## DESIGNING WITH ENGINEERING

# PLASTICS

with survey tables

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engineering plastics

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# TOLERANCES

*The competitive edge through engineered components made of plastic*

**1. Material-related tolerances for machined plastic component parts**

Plastics are often integrated into existing assemblies to replace conventional materials. As a rule, however, the production drawing is only altered in respect to the new material. Often the tolerances that have been specified for the steel component are not adapted to suit the new material. But even in the case of new designs where plastic is planned as a material, the tolerance fields that are normal for steel are still used. However, the special features of plastics preclude the use of the narrow production tolerances required for steel parts.

The decisive factor is not the possibility of manufacturing the parts, since this is virtually no problem with the use of modern CNC machine tools, but rather the permanent compliance with the tolerances after the manufacturing process. This applies especially to dimensions in a class of tolerances with very narrow fields (< 0.1 mm). These can change immediately after the part is taken from the machine due to the visco-elastic behaviour of the plastics. In particular, the higher level of thermal expansion, volume changes due to the absorption of moisture as well as form and dimensional changes caused by the relaxation of production-related residual stresses are just some of the possible causes.

Another problem is the fact that there is no general standard for machined plastic components. The lack of a common basis for material-related tolerances for parts such as this often leads to disagreement between the customer and the supplier in regard to the classification of rejects and/or defects in delivery. Choosing a tolerance field that is suitable for the respective material can avoid disputes and also ensure that the plastic components function and operate safely as intended.

The following sections of this chapter are based on our many years of experience with different plastics and are intended to assist design engineers in defining tolerances. The aim is to create a standard basis and to avoid unnecessary costs caused by rejects due to off-spec tolerances.

The tolerance fields that we recommend can be achieved with conventional production methods and without any additional expenditure. In general, the functioning and operating safety of the components were not limited because of the increased tolerance. Narrower tolerances than those stated here are possible to a certain extent, but would necessitate unjustifiably high processing expenditure, and the materials would also require intermediate treatment (annealing) during the production process. If component parts require tolerance fields of < 0.1 mm or ISO series IT 9 fits and smaller, we will be happy to advise you in the choice of a technically/economically practical and sustainable tolerance field.

**2. Plastic-related tolerances**

**2.1 General tolerances**

The general tolerances for untoleranced dimensions can be chosen according to DIN ISO 2768 T1, tolerance class »m«. In this standard, the tolerances are defined as follows:

Table 1: Limiting dimensions in mm for linear measures (DIN ISO 2768 T1)

| Tolerance class | Nominal size range in mm 0,5 up to 3 | above 3 up to 6 | above 6 up to 30 | above 30 up to 120 | above 120 up to 400γ | above 400 up to 1000 | above 1000 up to 2000 | above 2000 up 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 | ± 2.0 |
| g (rough) | ± 0.15 | ± 0.2 | ± 0.5 | ± 0.8 | ± 1.2 | ± 2.0 | ± 3.0 | ± 4.0 |
| v (very rough) | – | ± 0.5 | ± 1.0 | ± 1.5 | ± 2.5 | ± 4.0 | ± 6.0 | ± 8.0 |

Table 2: Limiting dimensions in mm for radius of curvature and height of bevel (DIN ISO 2768 T1)

| Tolerance class | Nominal size range in mm 0.5 up to 3 | above 3 up to 6 | above 6 |
|---|---|---|---|
| f (fine)<br>m (medium) | ± 0.2 | ± 0.5 | ± 1.0 |
| g (rough)<br>v (very rough) | ± 0.4 | ± 1.0 | ± 2.0 |

Table 3: Limiting dimensions in degrees for angle measurements (DIN ISO 2768 T1)

| Tolerance class | Nominal size range of the shorter leg in mm up to 10 | above 10 up to 50 | above 50 up to 120 | above 120 up to 400 | above 400 γ |
|---|---|---|---|---|---|
| f (fine)<br>m (medium) | ± 1° | ± 30' | ± 20' | ± 10' | ± 5' |
| g (rough)<br>v (very rough) | ± 1° 30'<br>± 3 | ± 1°<br>± 2° | ± 30'<br>± 1° | ± 15'<br>± 30' | ± 10'<br>± 20' |

For length measurements the choice of tolerance class »f« is possible in special cases. The lasting durability of the tolerance, based on the geometry of the workpiece, should be checked with the manufacturer of the component part.

**2.2 Shape and position**

The general tolerances for untoleranced dimensions can be selected according to DIN ISO 2768 T2, tolerance class »K«. In this standard the tolerances are defined as follows:

Table 4: General tolerances for straightness and evenness (DIN ISO 2768 T2)

| Tolerance class | Nominal size range in mm up to 10 | above 10 up to 30 | above 30 up to 100 | above 100 up to 300 | above 300 up to 1000 γ | above 1000 up to 3000 |
|---|---|---|---|---|---|---|
| H | 0.02 | 0.05 | 0.1 | 0.2 | 0.3 | 0.4 |
| K | 0.05 | 0.1 | 0.2 | 0.4 | 0.6 | 0.8 |
| L | 0.1 | 0.2 | 0.4 | 0.8 | 1.2 | 1.6 |

Table 5: General tolerances for rectangularity (DIN ISO 2768 T2)

| Tolerance class | Nominal size range in mm | | | |
|---|---|---|---|---|
| | up to 100 | above 100 up to 300 | above 300 up to 1000 | above 1000 up to 3000 |
| H | 0.2 | 0.3 | 0.4 | 0.5 |
| K | 0.4 | 0.6 | 0.8 | 1.0 |
| L | 0.6 | 1.0 | 1.5 | 2.0 |

Table 6: General tolerances for symmetry (DIN ISO 2768 T2)

| Tolerance class | Nominal size range in mm | | | |
|---|---|---|---|---|
| | to 100 | above 100 up to 300 | above 300 up to 1000 | above 1000 up to 3000 |
| H | 0.5 | | | |
| K | 0.6 | | 0.8 | 1.0 |
| L | 0.6 | 1.0 | 1.5 | 2.0 |

The general tolerance for run-out and concentricity for class »K« is 0.2 mm.

In special cases it is possible to choose tolerance class »H«. The general tolerance for run-out and concentricity for class »H« is 0.1 mm.
It is important to check with the manufacturer to make sure the tolerance can be held over the long term.

### 2.3 Press fit

As described above, it is not possible to apply the ISO tolerance system that is usually applied to steel components. Accordingly, the tolerance series IT 01-9 should not be used. In addition, to determine the correct tolerance series, the machining method and the type of plastic being used must be considered.

#### 2.3.1 Dimensional categories

The different plastics can be classified into two categories according to their dimensional stability. These are shown in Table 7.

Table 7: Dimension categories for plastics

| Dimension category | Plastics | Comments |
|---|---|---|
| A | POM, PET, PTFE+glass, PTFE+bronze, PTFE+carbon,PC,PVC-U, PVDF, PP-H, PEEK, PEI, PSU, HGW (laminated fabric) | Thermoplastics with or or without reinforcement/fillers (with low moisture absorption) |
| B | PE-HD, PE-HMW, PE-UHMW, PTFE, PA 6, **LiNNOTAM**, PA 66, PA 12 | Soft thermoplastics and polyamides with moisture absorption |

### 2.3.2 Classification of tolerance series for milled parts

Classification for milled parts with tolerances

| Dimension category: | | |
|---|---|---|
| | A | IT 10-12 |
| | B | IT 11-13 |

Table 8: ISO basic tolerances in µm according to DIN ISO 286

| Nominal size range mm | | ISO tolerance series (IT) 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| From up to | 1-3 | 6 | 10 | 14 | 25 | 40 | 60 | 100 | 140 | 250 | 400 | 600 |
| Above up to | 3-6 | 8 | 12 | 18 | 30 | 48 | 75 | 120 | 180 | 300 | 480 | 750 |
| Above up to | 6-10 | 9 | 15 | 22 | 36 | 58 | 90 | 150 | 220 | 360 | 580 | 900 |
| Above up to | 10-18 | 11 | 18 | 27 | 43 | 70 | 110 | 180 | 270 | 430 | 700 | 110 |
| Above up to | 18-30 | 13 | 21 | 33 | 52 | 84 | 130 | 210 | 330 | 520 | 540 | 1300 |
| Above up to | 30-50 | 16 | 25 | 39 | 62 | 100 | 160 | 250 | 390 | 620 | 1000 | 1600 |
| Above up to | 50-80 | 19 | 30 | 46 | 74 | 120 | 190 | 300 | 460 | 740 | 1200 | 1900 |
| Above up to | 80-120 | 22 | 35 | 54 | 87 | 140 | 220 | 350 | 540 | 870 | 1400 | 2200 |
| Above up to | 120-180 | 25 | 40 | 63 | 100 | 160 | 250 | 400 | 630 | 1000 | 1600 | 2500 |
| Above up to | 180-250 | 29 | 46 | 72 | 115 | 185 | 290 | 460 | 420 | 1150 | 1850 | 2900 |
| Above up to | 250-315 | 32 | 52 | 81 | 130 | 210 | 320 | 520 | 810 | 1300 | 2100 | 3200 |
| Above up to | 315-400 | 36 | 57 | 89 | 140 | 230 | 360 | 570 | 890 | 140 | 2300 | 3600 |
| Above up to | 400-500 | 40 | 63 | 97 | 155 | 250 | 400 | 630 | 970 | 1550 | 2500 | 4000 |

### 2.3.3 Classification of tolerance series for turned parts

Classification for turned parts with tolerances

| Dimension category: | | |
|---|---|---|
| | A | IT 10-11 |
| | B | IT 11-12 |

Table 8: ISO basic tolerances in µm according to DIN ISO 286

| Nominal size range mm | | ISO tolerance series (IT) 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| From up to | 1-3 | 6 | 10 | 14 | 25 | 40 | 60 | 100 | 140 | 250 | 400 | 600 |
| Above up to | 3-6 | 8 | 12 | 18 | 30 | 48 | 75 | 120 | 180 | 300 | 480 | 750 |
| Above up to | 6-10 | 9 | 15 | 22 | 36 | 58 | 90 | 150 | 220 | 360 | 580 | 900 |
| Above up to | 10-18 | 11 | 18 | 27 | 43 | 70 | 110 | 180 | 270 | 430 | 700 | 110 |
| Above up to | 18-30 | 13 | 21 | 33 | 52 | 84 | 130 | 210 | 330 | 520 | 540 | 1300 |
| Above up to | 30-50 | 16 | 25 | 39 | 62 | 100 | 160 | 250 | 390 | 620 | 1000 | 1600 |
| Above up to | 50-80 | 19 | 30 | 46 | 74 | 120 | 190 | 300 | 460 | 740 | 1200 | 1900 |
| Above up to | 80-120 | 22 | 35 | 54 | 87 | 140 | 220 | 350 | 540 | 870 | 1400 | 2200 |
| Above up to | 120-180 | 25 | 40 | 63 | 100 | 160 | 250 | 400 | 630 | 1000 | 1600 | 2500 |
| Above up to | 180-250 | 29 | 46 | 72 | 115 | 185 | 290 | 460 | 420 | 1150 | 1850 | 2900 |
| Above up to | 250-315 | 32 | 52 | 81 | 130 | 210 | 320 | 520 | 810 | 1300 | 2100 | 3200 |
| Above up to | 315-400 | 36 | 57 | 89 | 140 | 230 | 360 | 570 | 890 | 140 | 2300 | 3600 |
| Above up to | 400-500 | 40 | 63 | 97 | 155 | 250 | 400 | 630 | 970 | 1550 | 2500 | 4000 |

### 2.4 Surface quality

The degree of surface quality that can be achieved depends on the machining method. Table 9 shows the surface qualities that can be achieved without any additional expenditure for the individual processes.

Table 9: Achievable surface qualities for various machining processes

| Form of machining | Max. achievable degree of roughness | Average roughness value $R_a$ (µm) | Averaged depth of roughness $R_z$(µm) |
|---|---|---|---|
| Milling | N7 | 1.6 | 8 |
| Turning | N7 | 1.6 | 8 |
| Planing | N8 | 3.2 | 12.5 |
| Sawing | N8 | 3.3 | 26 |

It is possible to achieve better surface qualities than those shown in Table 9 in conjunction with higher production expenditure. However, the production possibilities must be discussed with the manufacturer of the component part in regard to the respective plastic and the machining method.

### 2.5 Tolerances for press fits

#### 2.5.1 Oversize for bushes

To ensure that friction bearing bushes sit properly in the bearing bore, the insertion of an oversized component has proved to be a good method. The oversize for plastic bushes is very large compared to metal bearing bushes. However, due to the visco-elastic behaviour of the plastics, this is especially important because of the effects of heat, as otherwise the bearing bush would become loose in the bore. If the maximum service temperature is 50 °C, it is possible to do without an additional securing device for the bearing bush if the oversizes from Diagram 1 are complied with. In the case of temperatures above 50 °C, we recommend that the bush be secured with a device commonly used in machine engineering (e.g. a retaining ring according to DIN 472, see also the chapter on »Friction bearings« section 2.5).

It should also be considered that when the bearing bush is being inserted, its oversize leads to it being compressed. Consequently the oversize must be considered as an excess to the operating bearing play, and the internal diameter of the bearing must be dimensioned accordingly. Diagram 2 shows the required bearing play in relation to the internal diameter of the bearing. To prevent the bearing from sticking at temperatures above 50 °C, it is necessary to correct the bearing play by the factors shown in the chapter on »Friction bearings« section 2.3.

Diagram 1:
Press-fit oversize for friction bearings

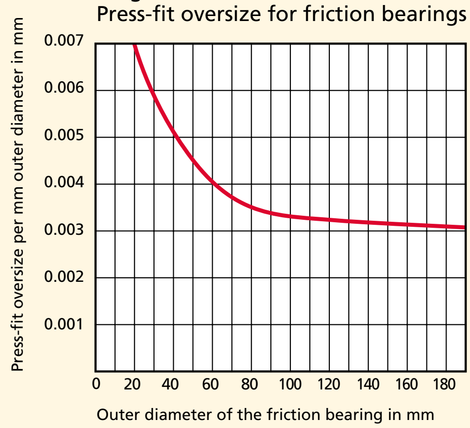
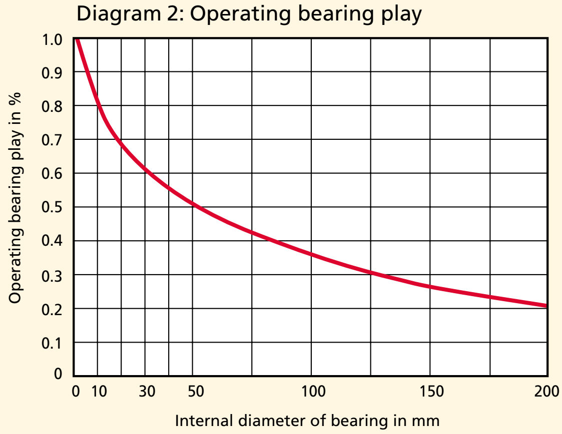



Diagram 2: Operating bearing play



In regard to dimensioning thin walled bearing bushes, rings and similar components, it must be noted that the measuring forces that are applied and the deformation that this causes can result in incorrect measurements. Hence, the tolerances for the outer diameter and wall thickness shown in Figure1 are recommended.

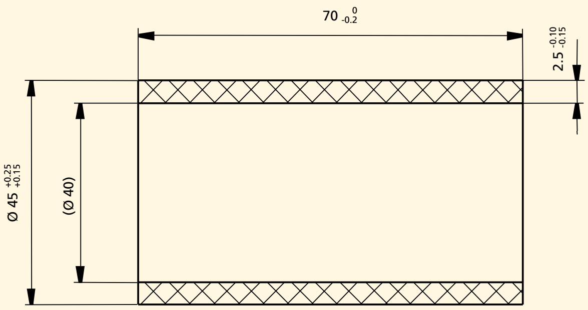
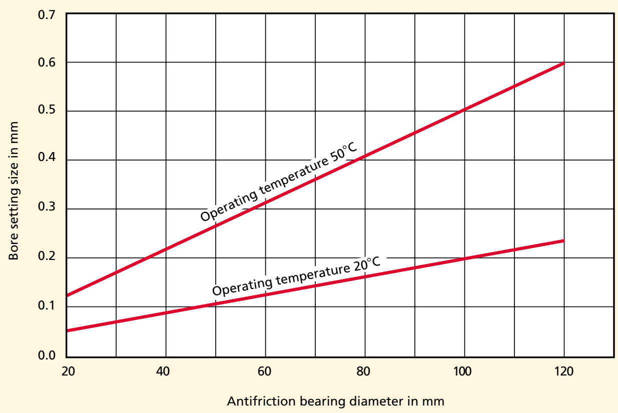



Figure 1: Example of tolerance for a bearing bush

**2.5.2 Press-fit undersize for antifriction bearings**

Antifriction bearings can be inserted directly into the undersized bearing seat for maximum operating temperatures of up to 50 °C. If low loads and low operating temperatures are expected, no additional securing is required for the bearing, but it is recommended for higher loads and operating temperatures. Again this is because of the visco-elastic behaviour of the plastics which can result in a reduction in the compression force and bearing migration. The bearing can also be secured with devices commonly used in machine engineering (e.g. retaining ring according to DIN 472). If the bearing is to be used in areas where high tempe-ratures or loads are expected, it is also possible to place a steel sleeve in the bearing bore. This steel sleeve is fixed in the bearing bore with additional securing elements, and the bearing is pressed in to this ring. Diagram 3 shows the required temperature-related undersizes for fixing the bearing in the bearing seat by compression.

Diagram 3: Bore setting sizes for bearing seats




For bearing seats into which anti-friction bearings are inserted for operation at normal temperature and load conditions, we recommend the following press-fit undersizes and tolerances:

Bearing seat diameter up to 50 mm ➜ -0,15/-0,25 mm
Bearing seat diameter above 50 up to 120 mm ➜ -0,25/-0,35 mm
Bearing seat diameter above 120 mm ➜ -0,40/-0,50 mm

In our many years of experience, bearing seats manufactured according to the above exhibit no excessive decrease in compression force and are able to keep the anti-friction bearings in position safely and securely. However, if this recommendation is taken, it should be noted that in the case of extremely small ratios between the bearing seat diameter and the outer diameter it is possible that the bearings loosen despite compliance with our recommendations. This can be attributed to the fact that the stresses caused by insertion can result in deformation of the plastic material. As a result of this, the bearing seat diameter becomes larger and the compression force needed to fix the bearing can no longer be maintained. This behaviour is exacerbated by high temperatures and/or flexing that occurs during operation. This can be negated to a certain extent by the securing measures described above.

**3. General information**

The basic tolerances and dimensions stated above can only be sustainably maintained under normal climatic conditions (23 °C/50% rel. humidity). If the environmental conditions differ, they must be considered by applying the respective correction factors. These can be found for the specific cases in the previous chapters.

**3.1 Dimensional and volume changes under the influence of temperature**

In general it can be said that elongation caused by temperature is approx. 0.1% per 10 K temperature change. In addition, in the case of polyamides, due to the absorption of moisture a change in volume of 0.15-0.20% per 1% water absorbed must be considered.

Considering the material-specific coefficient of elongation, the expected elongation and volume changes due to fluctuating temperatures can be calculated approximately. Hence, the expected elongation is

$$\Delta l = l \cdot \alpha \cdot (\upsilon_1 - \upsilon_2) \quad [\mathrm{mm}]$$

where

$\Delta l$ = expected elongation
$l$ = original length in mm
$\alpha$ = material-specific coefficient of elongation
$\upsilon_1$ = installation temperature in °C
$\upsilon_2$ = operating temperature in °C

The expected change in volume is calculated – with the assumption that the elongation is not hindered in any direction – from:

$$\Delta V = V \cdot \beta \cdot (\upsilon_2 - \upsilon_1) \quad [\mathrm{mm}^3]$$

and

$$\beta = 3 \cdot \alpha$$

where

$\Delta V$ = expected change in volume
$V$ = original volume in $mm^3$
$\alpha$ = material-specific coefficient of elongation
$\beta$ = material-specific coefficient of volume expansion
$\upsilon_1$ = installation temperature in °C
$\upsilon_2$ = operating temperature in °C

The material-specific coefficients of elongation can be found in Table 10.

Table 10: Linear coefficients of elongation of various plastics

| Product | Material | Coefficient of elongation $\alpha\ 10^{-5}\ .\ K^{-1}$ |
|---|---|---|
| **LiNNOTAM** | PA 6 C | 7 |
| **LiNNOTAM** CC | PA 6 C -CC | 8 |
| **LiNNOTAM***GLiDE* | PA 6 C + Oil | 7 |
| **LiNNOTAM***GLiDE PRO T* | PA 6 C + Solid lubricant | 7 |
| **LiNNOTAM***HiPERFORMANCE 612* | PA 6/12 G | 8 |
| **LiNNOTAM***HiPERFORMANCE 1200* | PA 12 G | 10 |
| Polyamide 6 | PA 6 | 9 |
| Polyamide 6 + 30% glass fibre | PA 6 C F30 | 3 |
| Polyamide 66 | PA 66 | 10 |
| Polyamide 12 | PA 12 | 12 |
| Polyacetal | POM-C | 10 |
| Polyacetal GF-filled | POM-C-GF30 | 2.5 |
| Polyethylene terephthalate | PET | 7 |
| Polyethylene terephthalate + lubricant additive | PET-GL | 8 |
| Polytetrafluoroethylene | PTFE | 19 |
| Polytetrafluoroethylene + 25% glass fibre | PTFE-GF25 | 13 |
| Polytetrafluoroethylene + 25% carbon | PTFE-K25 | 11 |
| Polytetrafluoroethylene + 40% bronze | PTFE-B40 | 10 |
| Polyethylene 500 | PE-HMW | 18 |
| Polyethylene 1000 | PE-UHMW | 18 |
| Polyetheretherketone | PEEK | 4 |
| Polyetheretherketone modified | PEEK-GL | 3 |
| Polysulfone | PSU | 6 |
| Polyetherimide | PEI | 6 |

### 3.2 Geometric shapes

The geometric relationships of a workpiece can cause changes in dimensions and shape after the machining process. Therefore, either the geometric shape has to be changed or the recommended tolerance series for workpieces with extreme geometric shape and wall thickness relationships, e.g. extreme one-sided machining, extremely thin walls, extreme wall thickness differences, must be adapted accordingly. If there is any uncertainty in regard to the definition of shape, dimension or position tolerances, we would be pleased to assist.

### 3.3 Measuring technology

It is very difficult to measure narrow tolerances in plastic workpieces, especially in thin-walled parts. The pressure exerted on the workpiece by the measuring instrument can deform the plastic part, or the low coefficient of friction of plastics can distort the starting torque of micrometre gauges. This inevitably leads to incorrect measured values. Therefore it is recommended that contactless measuring systems are used.

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