ZI/ZA F M V [W] [S]**

**Obligatory addresses:**
ZI incremental depth from the top edge of the hole
ZA absolute depth in workpiece coordinates
F thread pitch
M direction of tool rotation for plunging
M3 right-hand thread M4 left-hand thread
V safety distance to the top edge of the hole

**Optional addresses [..]:**
W retract level relative to the coordinate system of the workpiece




**Machining example**



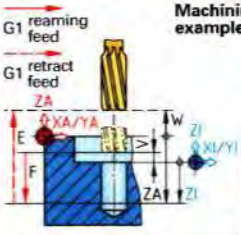

```
N10 ...
N15 G84 ZI-12 F1.25 M3 V4 W7 S800
N20 G79 X.. Y.. Z.. ;cycle call
```

### G85 Reaming cycle

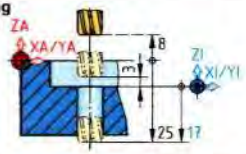
**Structure of NC block**
**G85 ZI/ZA [W] [E] [F] [S] [M]**

**Obligatory addresses:**
ZI/ZA drilling depth in the infeed axis
ZI incremental depth from the top edge of the hole
ZA absolute depth in workpiece coordinates
V safety distance from the top edge of the hole

**Optional addresses [..]:**
W retract level relative to the coordinate system of the workpiece
E feed speed of the retracting motion




**Machining example**




```
N10 ...
N15 G85 ZI-17 V3 W8 E260
G79 X.. Y.. Z.. ;cycle call
```

# Program structure of CNC machines according to PAL

## PAL cycles for milling machines

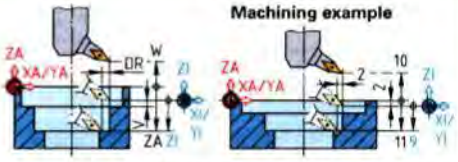
### G86 Boring cycle

**Structure of NC block**
**G86 ZI/ZA V [W] [DR] [F] [S] [M]**

**Obligatory addresses:**
ZI/ZA depth to be bored out
ZI depth of bore in the infeed axis
ZA absolute depth of bore relative to the coordinate system of the workpiece
V safety distance from the top edge of the hole

**Optional addresses [..]:**
W retract level relative to the coordinate system of the workpiece
DR radial retract distance to the contour

**Machining example**




```
N10 ...
N15 G86 ZI-9 V2 W10 DR2
N20 G79 X.. Y.. Z.. ;cycle call
```

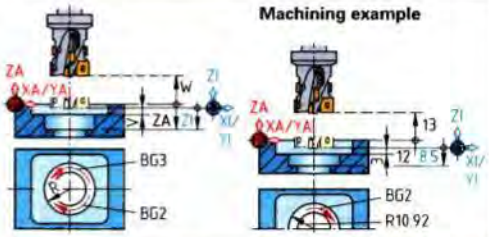
### G87 Plunge milling cycle

**Structure of NC block**
**G87 ZI/ZA R D V [W] [BG] [F] [S] [M]**

**Obligatory addresses:**
ZI/ZA depth of hole to be bored out
ZI incremental depth from the top edge
ZA absolute depth of bore relative to the coordinate system of the workpiece
R radius of the hole to be milled out
D infeed per helical line (pitch of the helical motion)
V safety distance from the top edge of the hole

**Optional addresses [..]:**
W retract level relative to the coordinate system of the workpiece
BG2 machining, clockwise
BG3 machining, counter clockwise

**Machining example**




```
N10 ...
N15 G87 ZI-8,5 R10.92 D3 V3 W13 D3 BG2
N20 G79 X.. Y.. Z.. ;cycle call
```

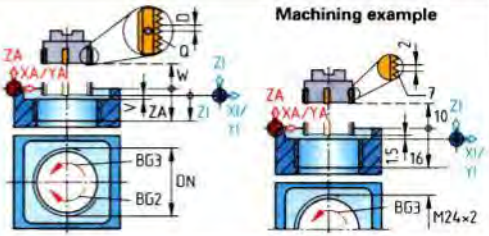
### G88 Internal thread milling cycle

**Structure of NC block**
**G88 ZI/ZA DN D Q V [W] [BG] [F] [S] [M]**

**Obligatory addresses:**
ZI/ZA depth of thread
ZI incremental depth of thread from the top edge
ZA absolute depth of thread relative to the coordinate system of the workpiece
DN nominal diameter of the internal thread
D thread pitch
Q number of thread grooves of the tool
V safety distance from the top edge of the hole

**Optional addresses [..]:**
W retract level relative to the coordinate system of the workpiece
BG2 machining, clockwise
BG3 machining, counter clockwise

**Machining example**




```
N10 ...
N15 G88 ZA-16 DN24 D2 Q7 V1.5 W10 BG3 F..
N20 G79 X.. Y.. Z.. ;cycle call
```

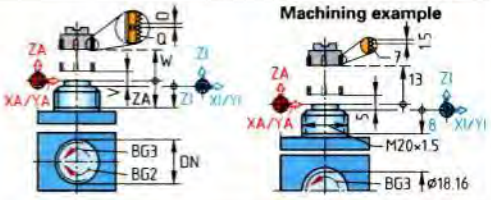
### G89 External thread milling cycle

**Structure of NC block**
**G89 ZI/ZA DN D Q V [W] [BG] [F] [S] [M]**

**Obligatory addresses:**
ZI incremental depth of thread from the top edge
ZA absolute depth of thread relative to the coordinate system of the workpiece
DN nominal diameter of the external thread
D thread pitch
Q number of thread grooves of the tool
V safety distance to the top edge of the hole

**Optional addresses [..]:**
W retract level
BG2 machining, clockwise
BG3 machining, counter clockwise

**Machining example**




```
N10 ...
N15 G89 ZI-8 DN18.16 D1.5 Q7 V5 W13 BG3 F..
N20 G79 X.. Y.. Z.. ;cycle call
```

# Program structure of CNC machines according to PAL

## PAL cycles for milling machines

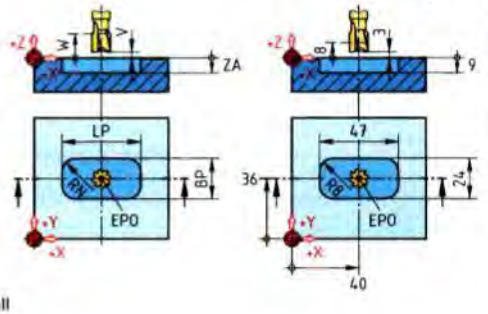
### G72 Rectangular pocket milling cycle

**Structure of NC block**
**G72 ZI/ZA LP BP D V [W] [RN] [AK] [AL] [EP] [DB] [RH] [DH] [O] [Q] [H] [E] [F] [S] [M]**

**Obligatory addresses:**
ZI/ZA depth of the circular pocket in the infeed axis
ZI incremental from the top edge of the pocket
ZA absolute, relative to the coordinate system of the workpiece
LP length of the rectangular pocket in X direction
BP width of the rectangular pocket in Y direction
D maximum depth of cut
V safety distance to the material surface

**Optional addresses [..]:**
AK pocket edge finish allowance
AL pocket bottom finish allowance
RN corner radius
EP0, EP1, EP2, EP3 definition of the setpoint at cycle call
W retract level, in fast motion
H type of machining
H1 rough machining H4 finishing
H2 face roughing of the rectangular surface
H14 rough-machining and finishing with the same tool
E feed rate for plunging

**Machining example**




```
N15 G72 ZA-9 LP47 BP24 D4 V3 AK0.4 AL0.5 W8
N20 G79 X40 Y36  ;cycle call for G72
```

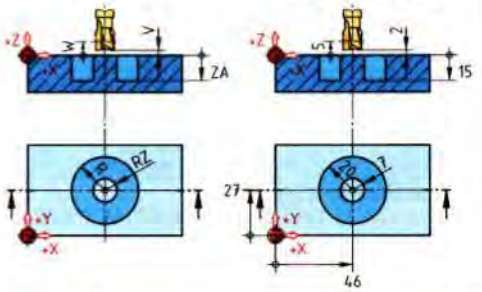
### G73 Circular pocket and spigot milling cycle

**Structure of NC block**
**G73 ZI/ZA R D V [W] [RZ] [AK] [AL] [DB] [RH] [DH] [O] [Q] [H] [E] [F] [S] [M]**

**Obligatory addresses:**
ZI/ZA depth of circular pocket in the feed axis
ZI incremental from the top edge of the pocket
ZA absolute, relative to the coordinate system of the workpiece
D maximum depth of cut
V safety distance to the material surface

**Optional addresses [..]:**
RZ radius of the optional spigot
AK pocket edge finish allowance
AL pocket bottom finish allowance
DB cutter path overlap in %
W retract level, in fast motion
H–E as with G72

**Machining example**




```
N15 G73 ZA-15 R20 D4 V2 AK0.4 AL0.5 W5
N20 G79 X46 Y27  ;cycle call for G73
```

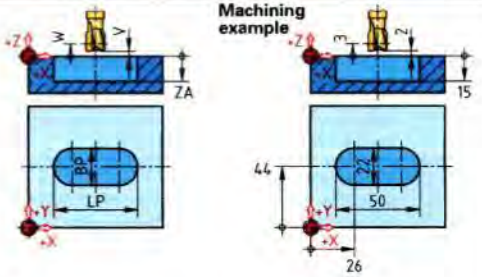
### G74 Slot milling cycle (longitudinal slot)

**Structure of NC block**
**G74 ZI/ZA R D V [W] [RZ] [AK] [AL] [DB] [RH] [DH] [O] [Q] [H] [E] [F] [S] [M]**

**Obligatory addresses:**
ZI/ZA depth of the slot in the infeed axis
ZI incremental from the top edge of the slot
ZA absolute, relative to the coordinate system of the workpiece
LP slot length
BP slot width
D maximum depth of cut
V safety distance

**Optional addresses [..]:**
W retract level
AK pocket edge finish allowance
AL pocket bottom finish allowance
EP0, EP1, EP2, EP3 definition of the setpoint at cycle call
O infeed motion
O1 vertical tool immersion
O2 ramping tool immersion
H–E as with G72

**Machining example**




```
N15 G74 ZA-15 LP50 BP22 D3 V2  ;definition of longitudinal slot via G74
N20 G79 X... Y...  ;cycle call at a particular point via G79
```

# Program structure of CNC machines according to PAL

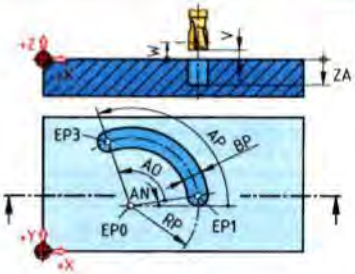
## PAL cycles for milling machines

### G75 Slot milling cycle (arc)

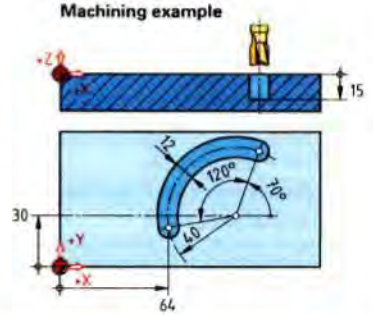
**Structure of NC block**
**G75 ZI/ZA BP RP AN/AO AO/AP D V [W] [AK] [AL] [EP] [O] [Q] [H] [E] [F] [S] [M]**

**Obligatory addresses:**
ZI/ZA slot depth
ZI incremental from the top edge of the slot
ZA absolute depth
BP slot width
RP slot radius
AN polar start angle relative to the positive X axis and the center point of the slot's first end radius
AO polar aperture angle between the center points of the slot's end radii
AP polar final angle relative to the positive X axis and the center point of the slot's second end radius
(only 2 of the 3 polar angles need to be defined)
D maximum depth of cut
V safety distance

**Optional addresses [..]:**
EP definition of the calling point for the slot cycle
EP0 center of the circular slot
EP1 center of the right or top semicircle at the rear end
EP3 center of the left or bottom semicircle at the rear end
W retract level, in fast motion
AK slot edge finish allowance
AL slot bottom finish allowance
Q direction of motion
Q1 climb milling
Q2 conventional milling
H type of machining
H1 rough machining
H4 finishing
H14 rough machining and finishing
E feed rate for plunging




**Machining example**



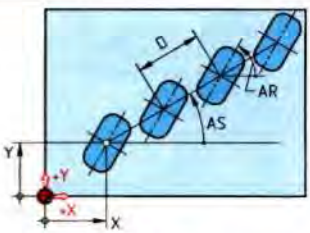

```
N15 G75 ZA-15 BP12 RP80 AN70 AO120 AK0.3 AL0.5 EP3 D5 V3 W6
N20 G79 X64 Y30  ;cycle call for G75 at EP3
```

### G76 Cycle call on a straight line (hole line)

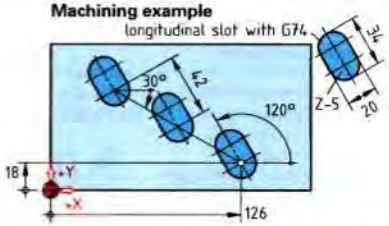
**Structure of NC block**
**G76 [X/XI/XA] [Y/YI/YA] [Z/ZI/ZA] AS D O [AR] [W] [H]**

**Obligatory addresses:**
AS angle of the straight line relative to the first geometry axis
+ counter clockwise
– clockwise
D spacing of the cycle calls on the line
O number of cycle calls on the line

**Optional addresses [..]:**
X, XI, XA X coordinate of the first point
X absolute or incremental X coordinate (G90, G91)
XI difference in coordinates between the current tool position and the first point on the line
XA absolute coordinate input of the starting point
Y, YI, YA Y coordinate of the first point
Y absolute or incremental Y coordinate (G90, G91)
YI difference in coordinates between the current tool position and the first point on the line
YA absolute coordinate input of the starting point
Z, ZI, ZA Z coordinate of the first point
Z absolute or incremental Z coordinate (G90, G91)
ZI difference in coordinates between the current tool position and the first point on the line
ZA absolute coordinate input of the starting point
AR angle of rotation relative to the positive X axis
W retract level, absolute
H reversing position
H1 tool travels to safety distance between two positions and to the retract level after the last position
H2 tool travels to the retract level between two positions




**Machining example**



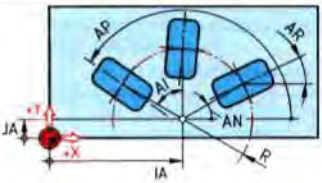

```
N15 G74 ZA-5 LP34 BP20 .... ;definition of longitudinal slot with
G74 N20 G76 X126 Y18 Z0 AS120 D42 O3 AR-30  ;cycle call
```

# Program structure with CNC machines according to PAL

## PAL functions for milling machines

### G77 | Cycle call on a pitch circle (hole circle)

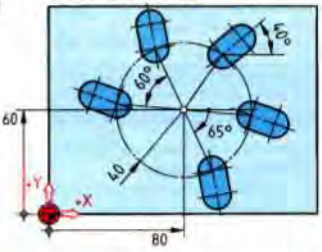
**Structure of NC block**
**G77 [I/IA] [J/JA] [Z/ZI/ZA] R AN/AI AI/AP O [AR] [W] [H] [FP]**




**Obligatory addresses:**
R radius of pitch circle
AN polar angle of first object
AI constant segment angle
AP polar angle of last object
O number of objects on the pitch circle

**Optional addresses [..]:**
I difference in X coordinates between the circle center and the starting point
IA absolute X coordinate of the circle center
J difference in Y coordinates between the circle center and the starting point
JA absolute Y coordinate of the circle center
Z absolute or incremental input via G90/G91
ZI difference in Z coordinates between the current tool position and the pitch circle center
ZA absolute coordinate of the target point
AR angle of rotation in direction of the positive first geometry axis
Q orientation of the object to be processed
Q1 forced rotation of the object Q2 fixed orientation of the object
W retract level, absolute
H retracting motion
H1 the tool travels to the safety distance V after completion of the machining process
H2 the tool travels to the retract level W after completion of the machining process
H3 like H1, but the tool travels to the next position on the pitch arc

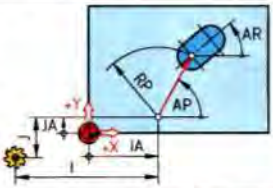
**Machining example**




```
N15 G74 ZA-5 LP34 BP20 .... ;longitudinal slot with G74
N20 G77 R40 AN-65 AI60 AR40 O5 IA80 JA60  ;cycle call
```

### G78 | Cycle call at a particular point (with polar coordinates)

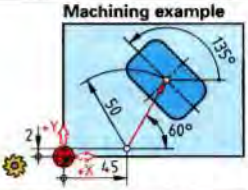
**Structure of NC block**
**G78 [I/IA] [J/JA] RP AP [Z/ZI/ZA] [AR] [W]**




**Obligatory addresses:**
I, IA X coordinate of the center of rotation
J, JA Y coordinate of the center of rotation
RP radius of the rotation circle
AP angle of rotation relative to the X axis

**Optional addresses [..]:**
Z, ZI, ZA Z coordinate of the top edge
AR angle of rotation of the object relative to the X axis
W retract level

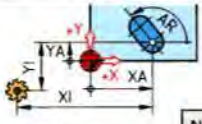
**Machining example**




```
N15 G72 ZA.. LP.. BR..  ;rectangular pocket with G72
N20 G78 IA45 JA2 RP50 AP60 AR135 ;cycle call G78
```

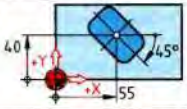
### G79 | Cycle call at a particular point (with Cartesian coordinates)

**Structure of NC block**
**G79 [X/XI/XA] [Y/YI/YA] [Z/ZI/ZA] [AR] [W]**




**Optional addresses [..]:**
X, XI, XA X coordinate of the first point
Y, YI, YA Y coordinate of the first point
Z, ZI, ZA Z coordinate of the first point
AR angle of rotation of the object relative to the X axis
W retract level, absolute in workpiece coordinates

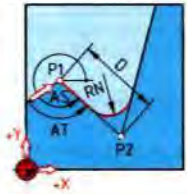
**Machining example**




```
N15 G72 ZA.. LP.. BP..  ;rectangular pocket with G72
N20 G79 XA55 YA40 AR-45  ;cycle call G79
```

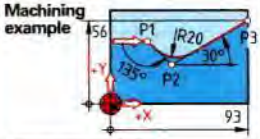
### G61 | Linear interpolation for contour routing

**Structure of NC block**
**G61 [XI/XA] [YI/YA] [Z/ZI/ZA] [D] [AT] [AS] [RN] [H] [O]**




**Optional addresses [..]:**
XI, XA X coordinate of the target point
YI, YA Y coordinate of the target point
Z, ZI, ZA infeed in the Z axis
D travelling distance AT transition angle
AS ascent angle relative to the X axis
RN+ rounding radius R– chamfer width
H1 small ascent angle H2 larger ascent angle
O1 short distance O2 longer distance

**Machining example**




```
N15 G1 X... Y...          ;P1
N20 G61 AT135 RN20        ;P2
N25 G61 XA93 YA56 AS30  ;P3
```

# Program structure of CNC machines according to PAL

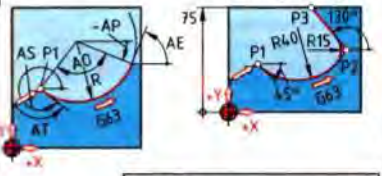
## PAL cycles for milling machines

### G62/G63 Circular interpolation for contour routing

**Structure of NC block**
**G62 *or* G63 [XI/XA] [YI/YA] [Z/ZI/ZA] [I/IA] [J/JA] [R] [AT] [AS] [AO] [O] [AE/AP] [RN] [H] [O] [F] [S] [M]**

**Optional addresses [..]:**
XI, XA, YI, YA coordinates of the target point
Z, ZI, ZA infeed in the Z axis
R radius of the arc
R+ shorter arc R– longer arc
AS angle between tangents AT transition angle (starting point)
AO aperture angle AE angle between tangents (end point)
AP polar angle of the arc's end point
RN+ rounding radius RN– chamfer width
H1 smaller AT angle H2 larger AT angle
O1 shorter arc O2 longer arc

**Machining example**




```
N15 G1 X... Y...          ;P1
N20 G63 R+40 AS-45 RN15   ;P2
N25 G61 Y75 AS130         ;P3
```

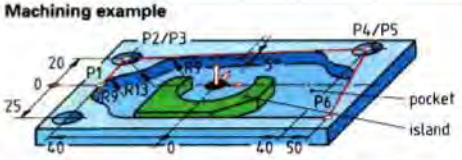
### G34–G39 Circular interpolation for contour routing

#### G34 Start-up of the contour pocket cycle (CPC)

**Structure of NC block GM ZI/ZA [AK] [AL]**
**Obligatory addresses:**
ZI depth of bore from tool position
ZA absolute depth of bore

**Optional addresses [..]:**
AK pocket edge finish allowance
AL pocket bottom finish allowance

**Machining example**




```
N5 G54                          ;adjustable absolute zero point
N10 T1 M.. G97 S.. G94 F..
N15 G34 ZA-10 AK0.5 AL0.5       ;start-up of contour pocket cycle
N20 G35 T01 D6 M3               ;rough-machining technology of the CPC
N25 G37 T02 D6 M3 S.. F..       ;finishing technology of the CPC
N30 G38 H1                      ;contour description of the pocket
N35 G0 X-40 Y0                  ;P1
N40 G61 AS90 RN+9               ;P2
N45 G63 JA20 R13 RN+9 O1        ;P3
N50 G61 AS5 RN+9                ;P4
N55 G63 IA40 R13 RN+9 O1        ;P5
N60 G1 X50 Y-25                 ;P6
N65 ...
N70 G80                         ;completion of G38
N75 G38 H2                      ;contour description of the island
N870 ...
N85 G80                         ;completion of G38
N90 G39 ...                     ;call the contour pocket cycle
```

#### G35 Rough-machining technology of the contour pocket cycle

**Structure of NC block**
**G35 T D [V] [TC] [TR] [TL] [DM] [DB] [RH] [DH] [O] [Q] [E] [F] [S] [M]**

#### G36 Residual material rough-machining technology of the contour pocket cycle

**Structure of NC block**
**G36 T D [V] [TC] [TR] [TL] [DM] [DB] [RH] [DH] [O] [Q] [E] [F] [S] [M]**

#### G37 Finishing technology of the contour pocket cycle

**Structure of NC block**
**G37 T D [V] [TC] [TR] [TL] [DB] [RH] [DH] [O] [Q] [H] [E] [F] [S] [M]**

**Obligatory addresses for G35, G36, G37:**
T tool number D absolute depth of bore

**Optional addresses for G35, G36, G37:**
V safety distance
T... addresses for tool change (p. 388)
DM infeed minimum for island height optimization
DB cutter path overlap at the bottom
RH radius of the center path of the helical infeed
DH infeed per helical turn
O1 plunging O2 helical plunging
Q1 climb milling Q2 conventional milling
H4 finishing of edge/bottom H4 finishing of bottom/edge
H6 finishing of edge only H7 finishing of bottom only
E feed rate for plunging

#### G38 Contour description of the contour pocket cycle

**Structure of NC block**
**G38 H [ZI/ZA] [(IA JA R) / (LP BP IA JA [RN] [AR])]**

**Obligatory addresses:**
H1 pocket H2 island H2 pocket in an island

**Optional addresses [..]: see on page 397**

#### G39 Call contour pocket cycle with either material removal parallel to the contour or loop-type material removal

**Structure of NC block**
**G39 Z/ZI/ZA V [W] [X/XI/XA] [Y/YI/YA] [AN] [H]**

**Obligatory addresses:**
Z, ZI, ZA material surface in Z
V safety distance to the material surface

**Optional addresses [..]:**
W height of retract level, absolute
X, XI, XA starting point of machining in X
Y, YI, YA starting point of machining in Y
AN angle for loop-type material removal, if AN is not defined, removal is parallel to the contour
H1 rough-machining H2 isolating (facing) H4 finishing
H8 isolating in finishing mode
H14 rough-machining and finishing

#### G80 Completion of a G38 pocket/island contour description

**Structure of NC block: G39**

# Numbering systems

## Decimal system

Base 10 Numbers: 0, 1, 2, 3, 4, 5, 6, 7, 8, 9

**Decimal number $n_{10}$** 205

| Place value | $10^2 = 100$ | $10^1 = 10$ | $10^0 = 1$ | |
|---|---|---|---|---|
| Value | $2 \cdot 100 = 200$ | $0 \cdot 10 = 0$ | $5 \cdot 1 = 5$ | |
| **Total value** $n_{10}$ (decimal) = | 200 + | 0 + | 5 | = 205 |

## Binary number system

Base 2 Numbers: 0, 1

**Binary number $n_2$** 1010

| Place value | $2^3 = 8$ | $2^2 = 4$ | $2^1 = 2$ | $2^0 = 1$ | |
|---|---|---|---|---|---|
| Value | $1 \cdot 8 = 8$ | $0 \cdot 4 = 0$ | $1 \cdot 2 = 2$ | $0 \cdot 1 = 0$ | |
| **Total value** $n_{10}$ (decimal) = | 8 + | 0 + | 2 + | 0 | = 10 |

## Hexadecimal numbering system

Base 16 Numbers and letters: 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E, F
Decimal value: 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15

**Conversion into decimal number:**

A2F

| Place value | $16^2 = 256$ | $16^1 = 16$ | $16^0 = 1$ | |
|---|---|---|---|---|
| Value | $10 \cdot 256 = 2560$ | $2 \cdot 16 = 32$ | $15 \cdot 1 = 15$ | |
| **Total value** $n_{10}$ (decimal) = | 2560 + | 32 + | 15 | = 2607 |

**Conversion into binary number:**
Every digit represents a group of 4 Bits

A2F

| Number value | 10 | 2 | 15 |
|---|---|---|---|
| 4 bit group (tetrad) | 1010 | 0010 | 1111 |
| Binary number $n_2$ = | 1010 0010 1111 | | |

## Binary numbers $n_2$ and hexadecimal numbers $n_{16}$ for decimal numbers $n_{10}$ up to 255

1st tetrad

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $b_8$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | |
| $b_7$ | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | |
| $b_6$ | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | |
| $b_5$ | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | |

| $b_8$ | $b_7$ | $b_6$ | $b_5$ | $b_4$ | $b_3$ | $b_2$ | $b_1$ | Bit pattern (binary numbers) | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1st tetrad | | | | 2nd tetrad | | | | No. | Decimal numbers and hexadecimal numbers | | | | | | | | | | | | | | |
| | | | | 0 | 0 | 0 | 0 | $n_{10}$ | 0 | 16 | 32 | 48 | 64 | 80 | 96 | 112 | 128 | 144 | 160 | 176 | 192 | 208 | 224 | 240 |
| | | | | | | | | $n_{16}$ | 00 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | A0 | B0 | C0 | D0 | E0 | F0 |
| | | | | 0 | 0 | 0 | 1 | $n_{10}$ | 1 | 17 | 33 | 49 | 65 | 81 | 97 | 113 | 129 | 145 | 161 | 177 | 193 | 209 | 225 | 241 |
| | | | | | | | | $n_{16}$ | 01 | 11 | 21 | 31 | 41 | 51 | 61 | 71 | 81 | 91 | A1 | B1 | C1 | D1 | E1 | F1 |
| | | | | 0 | 0 | 1 | 0 | $n_{10}$ | 2 | 18 | 34 | 50 | 66 | 82 | 98 | 114 | 130 | 146 | 162 | 178 | 194 | 210 | 226 | 242 |
| | | | | | | | | $n_{16}$ | 02 | 12 | 22 | 32 | 42 | 52 | 62 | 72 | 82 | 92 | A2 | B2 | C2 | D2 | E2 | F2 |
| | | | | 0 | 0 | 1 | 1 | $n_{10}$ | 3 | 19 | 35 | 51 | 67 | 83 | 99 | 115 | 131 | 147 | 163 | 179 | 195 | 211 | 227 | 243 |
| | | | | | | | | $n_{16}$ | 03 | 13 | 23 | 33 | 43 | 53 | 63 | 73 | 83 | 93 | A3 | B3 | C3 | D3 | E3 | F3 |
| | | | | 0 | 1 | 0 | 0 | $n_{10}$ | 4 | 20 | 36 | 52 | 68 | 84 | 100 | 116 | 132 | 148 | 164 | 180 | 196 | 212 | 228 | 244 |
| | | | | | | | | $n_{16}$ | 04 | 14 | 24 | 34 | 44 | 54 | 64 | 74 | 84 | 94 | A4 | B4 | C4 | D4 | E4 | F4 |
| | | | | 0 | 1 | 0 | 1 | $n_{10}$ | 5 | 21 | 37 | 53 | 69 | 85 | 101 | 117 | 133 | 149 | 165 | 181 | 197 | 213 | 229 | 245 |
| | | | | | | | | $n_{16}$ | 05 | 15 | 25 | 35 | 45 | 55 | 65 | 75 | 85 | 95 | A5 | B5 | C5 | D5 | E5 | F5 |
| | | | | 0 | 1 | 1 | 0 | $n_{10}$ | 6 | 22 | 38 | 54 | 70 | 86 | 102 | 118 | 134 | 150 | 166 | 182 | 198 | 214 | 230 | 246 |
| | | | | | | | | $n_{16}$ | 06 | 16 | 26 | 36 | 46 | 56 | 66 | 76 | 86 | 96 | A6 | B6 | C6 | D6 | E6 | F6 |
| | | | | 0 | 1 | 1 | 1 | $n_{10}$ | 7 | 23 | 39 | 55 | 71 | 87 | 103 | 119 | 135 | 151 | 167 | 183 | 199 | 215 | 231 | 247 |
| | | | | | | | | $n_{16}$ | 07 | 17 | 27 | 37 | 47 | 57 | 67 | 77 | 87 | 97 | A7 | B7 | C7 | D7 | E7 | F7 |
| | | | | 1 | 0 | 0 | 0 | $n_{10}$ | 8 | 24 | 40 | 56 | 72 | 88 | 104 | 120 | 136 | 152 | 168 | 184 | 200 | 216 | 232 | 248 |
| | | | | | | | | $n_{16}$ | 08 | 18 | 28 | 38 | 48 | 58 | 68 | 78 | 88 | 98 | A8 | B8 | C8 | D8 | E8 | F8 |
| | | | | 1 | 0 | 0 | 1 | $n_{10}$ | 9 | 25 | 41 | 57 | 73 | 89 | 105 | 121 | 137 | 153 | 169 | 185 | 201 | 217 | 233 | 249 |
| | | | | | | | | $n_{16}$ | 09 | 19 | 29 | 39 | 49 | 59 | 69 | 79 | 89 | 99 | A9 | B9 | C9 | D9 | E9 | F9 |
| | | | | 1 | 0 | 1 | 0 | $n_{10}$ | 10 | 26 | 42 | 58 | 74 | 90 | 106 | 122 | 138 | 154 | 170 | 186 | 202 | 218 | 234 | 250 |
| | | | | | | | | $n_{16}$ | 0A | 1A | 2A | 3A | 4A | 5A | 6A | 7A | 8A | 9A | AA | BA | CA | DA | EA | FA |
| | | | | 1 | 0 | 1 | 1 | $n_{10}$ | 11 | 27 | 43 | 59 | 75 | 91 | 107 | 123 | 139 | 155 | 171 | 187 | 203 | 219 | 235 | 251 |
| | | | | | | | | $n_{16}$ | 0B | 1B | 2B | 3B | 4B | 5B | 6B | 7B | 8B | 9B | AB | BB | CB | DB | EB | FB |
| | | | | 1 | 1 | 0 | 0 | $n_{10}$ | 12 | 28 | 44 | 60 | 76 | 92 | 108 | 124 | 140 | 156 | 172 | 188 | 204 | 220 | 236 | 252 |
| | | | | | | | | $n_{16}$ | 0C | 1C | 2C | 3C | 4C | 5C | 6C | 7C | 8C | 9C | AC | BC | CC | DC | EC | FC |
| | | | | 1 | 1 | 0 | 1 | $n_{10}$ | 13 | 29 | 45 | 61 | 77 | 93 | 109 | 125 | 141 | 157 | 173 | 189 | 205 | 221 | 237 | 253 |
| | | | | | | | | $n_{16}$ | 0D | 1D | 2D | 3D | 4D | 5D | 6D | 7D | 8D | 9D | AD | BD | CD | DD | ED | FD |
| | | | | 1 | 1 | 1 | 0 | $n_{10}$ | 14 | 30 | 46 | 62 | 78 | 94 | 110 | 126 | 142 | 158 | 174 | 190 | 206 | 222 | 238 | 254 |
| | | | | | | | | $n_{16}$ | 0E | 1E | 2E | 3E | 4E | 5E | 6E | 7E | 8E | 9E | AE | BE | CE | DE | EE | FE |
| | | | | 1 | 1 | 1 | 1 | $n_{10}$ | 15 | 31 | 47 | 63 | 79 | 95 | 111 | 127 | 143 | 159 | 175 | 191 | 207 | 223 | 239 | 255 |
| | | | | | | | | $n_{16}$ | 0F | 1F | 2F | 3F | 4F | 5F | 6F | 7F | 8F | 9F | AF | BF | CF | DF | EF | FF |

**Example of reading from table:** Binary number $n_2$ = **10110010** corresponds to decimal number $n_{10}$ = **178** or hexadecimal number $n_{16}$ = **B2**.

# ASCII code[1)]

## 7-Bit ASCII Code

| Dec | Hex | Char. | Dec | Hex | Char. | Dec | Hex | Char. | Dec | Hex | Char. | Dec | Hex | Char. | Dec | Hex | Char. | Dec | Hex | Char. | Dec | Hex | Char. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | NUL | 16 | 10 | DLE | 32 | 20 | SP | 48 | 30 | 0 | 64 | 40 | @ | 80 | 50 | P | 96 | 60 | \ | 112 | 70 | p |
| 1 | 1 | SOH | 17 | 11 | DC1 | 33 | 21 | ! | 49 | 31 | 1 | 65 | 41 | A | 81 | 51 | Q | 97 | 61 | a | 113 | 71 | q |
| 2 | 2 | STX | 18 | 12 | DC2 | 34 | 22 | " | 50 | 32 | 2 | 66 | 42 | B | 82 | 52 | R | 98 | 62 | b | 114 | 72 | r |
| 3 | 3 | ETX | 19 | 13 | DC3 | 35 | 23 | # | 51 | 33 | 3 | 67 | 43 | C | 83 | 53 | S | 99 | 63 | c | 115 | 73 | s |
| 4 | 4 | EOT | 20 | 14 | DC4 | 36 | 24 | $ | 52 | 34 | 4 | 68 | 44 | D | 84 | 54 | T | 100 | 64 | d | 116 | 74 | t |
| 5 | 5 | ENQ | 21 | 15 | NAK | 37 | 25 | % | 53 | 35 | 5 | 69 | 45 | E | 85 | 55 | U | 101 | 65 | e | 117 | 75 | u |
| 6 | 6 | ACK | 22 | 16 | SYN | 38 | 26 | & | 54 | 36 | 6 | 70 | 46 | F | 86 | 56 | V | 102 | 66 | f | 118 | 76 | v |
| 7 | 7 | BEL | 23 | 17 | ETB | 39 | 27 | ' | 55 | 37 | 7 | 71 | 47 | G | 87 | 57 | W | 103 | 67 | g | 119 | 77 | w |
| 8 | 8 | BS | 24 | 18 | CAN | 40 | 28 | ( | 56 | 38 | 8 | 72 | 48 | H | 88 | 58 | X | 104 | 68 | h | 120 | 78 | x |
| 9 | 9 | HT | 25 | 19 | EM | 41 | 29 | ) | 57 | 39 | 9 | 73 | 49 | I | 89 | 59 | Y | 105 | 69 | i | 121 | 79 | y |
| 10 | A | LF | 26 | 1A | SUB | 42 | 2A | * | 58 | 3A | : | 74 | 4A | J | 90 | 5A | Z | 106 | 6A | j | 122 | 7A | z |
| 11 | B | VT | 27 | 1B | ESC | 43 | 2B | + | 59 | 3B | ; | 75 | 4B | K | 91 | 5B | [ | 107 | 6B | k | 123 | 7B | { |
| 12 | C | FF | 28 | 1C | FS | 44 | 2C | ' | 60 | 3C | < | 76 | 4C | L | 92 | 5C | \ | 108 | 6C | l | 124 | 7C | \| |
| 13 | D | CR | 29 | 1D | GS | 45 | 2D | – | 61 | 3D | = | 77 | 4D | M | 93 | 5D | ] | 109 | 6D | m | 125 | 7D | } |
| 14 | E | SO | 30 | 1E | RS | 46 | 2E | . | 62 | 3E | > | 78 | 4E | N | 94 | 5E | ^ | 110 | 6E | n | 126 | 7E | ~ |
| 15 | F | SI | 31 | 1F | US | 47 | 2F | / | 63 | 3F | ? | 79 | 4F | O | 95 | 5F | – | 111 | 6F | o | 127 | 7F | DEL |

## Meanings of control characters

| Dec | Char. | Name | Dec | Char. | Name |
|---|---|---|---|---|---|
| 0 | NUL | NULL | 17 | DC1 | DEVICE CONTROL 1 |
| 1 | SOH | START OF HEADING | 18 | DC2 | DEVICE CONTROL 2 |
| 2 | STX | START OF TEXT | 19 | DC3 | DEVICE CONTROL 3 |
| 3 | ETX | END OF TEXT | 20 | DC4 | DEVICE CONTROL 4 |
| 4 | EOT | END OF TRANSMISSION | 21 | NAK | NEGATIVE ACKNOWLEDGE |
| 5 | ENQ | ENQUIRY | 22 | SYN | SYNCHRONOUS IDLE |
| 6 | ACK | ACKNOWLEDGE | 23 | ETB | END OF TRANSMISSION BLOCK |
| 7 | BEL | BELL | | | |
| 8 | BS | BACKSPACE | 24 | CAN | CANCEL |
| 9 | HT | HORIZONTAL TABULATION | 25 | EM | END OF MEDIUM |
| | | | 26 | SUB | SUBSTITUTE CHARACTER |
| 10 | LF | LINE FEED | 27 | ESC | ESCAPE |
| 11 | VT | VERTICAL TABULATION | 28 | FS | FILE SEPERATOR |
| 12 | FF | FORM FEED | 29 | GS | GROUP SEPERATOR |
| 13 | CR | CARRIAGE RETURN | 30 | RS | RECORD SEPERATOR |
| 14 | SO | SHIFT-OUT | | | |
| 15 | SI | SHIFT-IN | 31 | US | UNIT SEPERATOR |
| 16 | DLE | DATA LINK ESCAPE | 32 | SP | SPACE |
| | | | 127 | DEL | DELETE |

## Meanings of special characters (International reference version)

| Dec | Char. | Name | Dec | Char. | Name | Dec | Char. | Name |
|---|---|---|---|---|---|---|---|---|
| 32 | | space | 43 | + | plus | 64 | @ | at |
| 33 | ! | exclamation point | 44 | , | comma | 91 | [ | bracket open |
| 34 | " | quotes | 45 | – | minus, dash | 92 | \ | back slash |
| 35 | # | number symbol | 46 | . | period, decimal point | 93 | ] | bracket closed |
| 36 | $ | dollar symbol | 47 | / | forward slash | 94 | ^ | circumflex |
| 37 | % | percent | 58 | : | colon | 95 | — | underline |
| 38 | & | business 'And' | 59 | ; | semicolon | 96 | ` | accent grave |
| 39 | ' | apostrophe | 60 | < | less than | 123 | { | curly bracket open |
| 40 | ( | parenthesis open | 61 | = | equal to | 124 | \| | vertical line |
| 41 | ) | parenthesis closed | 62 | > | greater than | 125 | } | curly bracket closed |
| 42 | * | asterisk | 63 | ? | question mark | 126 | ~ | tilde |

Control symbols (0–32 and 127 decimal) cannot be seen on monitor or printer; they are for transmitting system commands.

Numbers 128–255 (decimal) in expanded ASCII code are either coded like symbols 0–127 or they are used for special symbols (cursive symbols, graphic symbols, user defined code). For example, number 128 is the EURO symbol €.

[1)] ASCII = AMERICAN STANDARD CODE FOR INFORMATION INTERCHANGE

# Graphical symbols for data processing

## Symbols for program flow charts

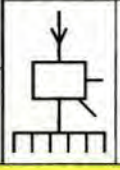
cf. DIN 66001 (1983-12)

| Symbol | Name, comments |
|---|---|
| | Process, e.g. addition, subtraction<br>Processing unit, e.g. person, computer |
| | Manual process, e.g. reading, writing<br>Manual processing location |
| | Branch, e.g. decision<br>Selector device, e.g. switch |
| | Loop start, beginning of a repeating program section |
| | Loop end, end of a repeating program section |
| | Synchronization in parallel processing<br>Synchronization device |
| | Call with return |
| | Call with no return |
| | Interruption, external |
| | Control, external |

| Symbol | Name, comments |
|---|---|
| | Data, general<br>Data storage medium, general |
| | Data to be machine processed<br>Data storage medium for data to be machine processed |
| | Data to be manually processed<br>Manual filing, e.g. card file, archive |
| | Data on paper, e.g. document; input/output device for paper, e.g. document reader, printer |
| | Data on card, e.g. punch card<br>Punch card device reader, puncher |
| | Data on punched tape<br>Punch tape device reader, puncher |
| | Data or device: memory with **only** sequential access, e.g. magnetic tape |
| | Data or device: memory that is directly accessed, e.g. disk or hard drive |

| Symbol | Name, comments |
|---|---|
| | Data in main memory<br>Main memory |
| | Optical or acoustic data, e.g. picture, sound<br>Optical or acoustic output device, e.g. monitor, loudspeaker |
| | Manual, optical or acoustic data<br>Input device, e.g. keyboard, microphone |
| | Process sequence<br>Access path |
| | Data transmission path |
| | Interface to environment, e.g. start |
| | Connector, connects graphic displays |
| | Refinement, refers to magnific. or zooming |
| | Comment for inserting explanatory text |

**Representation of connection lines**



Direction of action

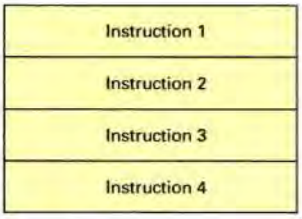
Connection at symbol

Fanning out

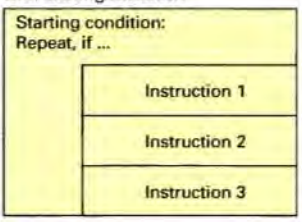
## Symbols for Nassi-Shneiderman diagrams

cf. DIN 66261 (1985-11)

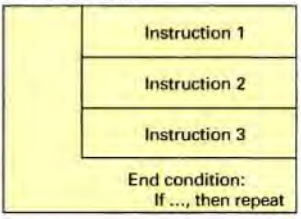
**Sequence block**



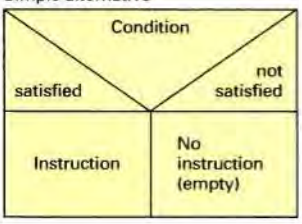

**Repeating block**
with starting condition



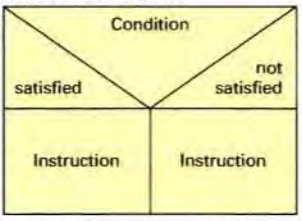

**Repeating block**
with end condition



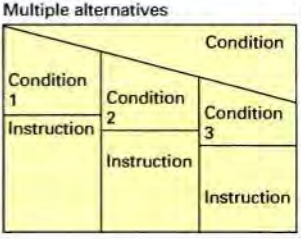

**Alternative**
Simple alternative




**Alternative**
Conditional alternative



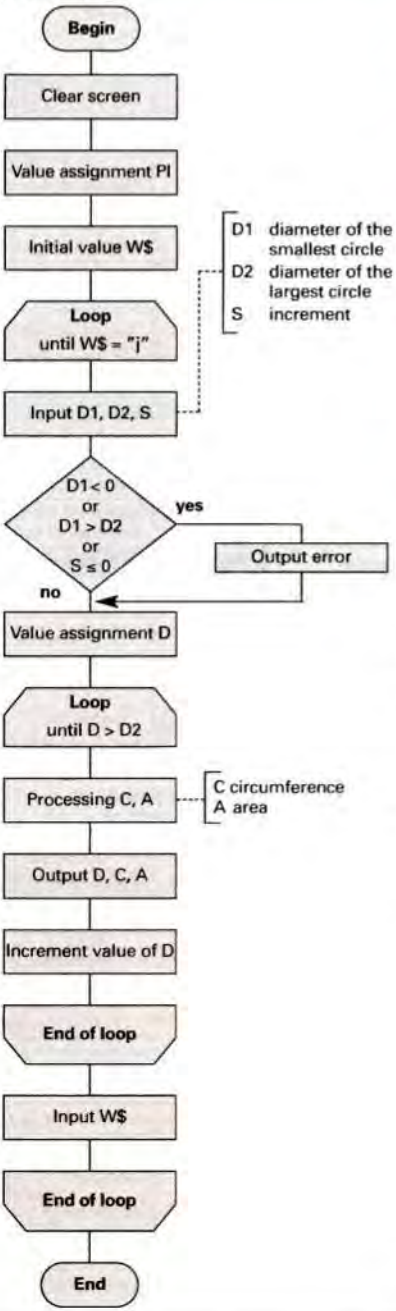

**Alternative**
Multiple alternatives



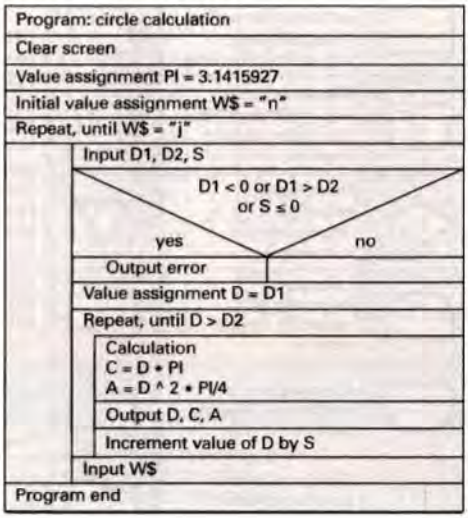
# Graphical symbols for data processing

## Program flow chart and Nassi-Shneiderman diagram

**Example: Circle calculations**
**Program flow chart**




**Nassi-Shneiderman diagram**




**BASIC program**

```
REM     *** Circle Calculation Program ***
REM     *** for circumference and area of circle ***
CLS
PRINT
CONST PI = 3.1415927 #
W$ = "n"
REM     *** Input value ***
DO UNTIL W$ = "j"
  PRINT "Diameter initial value:";
  INPUT D1
  PRINT "Diameter end value:";
  INPUT D2
  PRINT "Increment:";
  INPUT S
        IF D1 < 0 OR D1 > D2 OR S < = 0
        THEN
        PRINT "Invalid input"
        END IF
  REM *** Processing and Output ***
  PRINT "D", "C", "A"
  D = D1
        DO UNTIL D > D2
          C = D * PI
          A = D ^ 2 * PI/4
          PRINT D, C, A
          D = D + S
        LOOP
  REM *** End ***
  PRINT "End program? (y/n)";
  INPUT W$
LOOP
END
```

# MS WORD word processing commands

| Command | Explanation |
|---|---|
| **File Menu** | |
| New | Creates a new document. |
| Open | Opens an existing document. |
| Close | Closes the current document. |
| Save | Saves the current document. |
| Save as | Saves the current document under a user-selected name. |
| Page setup | Sets margins, page orientation, paper size and paper source. |
| Print Preview | Displays a print image of the document. |
| Print | Configures printer and printout. |
| Exit | Ends MS-Word. |
| **Edit Menu** | |
| Undo | Undoes the last action. |
| Repeat | Repeats the last action. |
| Cut | Deletes selected text and saves it to the clipboard. |
| Copy | Copies selected text or graphics to the clipboard. |
| Paste | Inserts the clipboard contents. |
| Select All | Selects the entire document. |
| Find | Searches for text or formatting. |
| Replace | Searches and replaces text or formatting. |
| Go to | Jumps to point in text or specific page. |
| **View Menu** | |
| Normal | Normal view for creating documents. |
| Print layout | Displays print layout of a document. |
| Outline | Shows outline of a document. |
| Toolbars | Shows/hides toolbars. |
| Ruler | Shows/hides ruler. |
| Header and Footer | Inserts text at top or bottom of page. |
| Zoom | Magnifies or reduces the screen display. |
| **Format Menu** | |
| Font | Defines font type and character sets. |
| Paragraph | Configures paragraph settings. |
| Bullets and Numbering | Configures numbering and bullets. |
| Borders and Shading | Configures border type and shading. |
| Tabs | Sets tab stop locations. |
| Text direction | Changes orientation of text from horizontal to vertical. |

| Command | Explanation |
|---|---|
| **Insert Menu** | |
| Break | Configures page break or column break. |
| Page Numbers | Defines location and layout. |
| AutoText | Inserts predefined text. |
| Symbol | Inserts special characters from available character sets. |
| Index and Tables | Selects text for an index, creates table of contents. |
| Picture | Inserts graphics. |
| Text Box | Inserts a text box. |
| File | Inserts a file. |
| Object | Inserts a formula, table, etc. |
| Hyperlink | Inserts a link to an URL.<br>URL = Uniform Resource Locator (Internet address) |
| **Window Menu** | |
| New Window | Opens a new window with contents of current window. |
| Arrange All | Arranges all open documents. |
| Split | Splits a document into two windows. |
| 1 Document 1 | List of opened documents. |
| **Tools Menu** | |
| Spelling and grammar | Checks document for spelling and grammatical errors. |
| Language | Sets the language for corrections. |
| Letters and Mailings | Links document to data of a control file (database). |
| Macro | Combines individual commands into one action. |
| Customize | Configures screen layout. |
| Options | Defines settings for MS-Word. |
| **Table Menu** | |
| Insert Table | Creates a table. |
| Insert | Inserts individual cells (rows, columns). |
| Delete | Deletes individual cells (rows, columns). |
| Select | Selects individual cells (rows, columns). |
| Merge Cells | Combines cells into one cell. |
| Split cells | Splits individual cells into multiple cells. |
| Convert | Converts table to text and vice versa. |
| Table Properties | Defines cell height, column width and table layout. |

# EXCEL Spreadsheet Commands

| Command | Explanation |
|---|---|
| **File Menu** | |
| New | Creates a new workbook, chart or macro template. When opening a chart the commands on the menu bar change. |
| Open | Opens an existing workbook. |
| Close | Closes the current workbook. |
| Save | Saves the current workbook. |
| Save as | Saves the current workbook under a newly chosen name and file format. |
| Page setup | Sets margins, page orientation, paper size and headers/footers. |
| Print Area | Sets the selected print area. |
| Print Preview | Displays a print preview of the workbook. |
| Print | Configures printer and printout. |
| Exit | Ends Excel. |
| **Edit Menu** | |
| Undo | Undoes the last action. |
| Repeat | Repeats the last action. |
| Cut | Deletes selected area of worksheet and saves it to the clipboard. |
| Copy | Copies selected text or graphics to the clipboard. |
| Paste | Inserts diagrams or data series from the clipboard or other applications. |
| Fill | Copies contents of selected cells downwards, upwards, to the right or left. |
| Delete Sheet | Deletes worksheet of a workbook. |
| Move or Copy Sheet | Moves or copies single worksheets within a workbook. |
| Find | Searches for text or formatting. |
| Replace | Searches and replaces text or formatting. |
| **Data Menu** | |
| Sort | Sorts table area in alphabetical order. |
| Import External Data | Enables importing from external databases, tables or text. |
| **View Menu** | |
| Page Break Preview | Displays expansion of a table on one or more pages. |
| Toolbars | Switches the toolbars on and off. |
| Ruler | Turns ruler on and off. |
| Header and Footer | Inserts text at the top and/or bottom of all pages. |
| Zoom | Magnifies or reduces the screen display. |

| Command | Explanation |
|---|---|
| **Insert Menu** | |
| Cells | Inserts individual cells. |
| Rows | Inserts entire rows. |
| Columns | Inserts entire columns. |
| Worksheet | Inserts a new worksheet in the workbook. |
| Chart | Inserts charts in the workbook. |
| Page Break | Sets page and/or column breaks. |
| Function | Inserts mathematical functions for calculation. |
| Picture | Inserts graphics. |
| Object | Inserts a formula, a table, a chart, etc. |
| Hyperlink | Inserts a link to an URL.<br>URL = Uniform Resource Locator (Internet address) |
| **Window Menu** | |
| New Window | Opens a new window with contents of current window. |
| Arrange | Configures window layout for opened workbooks. |
| Split | Splits a workbook into two windows. |
| Freeze Panes | Freezes a worksheet in the screen view. |
| 1 Workbook 1 | List of opened workbooks. |
| **Tools Menu** | |
| Spelling | Checks table for spelling errors. |
| Share workbook | Lets multiple users work on the workbook simultaneously. |
| Protection | Protects workbook or individual worksheets from unauthorized access. |
| Formula Auditing | Searches for errors within functions and cross-references. |
| Macro | Combines individual commands into one action. |
| Customize | Defines screen layout. |
| Options | Configures settings for EXCEL. |
| **Format Menu** | |
| Cells | Sets number format, orientation, font and frames. |
| Rows | Sets cell height. |
| Columns | Sets column width. |
| Sheet | Sets name of sheet. |
| Conditional Formatting | Applies the format of a cell if a specific condition is true. |

# International Material Comparison Chart

## Chart I

| Germany | | USA | U. K. | France | Japan | Sweden |
|---|---|---|---|---|---|---|
| | | | Standard | | | |
| DIN, DIN EN | Mat. No. | AISI/SAE | BS | AFNOR | JIS | SS |
| **Structural and machine construction steels** | | | | | | |
| S185 | 1.0035 | A 283 (A) | 1449 15 HR; HS | A 33 | – | 1300 |
| S235JR | 1.0037 | 1015, A 283 | Fe 360 B | E 24-2 | STKM 12 A; C | 1311 |
| S235JRG1 | 1.0036 | A 283 (C) | Fe 360 B 4360-40 B | – | – | 1311, 1312 |
| S235JRG2 | 1.0038 | A550.36 | Fe 360 B; 6323-ERW 3; CEW 3 | E 24-2 NE | STKM 12A; C | 1312 |
| S235J0 | 1.0114 | – | 4360-40 C | E 24-3, E 24-4 | – | – |
| S235J2G3 | 1.0116 | A 515 (55) | Fe 360 D 1 FF | E 24-3, E 24-4 | – | 1312, 1313 |
| S235J2G4 | 1.0117 | 1513 | A 2 | E 36-4 | – | – |
| S275JR | 1.0044 | 1020 | Fe 430 B FU | E 28-2 | SN 400 B; C; SN 490 B; C | 1412 |
| S275J0 | 1.0143 | A 572 (42) | 4360-43 C | E 28-3, E 28-4 | – | 1414-01 |
| S275J2G3 | 1.0144 | A 500 (A; B; D) | Fe 430 D1 FF | E 28-3, E 28-4 | SM 400 A; B; C | 1411, 1412, 1414 |
| S355JR | 1.0045 | – | 4360-50 B | E 36-2 | STK 400 | 2172 |
| S355J0 | 1.0553 | A 678 (C) | A 3 | 320-560 M | – | 1606 |
| S355J2G3 | 1.0570 | 1024; 1524 | 1449 50/35 HR; HS | E 36-3, E 36-4 | STK 500 | 2132 to 2134, 2174 |
| S355J2G4 | 1.0577 | A 738 (A; C) | Fe 510 D2 FF | A 52 FP | – | 2174 |
| S355K2G3 | 1.0595 | A 678 (C) | 224-430 | – | – | – |
| S355K2G4 | 1.0596 | A 678 (C) | 224-430 | – | – | – |
| E295 | 1.0050 | A 570 (50) | Fe 490-2 FN | A 50-2 | SS 490 | 1550, 2172 |
| E335 | 1.0060 | A 572 (65) | Fe 590-2 FN | A 60-2 | SM 570 | 1650 |
| E360 | 1.0070 | – | Fe 590-2 FN | SM 570 | 1650 | – |
| **Unalloyed quality steels** | | | | | | |
| S275N | 1.0490 | A 516 (60) | – | – | – | – |
| S275M | 1.8818 | A 715 (7) | – | – | – | – |
| S355N | 1.0545 | A 714 (III) | 4360-50 E | E 355 R | – | 2334-01, 2134-01 |
| S355M | 1.8823 | A 715 (7) | – | – | – | – |
| **Alloy high grade steels** | | | | | | |
| S420N | 1.8902 | A 633 m | – | E 420 R | – | – |
| S420M | 1.8825 | – | – | – | – | – |
| S460N | 1.8901 | A 633 m | – | E 460 R | – | – |
| S460M | 1.8827 | A 734 (B) | – | – | – | – |
| **Quenched and tempered structural steels with higher yield strength** | | | | | | |
| S460QL | 1.8906 | – | 4360-55 F | S 460 Q, T | SM 520 B, C | 2143 |
| S500QL | 1.8909 | – | – | S 500 T | – | – |
| S620QL | 1.8927 | – | – | S 620 T | – | – |
| S960QL | 1.8933 | – | – | S 960 T | – | – |
| **Unalloyed steels – Case hardened steels** | | | | | | |
| C10E | 1.1121 | 1010 | 040 A 10, 045 M 10 | C 10, CX 10 | S 9 CK, S 10 C | 1265 |
| C10R | 1.1207 | 1011 | – | E 355 C | – | – |
| C15E | 1.1141 | 1015 | 040 A 15, 080 M 15 | XC 12 | S 15, S 15 CK | 1370 |
| C15R | 1.1140 | 1016 | 080 A 20 | – | – | – |
| **Alloy steels – Case hardened steels** | | | | | | |
| 16MnCr5 | 1.7131 | 5115 | 527 M 17 | 16 MC 5, 16 Mn Cr 5 | – | 2173 |
| 16MnCrS5 | 1.7139 | 5115 | 620-440 | 16 MC 5 | – | 2127 |
| 18CrMo4 | 1.7243 | 5120/5120 H | 527 M 20 | 20 MC 5 | Scr 420 M | 2523 |
| 18CrMoS4 | 1.7244 | 5120/5120 H | 527 M 20 | 20 MC 5 | Scr 420 M | 2523 |
| 20MoCr4 | 1.7321 | K 12220 | – | – | – | – |
| 20MoCrS4 | 1.7323 | K 12220 | – | – | – | – |
| 15NiCr13 | 1.5752 | 3310 | 655 H 13 | 12 NC 15 | SNC 815 (H) | – |
| 20NiCrMo2-2 | 1.6523 | 8620 H | 805 H 20 | 20 NCD 2 | SNCM 220 H | 2506 |
| 20NiCrMoS2-2 | 1.6526 | 8620/8620 H | – | 20 NCD 2 | SNCM 220 M | 2506 |
| 17NiCrMo6-4 | 1.6566 | – | 815 M 17 | 18 NCD 6 | – | 2523 |

# International Material Comparison Chart

## Chart II

| Germany | | USA | U. K. | France | Japan | Sweden |
|---|---|---|---|---|---|---|
| | | | Standard | | | |
| DIN, DIN EN | Mat. No. | AISI/SAE | BS | AFNOR | JIS | SS |
| 17NiCrMoS6-4 | 1.6569 | 4718/47 18 H | – | – | – | – |
| 20MnCr5 | 1.7147 | 5120 | 527 M 20 | 20 MC 5 | SMn C 420 H | – |
| 20MnCrS5 | 1.7149 | 5120/5120 H | 527 M 20 | 20 MC 5 | Scr 420 M | 2523 |
| 14NiCrMo13-4 | 1.6657 | 9310 | 832 M 13 | 16 NCD 13 | – | – |
| 18CrNiMo7-8 | 1.6587 | – | – | 18 NCD 6 | – | – |
| **Unalloyed steels – Quenched and tempered steels** | | | | | | |
| C22 | 1.0402 | 1020 | 055 M 15 | AF 42 C 20 | S 20 C, S 22 C | 1450 |
| C22E | 1.1151 | 1023 | 055 M 15 | 2 C 22, XC 18, XC 25 | S 20 C | 1450 |
| C25 | 1.0406 | 1025 | 070 M 26 | 1 C 25 | – | – |
| C25E | 1.1158 | 1025 | (070 M 26) | 2 C 25, XC 25 | S 25 C, S 28 C | 1450 |
| C35 | 1.0501 | 1035 | 060 A 35 | C 35, 1 C 35 | S 35 C, S 35 CM | 1572, 1550 |
| C35E | 1.1181 | 1035 | 080 A 35 | C 35 | S 35 C | 1550, 1572 |
| C45 | 1.0503 | 1045 | 080 A 46 | C 45 | S 45 C, S 45 CM | 1672, 1650 |
| C45E | 1.1191 | 1042, 1045 | 080 M 46 | XC 42 H 1 | S 45 C | 1672 |
| C60 | 1.0601 | 1060 | 060 A 62 | C 60 | S 58 C | – |
| C60E | 1.1221 | 1064 | 060 A 62, 070 M 60 | 2 C 60 | S 58 C, S 60 CM, S 65 CM | 1665, 1678 |
| C30 | 1.0528 | G 10300 | 080 A 30 | XC 32 | S 30 C | – |
| C35 | 1.0501 | 1035 | 060 A 35 | – | – | – |
| C40 | 1.0511 | 1040 | 080 M 40 | AF 60 C 40 | – | F. 114A |
| C50 | 1.0540 | G 10500 | 080 M 50 | XC 50 | S 50 C | – |
| C55 | 1.0535 | 1055 | 070 M 55, 5770-50 | C 54; 1 C 55 | S 55 C, S 55 CM | 1655 |
| **Alloy steels – Quenched and tempered steels** | | | | | | |
| 38Cr2 | 1.7003 | – | 120 M 36 | 38 C 2, 38 Cr 2 | – | – |
| 38CrS2 | 1.7023 | 5140 | 530 A 40 | 42 C 4 | Scr 440 M | 2245 |
| 46Cr2 | 1.7006 | 5045 | – | 42 C 2, 46 Cr 2 | – | – |
| 46CrS2 | 1.7025 | A 768 (95) | – | – | SNB 5 | – |
| 34Cr4 | 1.7033 | 5132 | 530 A 32 | 32 C 4, 34 Cr 4 | SCr 430 (H) | – |
| 34CrS4 | 1.7037 | 4340/4340 H | 818 M 40 | 35 NCD 6 | SNCM 439 | – |
| 37Cr4 | 1.7034 | 5135 | 530 A 36 | 37 Cr4, 38 C 4 | Scr 435 (H) (M) | – |
| 37CrS4 | 1.7038 | 5135/5135 H | – | 38 Cr 4 | Scr 435 H | – |
| 25CrMo4 | 1.7218 | 4118 | 708 M 25 | 25 CD 4 | SCM 420 | 2225 |
| 24CrMoS4 | 1.7213 | 4130/4130 H | CDS 110 | 30 CD 4 | SCM 430 M | 2223-01 |
| 41Cr4 | 1.7035 | 5140 | 530 A 40 | 41 Cr 4, 42 C 4 | Scr 440 (H) (M) | – |
| 41CrS4 | 1.7039 | L 1 | 524 A 14 | – | – | 2092 |
| 34CrMo4 | 1.7220 | 4137 | 708 A 37 | 35 CD 4 | SCM 432 | 2234 |
| 42CrMo4 | 1.7225 | 4140 | 708 M 40 | 42 CD 4 | SCM 440 (H) | 2244 |
| 50CrMo4 | 1.7228 | 4150, 4147 | 708 A 47 | 50 Cr Mo 4 | SCM 4454 (H) | 2512 |
| 51CrV4 | 1.8159 | 6150 | 735 A 50 | 50 CV 4 | SUP 10 | 2230 |
| 36CrNiMo4 | 1.6511 | 9840 | 817 M 37 | 36 CrNiMo 4, 35 NCD 5, 40 NCD 3 | – | – |
| 34CrNiMoS4 | 1.6582 | 4337, 4240 | 816 M 40, 817 M 40 | 34 CrNiMo 8 | SNCM 447 | 2541 |
| 30NiCrMo8 | 1.6580 | | 823 M 30 | 30 CrNiMo 8 | SNCM 431 | – |
| 36NiCrMo16 | 1.6773 | 5135/5135 H | – | 38 Cr 4 | Scr 435 M | – |
| **Nitriding steels** | | | | | | |
| 31CrMo12 | 1.8515 | – | 722 M 24 | 30 CD 12 | – | 2240 |
| 34CrAlMo5-10 | 1.8507 | A 355 Cl.D | – | 30 CAD 6.12 | – | – |
| 40CrAlMo7-10 | 1.8509 | E 7140 | 905 M 39, En 41 B | 40 CAD 6.12 | SACM 1, SACM 645 | 2940 |
| 40CrMoV13-9 | 1.8523 | – | 897 M 39 | – | – | – |
| **Steels for flame and induction hardening** | | | | | | |
| Cf45 | 1.1193 | 1045 | 060 A 47, 080 M 46 | XC 42 H 1 TS | S 45 C, S 45 CM | 1672 |
| 42Cr4 | 1.7045 | 5140 | 530 A 40 | 42 C 4 TS | Scr 440 | 2245 |
| 41CrMo4 | 1.7223 | 4142 | 708 M 40, 3111-5/1 | 42 CD 4 TS | SNB 22, SCM 440 | 2244 |
| Cf35 | 1.1183 | 1035 | 080 A 35 | XC 38 H 1 TS | S 35 C, S 35 CM | 1572 |

# International Material Comparison Chart

## Chart III

| Germany | | USA | U. K. | France | Japan | Sweden |
|---|---|---|---|---|---|---|
| Standard | | | | | | |
| DIN, DIN EN | Mat. No. | AISI/SAE | BS | AFNOR | JIS | SS |
| Cf53 | 1.1213 | 1050 | 070 M 55 | XC 48 H 1 TS | S 50 C, S 50 CM | 1674 |
| Cf70 | 1.1249 | – | – | – | – | – |
| **Free cutting steels** | | | | | | |
| 11SMn30 | 1.0715 | 1213 | 230 M 07 | S 250 | SUM 22 | 1912 |
| 11SMnPb30 | 1.0718 | 12 L 13 | – | S 250 Pb | SUM 23 L | 1914 |
| 11SMn37 | 1.0736 | 1215 | – | S 300 | SUM 25 | – |
| 11SMnPb37 | 1.0737 | 12 L 14 | – | S 300 Pb | – | 1926 |
| 10S20 | 1.0721 | 1108, 1109 | (210 M 15) | 10 F 2 | – | – |
| 10SPb20 | 1.0722 | – | – | 10 Pb F 2 | – | – |
| 35S20 | 1.0726 | 1140 | 212 M 36 | 35 MF 6 | – | 1957 |
| 46S20 | 1.0727 | 1146 | En 8 DM | 45 MF 4 | SUM 43 | – |
| **Cold work steels, unalloyed** | | | | | | |
| C80U | 1.1525 | W 108 | – | C 80 E 2 U, $Y_1$ 80 | – | – |
| C105U | 1.1545 | W 1 | BW 1 A | Y 105 | SK 3 | 1880 |
| **Cold work steels, alloy** | | | | | | |
| 45WCrV7 | 1.2542 | S 1 | BS 1 | 45 WCrV 8 | S 1 | 2710 |
| 60WCrV8 | 1.2550 | S 1 | BS 1 | 55 WC 20 | – | – |
| 100MnCrW4 | 1.2510 | O 1 | BO 1 | 90 MnWCrV 5 | SKS 3 | – |
| 90MnCrV8 | 1.2842 | O 2 | BO 2 | 90 Mn V 8, 90 MV 8 | – | – |
| X210Cr12 | 1.2080 | P 3 | BD 3 | Z 200 C 12 | SKD 12 | 2710 |
| 102Cr6 | 1.2067 | L 3 | (BL 3) | 100 Cr 6, Y 100 C 6 | SUJ 2 | – |
| 45NiCrMo16 | 1.2767 | – | BP 30 | Y 35 NCD 16 | – | – |
| X153CrMoV12 | 1.2379 | D 2 | BD 2 | Z 160 CDV 12 | SKD 12 | 2260 |
| X100CrMoV51 | 1.2363 | A 2 | BA 2 | Z 100 CDV 5 | SKD 12 | 2260 |
| X40CrMoV51 | 1.2344 | H 13 | BH 13 | Z 40 CDV 5 | SKD 61 | 2242 |
| X210CrW12 | 1.2436 | D4 (D6) | BD 6 | Z 210 CW 12-01 | SKD 2 | 2312 |
| **Hot work steels** | | | | | | |
| 55NiCrMoV7 | 1.2714 | – | – | – | SKS 51 | – |
| X37CrMoV5-1 | 1.2343 | H 11 | BH 11 | Z 38 CDV 5 | SKD 6 | – |
| 32CrMoV12-28 | 1.2365 | H 10 | BH 10 | 32 CDV 12-28 | – | – |
| **High speed steels** | | | | | | |
| HS6-5-2C | 1.3343 | M 2 | BM 2 | HS 6-5 | SKH 51 | 2722 |
| HS6-5-2-5 | 1.3243 | M 35 | BM 35 | Z 85 WDKCV 06-05-04-02 | SKH 55 | 2723 |
| HS10-4-3-10 | 1.3207 | – | BT 42 | HS 10-4-3-10 | SKH 57 | – |
| HS2-9-2 | 1.3348 | M 7 | – | HS 2-9-2,<br>Z 100 DCWV 09-04-02-02 | – | 2782 |
| HS2-9-1-8 | 1.3247 | M 42 | BM 42 | HS 2-9-1-8 | SKH 59 | 2716 |
| S2-9-2-8 | 1.3249 | M 42 | BM 34 | – | – | – |
| **Stainless steels, austenitic** | | | | | | |
| X10CrNi18-8 | 1.4310 | 301 | 301 S 21/22 | Z 12 CN 18-09 | SUS 301 | 2331 |
| X2CrNi18-9 | 1.4307 | F 304 L | 304 L | – | SUS F 304 L | – |
| X5CrNi18 9 | 1.4350 | 304 | 304 S 31 | Z 5 CN 18.09 | SUS 304 | 2332 |
| X2CrNiN19-11 | 1.4306 | 304 L | 304/305 S 11 | Z 2 CN 18-10 | SCS 19, SUS 304 L | 2352 |
| X2CrNi18-10 | 1.4311 | 304 LN | 304 S 61 | Z 3 CN 18-07 Az | SUS 304 LN | 2371 |
| X5CrNi18-10 | 1.4301 | 304 | 304 S 17 | Z 5 CN 17-08 | SUS 304 | 2332, 2333 |
| X8CrNiS18-9 | 1.4305 | 303 | 303 S 22/31 | Z 8 CNF 18-09 | SUS 303 | 2346 |
| X6CrNiTi18-10 | 1.4541 | 321 | 321 S 31/51 | Z 6 CNT 18-10 | SUS 321 | 2337 |
| X4CrNi18-12 | 1.4303 | 305/308 | 305 S 17, 305 S 19 | Z 5 CN 18-11 FF | SUS 305 J1, SUS 305 | – |
| X5CrNiMo17-12-2 | 1.4401 | 316 | 316 S 13/17/19 | Z 3 CND 17-11-01 | SUS 316 | 2347 |
| X6CrNiMoTi17-12-2 | 1.4571 | 316 Ti | 320 S 18/31 | Z 6 CNDT 17-12 | SUS 316 Ti | 2350 |
| X2CrNiMo18-14-3 | 1.4435 | 316 L | 316 S 11/13/14 | Z 3 CND 17-12-03/<br>Z 3 CND 18-14-03 | SUS 316 L | 2353 |

# International Material Comparison Chart

## Chart IV

| Germany | | USA | U. K. | France | Japan | Sweden |
|---|---|---|---|---|---|---|
| Standard | | | | | | |
| DIN, DIN EN | Mat. No. | AISI/SAE | BS | AFNOR | JIS | SS |
| X2CrNiMoN17-13-3 | 1.4429 | 316 LN | 326 S 63 | Z 3 CND 17-12 Az | (SUS 316 LN) | 2375 |
| X2CrNiMoN17-13-5 | 1.4439 | 316 L | 316 S 11 | Z 2 CND 17-12 | SUSF 316 L | 2348 |
| X1NiCrMoCu25-20-5 | 1.4539 | USN N 08904 | – | Z 2 NCDU 25-20 | – | 2562 |
| **Stainless steels, ferritic** | | | | | | |
| X2CrNi12 | 1.4003 | A 268 | – | – | – | – |
| X6Cr13 | 1.4000 | 403 | 403 S 17 | Z 8 C 12, Z 8 C 13 FF | SUS 403 | 2301 |
| X6Cr17 | 1.4016 | 430 | 430 S 15 | Z 8 C 17 | SUS 430 | 2320 |
| X2CrTi12 | 1.4512 | 409 | 409 S 19 | Z 3 CT 12 | SUH 409 | – |
| X6CrMo17-1 | 1.4113 | 434 | 434 S 17 | Z 8 CD 17.01 | SUS 434 | – |
| X2CrMoTi18-2 | 1.4521 | 443/444 | – | – | SUS 444 | 2326 |
| **Stainless steels, martensitic** | | | | | | |
| X12CrS13 | 1.4005 | 416 | 416 S 21 Z 11 CF13 | SUS 416 | – | 2380 |
| X12Cr13 | 1.4006 | 410 | 410 S 21 | Z 10 C 13 | SUS 410 | 2302 |
| X20Cr13 | 1.4021 | 420 | 420 S 37 | Z 20 C 13 | SUS 420 J 1 | 2303 |
| X30Cr13 | 1.4028 | 420 F | 420 S 45 | Z 30 C 13 | SUS 420 J 2 | 2304 |
| X46Cr13 | 1.4034 | – | (420 S 45) | Z 44 C 14, Z 38 C 13 M | SUS 420 J2 | 2304 |
| X39CrMo17-1 | 1.4122 | 5925 | – | – | – | – |
| X3CrNiMo13-4 | 1.4313 | CA 6-NM | 425 C 11 | Z 4 CND 13.4 M | SCS 5, SCS 6 | 2384 |
| **Hot rolled steels for springs** | | | | | | |
| 38Si7 | 1.5023 | – | – | 41 Si 7 | – | – |
| 46Si7 | 1.5024 | 9255 | – | 51 S 7, 51 Si 7 | – | 2090 |
| 55Cr3 | 1.7176 | 5155 | 525 A 58 | 55 Cr 3, 55 C 3 | SUP 9 (A) (M) | 2253 |
| 61SiCr7 | 1.7108 | 9261, 9262 | – | 61 SC 7 | – | – |
| 51CrV4 | 1.8159 | 6150 | 735 A 50 | 55 Cr V 4 | SUP 10 | 2230 |
| **Cold rolled strip and sheet from soft steels** | | | | | | |
| DC03 | 1.0347 | A 619 | 1449 3 CR | E | CR 2 | 1146 |
| DC04 | 1.0338 | A 620 (1008) | 1449 2 CR; 3 CR | ES | SPCE; HR 4 | 1147 |
| **Cast iron with flake graphite (gray iron)** | | | | | | |
| EN-GJL-100 | EN-JL-1010 | A 48 20 B | 1452 Grade 100 | Ft 10 D | G 5501 FC 10 | 0110-00 |
| EN-GJL-150 | EN-JL-1020 | A 48 25 B | 1452 Grade 150 | A 32-101 FGL 150; FT 15 D | G 5501 FC 15 | 0115-00 |
| EN-GJL-200 | EN-JL-1030 | A 48 30 B | 1452 Grade 220 | A 32-101 FGL 200; FT 20 D | G 5501 FC 20 | 0120-00 |
| EN-GJL-250 | EN-JL-1040 | A 48 40 B | 1452 Grade 250/ 260 | A 32-101 FGL 250; FT 25 D | G 5501 FC 25 | 0125-00 |
| EN-GJL-300 | EN-JL-1050 | A 48 45 B | 1452 Grade 300 | A 32-101 FGL 300; FT 30 D | G 5501 FC 30 | 0130-00 |
| EN-GJL-350 | EN-JL-1060 | A 48 50 B | 1452 Grade 350 | A 32-101 FGL 350; FT 35 D | G 5501 FC 35 | 0135-00 |
| **Cast iron with spheroidal (nodular) graphite** | | | | | | |
| EN-GJS-350-22 | EN-JS-1010 | – | – | – | – | 0717-15 |
| EN-GJS-500-7 | EN-JS-1050 | A 536 60-45-12 | 2789 Grade 500/7 | A 32-201 FGS 500-7 | G 5502 FCD 500 | 0727-02 |
| EN-GJS-600-3 | EN-JS-1060 | A 536 80-55-06 | 2789 Grade 600/3 | A 32-201 FGS 600-3 | G 5502 FCD 600 | 0732-03 |
| EN-GJS-700-2 | EN-JS-1070 | A 536 100-70-03 | 2789 Grade 700-2 | A 32-201 FGS 700-2 | G 5502 FCD 700 | 0737-01 |
| **Malleable cast iron** | | | | | | |
| EN-GJMW-350-4 | EN-JM 1010 | – | 86681 W 35-04 | A 32-701 MB 35-7 | G 5703 FCMW 330 | – |
| EN-GJMW-400-5 | EN-JM 1030 | – | 6681 W 40-05 | A 32-701 MB 40-05 | G 5703 FCMW 370 | – |
| EN-GJMW-450-7 | EN-JM 1040 | – | 6681 45-07 | A 32-701 MB 450-7 | G 5703 FCMWP 440 | – |
| EN-GJMB-350-10 | EN-JM 1130 | A 47 Grade 22010+32510 | 310 B 340/12 | A 32-702 MN 350-10 | G 5703 FCMB 340 | 0815-00 |
| EN-GJMB-450-6 | EN-JM 1140 | – | 6681 P 45-06 | A 32-703 MP 50-5 | – | 0854-00 |
| EN-GJMB-550-4 | EN-JM 1160 | – | 6681 P 55-04 | A 32-703 MP 60-3 | G 5703 FCMP 540 | 0856-00 |
| EN-GJMB-650-2 | EN-JM 1180 | – | 6681 P 65-02 | – | – | 0862-03 |
| EN-GJMB-700-2 | EN-JM 1190 | A220 Grade 70003 | 6681 P 70-02 | A 32-703 MP 70-2 | G 5703 FCMP 690 | 0862-03 |

# International Material Comparison Chart

## Chart V

| Germany | | USA | U. K. | | France | | Japan | Sweden |
|---|---|---|---|---|---|---|---|---|
| | | | Standard | | | | | |
| DIN, DIN EN | Mat. No. | AISI/SAE | BS | | AFNOR | | JIS | SS |
| **Cast steels for general applications** | | | | | | | | |
| GS-38 | 1.0420 | – | – | | – | | SC 360 | – |
| GS-45 | 1.0446 | A 27 | – | | – | | SC 450 | – |
| **Cast steels for pressure vessels** | | | | | | | | |
| GP240GH | 1.0619 | A 216 Grade WCC | 1504-161 Gr. B | | – | | – | – |
| G17CrMo5-5 | 1.7357 | A 217 Grade WC 6 | – | | – | | – | – |
| **Aluminum and wrought aluminum alloys** | | | | | | | | |
| | | | old | new | old | new | | |
| Al 99.5 | 1050 A | 1050 A | 1 B | 1050 A | A-5 | 1050 A | A 1050 | 4007 |
| Al Mn1 | 3103 | 3103 | N 3 | 3103 | – | | – | 4054 |
| Al Mn1Cu | 3003 | 3003 | | (3103) | A-M 1 | 3003 | A 3003 | – |
| Al Mg1 | 5005 A | 5005 A | N 41 | 5005 | A-G 0.6 | 5005 | A 5005 | 4106 |
| Al Mg2 | 5251 | 5251 | N 4 | 5251 | A-G 2 M | 5251 | – | – |
| Al Mg3 | 5754 | 5754 | – | | A-G 3 M | 5754 | – | 4125 |
| Al Mg5 | 5019/5119 | 5019/5119 | – | | A-G 5 | | – | – |
| Al Mg3Mn | 5454 | 5454 | N 51 | 5454 | A-G 3 MC | 5454 | A 5454 | – |
| Al Mg4.5Mn0.7 | 5083 | 5083 | N 8 | 5083 | A-G 4.5 MC | | A 5083 | 4140 |
| AlCuPbMgMn | 2007 | 2007 | – | | A-U 4 PB | | – | 4335 |
| Al Cu4PbMg | 2030 | 2030 | – | | – | | – | – |
| Al MgSiPb | 6012 | 6012 | – | | A-SGPB | | – | – |
| Al Cu4SiMg | 2014 | 2014 | H 15 | (2014 A) | A-U 4 SG | | – | – |
| Al Cu4MgSi | 2017 | 2017 | – | | A-U 4 G | | A 2017 | – |
| Al Cu4Mg1 | 2024 | 2024 | 2 L 97/9 | 2024 | A-U 4 G1 | 2024 | A 2024 | – |
| Al MgSi | 6060 | 6060 | H 9 | (6063) | A-GS | 6060 | A 6063 | 4103 |
| Al Si1MgMn | 6082 | 6082 | H 30 | 6082 | A-SGM 0.7 | 6082 | – | 4212 |
| Al Zn4.5Mg1 | 7020 | 7020 | H 17 | 7020 | A-Z 5 G | 7020 | (A 7 N 01) | 4425 |
| Al Zn5Mg3Cu | 7022 | 7022 | – | | A-Z 4 GU | | – | – |
| Al Zn5.5MgCu | 7075 | 7075 | 2 L 95/96 | 7075 | A-Z 5 GU | 7075 | A 7075 | – |
| **Aluminum casting alloys** | | | | | | | | |
| AC-AlSi7Mg | AC-42000 | A 356 | L M 25 | | A-S 7 g | | – | – |
| **Magnesium alloys, Titanium, Titanium alloys** | | | | | | | | |
| MgMn2 | 3.3520 | M 1 A | MAG-E-101 | | G-M 2 | | – | – |
| MgAl3Zn | 3.5312 | AZ 31 B | MAG-E-111 | | G-A 3 Z 1 | | – | – |
| MgAl6Zn | 3.5612 | AZ 61 A | MAG-E-121 | | G-A 6 Z 1 | | – | – |
| MgAl8Zn | 3.5812 | AZ 80 A | – | | G-A 7 Z 1 | | – | – |
| Ti1 | 3.7025 | – | T A 1 | | – | | – | – |
| Ti2 | 3.7035 | – | T A 2 | | – | | – | – |
| TiAl6V4 | 3.7165 | – | T A 10-13, 28, 56 | | – | | – | – |
| TiAlMo4Sn2 | 3.7185 | – | T A 45-51, 57 | | – | | – | – |

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