N 2555

Geometrical tolerancing

Overview

7th edition (2006-09)
Corrected and enlarged (2008-06)
4 497 017 719

BOSCH
Invented for life

N2555

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Overview

7th edition (2006-09)

Part number: 4 497 017 719

Corrected and enlarged (2008-06)

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The main costs of a product originate not only during the development but already during the construction phase. Particularly in series and mass production, tolerancing determines function and fitting properties as well as in a decisive way the production and inspection costs.
The ongoing technical development striving for higher power and efficiency, more reliability and lower environmental impacts requires complete tolerancing adapted to function, production and inspection, and tends to continuously decreasing tolerances.
The international division of labor requests that in order to avoid misinterpretations, tolerancing of components is based on international standards.
This fact has effects on the international standardization process itself. During the last years many standards have been created, supplemented or changed.

In order to assist you on your way toward the field of tolerancing based on valid international standards, and also to point out methods to achieve a cost-effective tolerancing, the N2555 brochure at hand has been completely revised and adapted to currently valid international standards.

Contents

Workpieces cannot be manufactured with a geometrically ideal form. There are not only dimensional deviations, but also deviations in form, location, orientation and run-out. Such deviations occur during the manufacturing process for example through:

- elastic deformations
- oscillations
- varying cutting speeds
- wear of tools or machines
- guidance inaccuracies
- release of residual stresses
- temporal material behavior
- temperature variations

Thus, it has to be defined which deviations from the ideal geometry are still permissible to guarantee function and compatibility of all manufactured workpieces, in particular with series and mass production.

Due to profitability reasons it always applies the following principle:

As exact as necessary, but not as exact as possible!

Compared to ISO 1101:1983 some symbols which offer enlarged tolerance definitions were included (see also table Symbols on pages 7 + 8):

Ⓛ Ⓡ Ⓕ  CZ LD MD PD LE NC ACS

Some drawing entries of geometrical tolerances became precised (see also page 19):

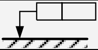
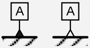
- Datums are always identified separately and specified in the tolerance frame. Tolerance frames are no longer directly connected to the datum feature.
- The indication of several interrelationships in a tolerance frame is given as a common relation or in ranking order. Because it is ambiguous, it is no longer permissible to indicate several datums without ranking order.
- For the indication of a common zone the symbol CZ has been defined. „Common zone“ or other similar indications are no more permissible.
- Geometrical tolerances and datums for axis/median plane are aligned to the dimensional arrow. Because it is ambiguous, the direct alignment to the axis/median plane is not permissible.

All other previous tolerancing possibilities remain valid and the interpretations unchanged.

6 | Symbols

Tolerance	Characteristics	Symbol	Datum	Page
Form	Straightness	⏤	no	20
	Flatness	⏥	no	21
	Roundness	○	no	22
	Cylindricity	⌭	no	22
	Profile any line	⌒	no	23
	Profile any surface	⌓	no	24
Orientation	Parallelism	//	yes	25
	Perpendicularity	⟂	yes	29
	Angularity	∠	yes	32
	Profile any line	⌒	yes	23
	Profile any surface	⌓	yes	24

Tolerance	Characteristics	Symbol	Datum	Page
Location	Position	⌖	no / yes	41
	Concentricity (for centre points)	◎	yes	35
	Coaxiality (for axes)	◎	yes	36
	Symmetry	⌯	yes	36
	Profile any line	⌒	yes	23
	Profile any surface	⌓	Yes	24
Run-out	Circular run-out, radial, axial or in any random or specified direction	↗	yes	37
	Total run-out, radial, axial	⌰	yes	40

Description	Symbol	Page
Toleranced feature indication		15
Datum feature indication		15
Datum target indication		-
Theoretically exact dimension	50	41
Projected tolerance zone	Ⓟ	16
Maximum material requirement (MMR)	Ⓜ	44
Least material requirement (LMR) *)	Ⓛ	46
Reciprocity requirement (RPR) (ISO 2692)	Ⓡ	48
Free state condition (non-rigid parts) *)	Ⓕ	17
Envelope requirement (when ISO 8015 is used)	Ⓔ	49
All around (profile)		-
Common zone *)	CZ	19
Minor diameter *)	LD	18
Major diameter *)	MD	18
Pitch diameter *)	PD	18
Line element *)	LE	27
Not convex *)	NC	17
Any cross-section *)	ACS	35

*) New in ISO 1101:2004 compared to ISO 1101:1983

Datum

Theoretically exact geometrical feature (for example axis, plane, straight line) to which toleranced features refer. May be based on one or more datum features.

Datum feature

Datums belonging to a part (for example edge, plane surface, bore) which is used for the determination of location and orientation of a feature.

Datum system

Group of several individual datums referring to the toleranced feature. The ranking order of the datums of a toleranced feature is exactly specified through their arrangement within the tolerance frame.

Datum target indication

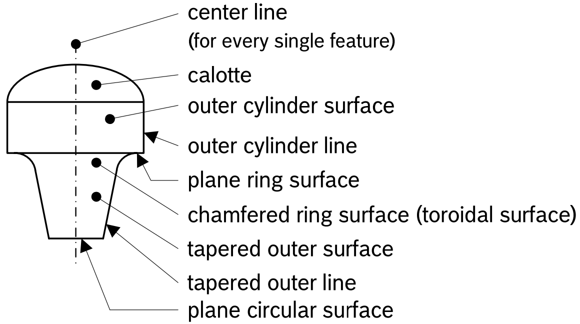
Points where the test equipment touches the workpiece (points, lines or limited surfaces) and which determine the required reference elements.

Form tolerance

Limits the deviation from the geometrically ideal form of an individual feature and determines the tolerance. The feature shall comply with this tolerance, and may have any random form.

Geometrical feature (also called form element)

Surfaces or lines on workpieces. Each workpiece consists of several individual geometrical features, for example:



Geometrical tolerance

Collective term of all tolerances of form, location, orientation and run-out, however **without** dimensional tolerances.

Envelope principle / envelope condition (DIN 7167)

Geometrical feature (cylinder or two opposite parallel surfaces) must not break through the geometrical ideal envelope with maximum material dimension.

Tolerances of location, orientation and run-out

Limits the deviation from the geometrical ideal position between two or more elements.

These tolerances are tolerances of location, orientation and run-out.

Dimensional tolerance

Difference between permissible upper and lower deviation. The dimensional tolerance is an absolute value without sign.

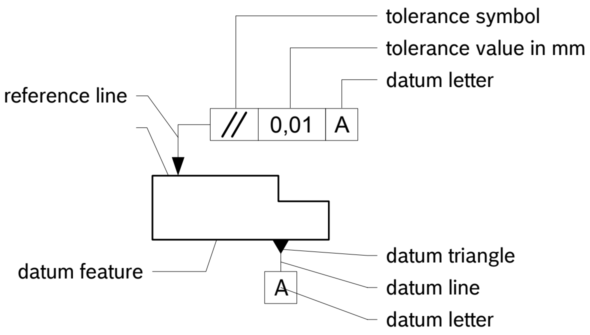
Maximum material dimension

- Maximum dimension of external dimensions (for example shafts)
- Minimum dimension of internal dimensions (for example bores)

Principle of independence (ISO 8015)

Geometrical tolerances are valid independently of the actual dimension of the form element. They do not have any mutual relationship – provided that no special interrelations or dependencies are indicated.

Other terms



12 | Correlation between dimensional tolerances and geometrical tolerances

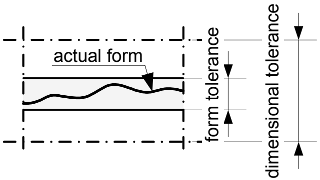
As a rule, at **Bosch** the **envelope principle** in accordance with DIN 7167 is applicable for dimensioning and tolerancing. It always applies if not specified otherwise on the drawing.
In order to avoid misinterpretations it is recommended to indicate the applicability of the envelope principle in accordance with DIN 7167 on all drawings.
Under the envelope principle the **dimensional tolerance is** limiting

- the dimensional deviation,
- all deviations in form,
- the deviation from parallelism

and

- the camming deviation.

The actual form of the toleranced feature shall be within the indicated form tolerance. The form tolerance may be at any random place within the dimensional tolerance.



The form tolerance shall always be less than or equal to the dimensional tolerance.
However, what is used for geometrical deviations, cannot be used for dimensional deviations.

The following geometrical deviations are always independent from the dimensional tolerance:

- perpendicularity deviation
- angularity deviation
- symmetry deviation
- coaxiality deviation
- concentricity deviation
- position deviation
- circular run-out deviation

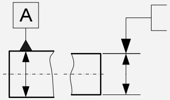
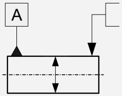
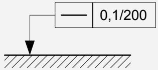
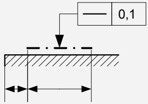
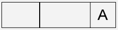
For all the above specified geometrical deviations the tolerances have to be given either as collective indication in form of general tolerances or as direct tolerance entry.
Otherwise the specification is incomplete.

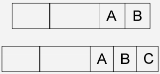
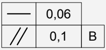
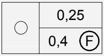
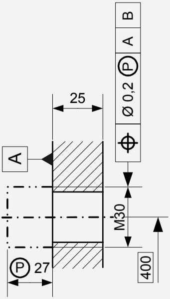
Dimensional and geometrical tolerances are given directly at the geometrical feature (for example: *H11* or *±0,1* for dimensional tolerances or | ○ | 0,05 | for roundness tolerances) or for all not directly toleranced features as collective indication using general tolerances (for example: *ISO 2768-mH* for metal-cutting parts or *DIN 16901-140* for molded plastic parts).

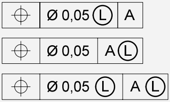
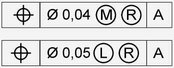
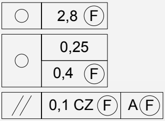
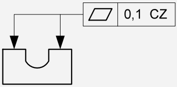
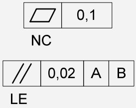
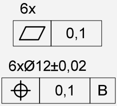
Collective indication

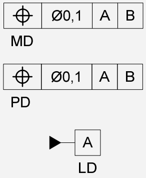
For some manufacturing procedures there are standards specifying general tolerances which are often distinguished by tolerance classes. In these cases the collective indication consists of standard number and tolerance class.

Note:
The amount of the general tolerances defined in these standards varies significantly with regard to the tolerance types. An overview of the tolerance types, each covered by standardized general tolerances can be found in this brochure, beginning at page 57.

Description	Representation
If the entry refers to the axis or the median plane, the datum arrow or the datum triangle are aligned ***onto*** the dimension line.	
If the entry refers to the surface (surface or line in any random direction), the datum arrow or the datum triangle is placed clearly ***beside*** the dimension line.	
If the tolerance is applied to a restricted length, lying anywhere within the total extent of the feature, the value of the restricted length shall be added after the tolerance value and separated from it by an oblique stroke.	
If the tolerance is applied to a restricted part of the feature only, this restriction shall be shown as a wide, long dashed-dotted line and dimensioned.	
Datum established by one feature	
Common datum established by two features	

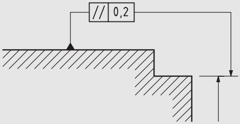
Description	Representation
Datum system established by two or three features. **A** – primary datum, **B** – secondary datum, **C** - tertiary datum	
If multiple tolerances have to be established for one datum, the tolerance frames may be stacked.	
If different conditions of a feature have to be toleranced, the tolerance frames can be stacked and the feature symbol can be indicated only once.	
The **projected tolerance zone** is shown as a narrow dash double-dotted line, the length dimensioned and the symbol Ⓟ indicated before the dimension figure. The symbol Ⓟ is additionally indicated in the tolerance frame of the toleranced feature after the tolerance value.	
The **maximum material requirement** shall be indicated by the symbol Ⓜ. The symbol Ⓜ is placed after the tolerance value or/and the datum letter.	

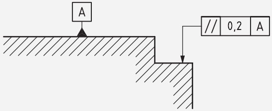
Description	Representation
The **least material requirement** shall be indicated by the symbol Ⓛ. The symbol Ⓛ shall be placed after the tolerance value or/and the datum letter.	
The **reciprocity requirement** shall be indicated by the symbol Ⓡ. It is indicated in addition to the maximum and least material requirement.	
The **free state condition** shall be indicated by the symbol Ⓕ. The symbol Ⓕ is placed after the tolerance value and/or the datum letter.	
Where a single tolerance zone is applied to several separate features, the symbol CZ (common zone) shall be indicated following the tolerance.	
Additional indications shall be placed below the tolerance frame.	
Where the tolerance applies to several features, the number and dimension shall be indicated above the tolerance frame.	

Description	Representation
Where the tolerance or the datum applies to a certain profile diameter, this shall be indicated below the frame. **Exception:** For threads the indicated pitch diameter applies, if not otherwise specified.	

Previous practice	Valid standard

Datum identification

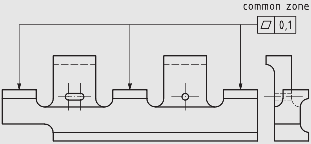


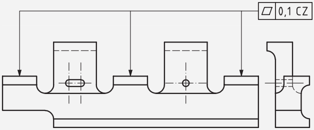


Datum system or common datum

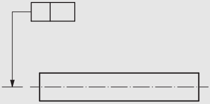
Previous practice	Valid standard
AB	A B B A A - B

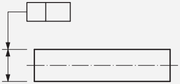
Common zone



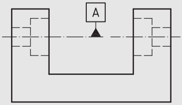


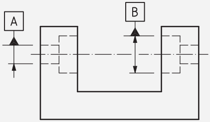
Tolerancing of axes and median planes



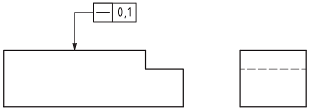
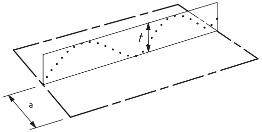


Axes and median planes applied as datum



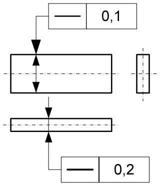
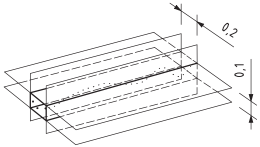


Straightness tolerance

Drawing entry	Tolerance zone
	

Any extracted line on the upper surface, parallel to the plane of projection of the toleranced representation, shall be contained between two parallel straight lines a distance *t=0,1* apart.

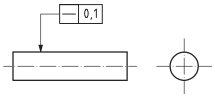
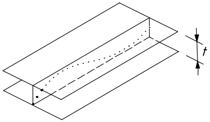
The tolerance zone, in the considered plane any distance *a* apart, is limited by two parallel straight lines a distance *t=0,1* apart and the length of the workpiece and in the specified direction only. As a rule, 3, 5 or 7 lines are considered on a surface.

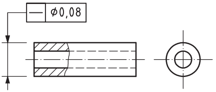
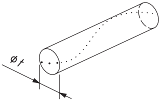
Drawing entry	Tolerance zone
	

The bar axis shall be within a rectangular parallelepiped with a height t_1=*0,1* and width t_2=*0,2*.

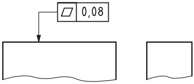
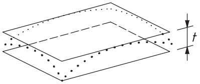
Where the tolerance is indicated in two directions vertical to each other, the tolerance zone is limited by a rectangular parallelepiped of a cross section t_1*(=0,1) x* t_2 *(=0,2)*.

Straightness tolerance (continued)

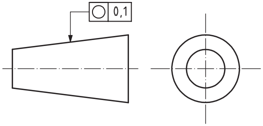
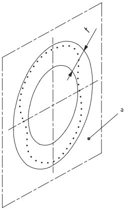
Drawing entry	Tolerance zone
	
Any extracted generating line on the cylindrical surface shall be contained between two parallel planes a distance *t=0,1* apart.	The tolerance zone is limited by two parallel planes a distance *t=0,1* apart.

Drawing entry	Tolerance zone
	
The actual axis of the toleranced cylinder shall be within a cylindrical tolerance zone of diameter *t=0,08*.	Where the tolerance value is preceded by the symbol **∅**, the tolerance zone is limited by a cylinder of diameter *t=0,08*.

Flatness tolerance

Drawing entry	Tolerance zone
	
The surface is limited by two parallel planes a distance *t=0,08* apart.	The tolerance zone is limited by two parallel planes a distance *t=0,08* apart.

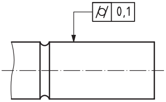
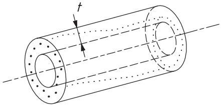
Roundness tolerance

Drawing entry	Tolerance zone
	

The circumferential line of any cross section shall be contained between two co-planar concentric circles a distance *t=0,1* apart.

The tolerance zone of the considered plane *a* is limited by two concentric circles with a difference in radii of *t=0,1*.

Cylindricity tolerance

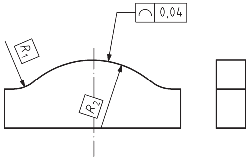
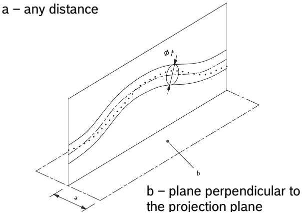
Drawing entry	Tolerance zone
	

The extracted cylindrical surface shall be contained between two coaxial cylinders with distance of *t=0,1* apart.

The tolerance zone is limited by two coaxial cylinders with a distance *t=0,1* apart.

See also Helpful hints beginning on page 49.

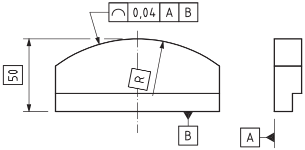
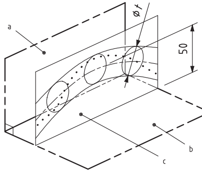
Profile tolerance - line not related to a datum

Drawing entry	Tolerance zone
	

In each section, parallel to the plane of projection, the toleranced profile shall be contained between two lines enveloping circles of diameter *t=0,04*, the centers of which are situated on a line having the theoretically exact geometrical form.

The tolerance zone is limited by two lines enveloping circles of diameter *t=0,04*, the centers of which are situated on a line having the theoretically exact geometrical form.

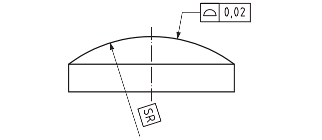
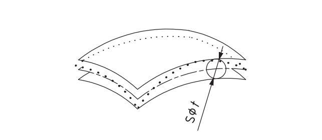
Profile tolerance - line related to a datum system

Drawing entry	Tolerance zone
	

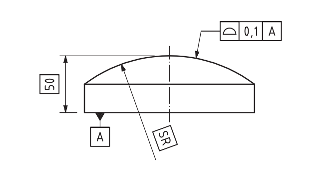
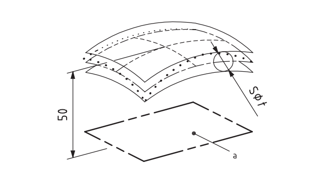
In each section, parallel to the plane of projection, the profile line shall be contained between two equidistant lines enveloping circles of diameter *t=0,04*, the centers of which are situated on a line having a theoretically exact geometrical form with respect to datum plane A and datum plane B.

The tolerance zone is limited in any plane of projection *c* by two lines enveloping circles of diameter *t=0,04* , the centers of which are situated on a line having a theoretically exact geometrical form with respect to datum plane *a* (=A) and datum plane *b* (=B).

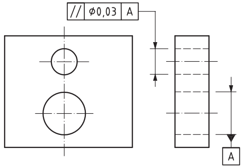
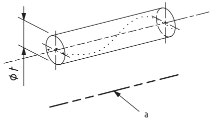
Profile tolerance - surface not related to a datum

Drawing entry	Tolerance zone
	
The extracted (actual) surface shall be contained between two equidistant surfaces enveloping spheres of diameter *t=0,02*, the centers of which are situated on a surface having a theoretically exact geometrical form.	The tolerance zone is limited by two surfaces enveloping spheres of diameter *t=0,02*, the centers of which are situated on a surface having a theoretically exact geometrical form.

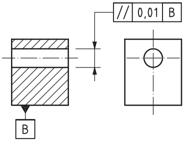
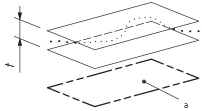
Profile tolerance - surface related to a datum

Drawing entry	Tolerance zone
	
The extracted (actual) surface shall be contained between two equidistant surfaces enveloping spheres of diameter *t=0,1*, the centers of which are situated on a surface having the theoretically exact geometrical form with respect to datum plane A.	The tolerance zone is limited by two surfaces enveloping spheres of diameter *t=0,1*, the centers of which are situated on a surface having the theoretically exact geometrical form with respect to datum plane a (=A).

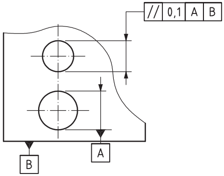
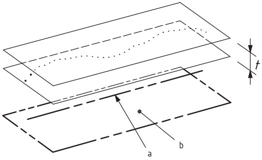
Parallelism tolerance - line related to a datum line

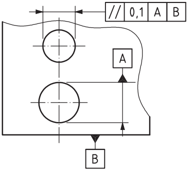
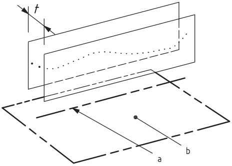
Drawing entry	Tolerance zone
	
The extracted (actual) line shall be within a cylindrical zone of diameter *t=0,03*, parallel to the datum axis A.	The tolerance zone is limited by a cylinder of diameter *t=0,03,* parallel to the datum a (=A).

Parallelism tolerance - line related to a datum surface

Drawing entry	Tolerance zone
	
The extracted (actual) median line shall be contained between two parallel planes distance *t=0,01* apart which are parallel to the datum plane B.	The tolerance zone is limited by two planes a distance *t=0,01* apart, parallel to the datum a (=B).

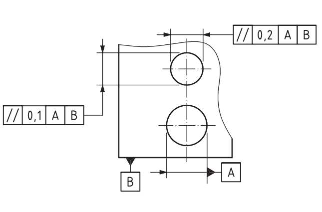
Parallelism tolerance - line related to a datum system

Drawing entry	Tolerance zone
	
The extracted (actual) median line shall be contained between two parallel planes *t=0,1* apart, which are parallel to the datum axis A, oriented with respect to datum plane B and in the direction specified.	The tolerance zone is limited by two parallel planes a distance *t=0,1* apart. The planes are parallel to the datums a (=A) and b (=B) and in the direction specified.

Drawing entry	Tolerance zone
	
The extracted (actual) median line shall be contained between two parallel planes *t=0,1* apart, which are parallel to the datum axis A, oriented with respect to datum plane B, and in the direction specified.	The tolerance zone is limited by two parallel planes a distance *t=0,1* apart. The planes are parallel to the datums a (=A) and b (=B), and in the direction specified.

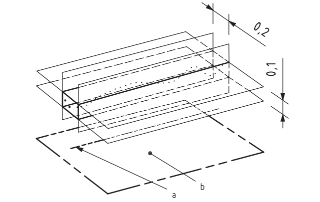
Parallelism tolerance - line related to a datum system

Drawing entry



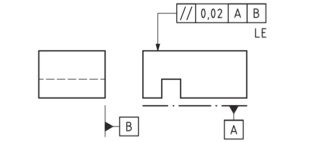
The extracted (actual) median line shall be contained between two pairs of parallel planes $t_1=0,2$ and $t_2=0,1$ respectively apart, be parallel to the datum axis A, and in the direction specified with respect to datum plane B, and perpendicular to each other.

Tolerance zone



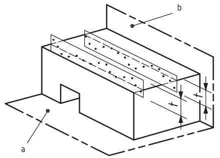
The tolerance zone is limited by two pairs of parallel planes a distance $t_1=0,2$ and $t_2=0,1$ respectively apart and perpendicular to each other. The planes are parallel to the datum axis a (=A) and in specified direction to datum plane b (=B).

Drawing entry



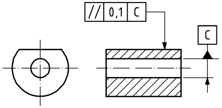
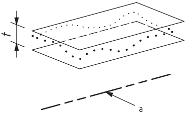
Each extracted (actual) line shall be contained between two parallel lines $t=0,02$ apart, parallel to the datum plane A and perpendicular to datum plane B.

Tolerance zone

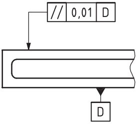
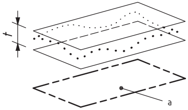


The tolerance zone is limited by two parallel lines $t=0,02$ apart, which are parallel to the datum plane a (=A) and perpendicular to datum plane b (=B).

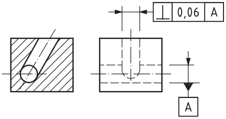
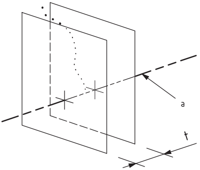
Parallelism tolerance - surface related to a datum line

Drawing entry	Tolerance zone
	
The extracted (actual) surface shall be contained between two parallel planes *t=0,1* apart which are parallel to the datum axis C.	The tolerance zone is limited by two parallel planes a distance *t=0,1* apart and parallel to the datum axis a (=C).

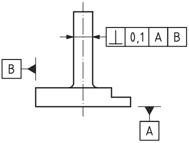
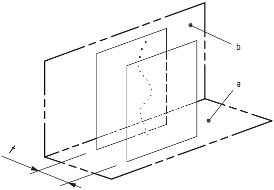
Parallelism tolerance - surface related to a datum surface

Drawing entry	Tolerance zone
	
The extracted (actual) surface shall be contained between two parallel planes *t=0,01* apart which are parallel to datum plane D.	The tolerance zone is limited by two parallel planes a (=D) distance *t=0,01* apart and parallel to the datum plane.

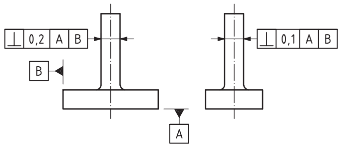
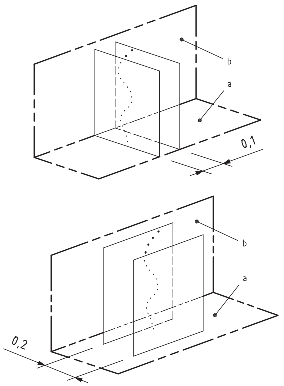
Perpendicularity tolerance - line related to a datum line

Drawing entry	Tolerance zone
	
The extracted median (actual) line of the boring shall be contained between two parallel planes *t=0,06* apart that are perpendicular to datum axis A.	The tolerance zone is limited by two parallel planes a distance *t=0,06* apart and perpendicular to datum axis a (=A).

Perpendicularity tolerance - line related to a datum system

Drawing entry	Tolerance zone
	
The extracted median (actual) line of the cylinder shall be contained between two parallel planes *t=0,1*, perpendicular to the datum plane A and in the direction specified with respect to datum plane B.	The tolerance zone is limited by two parallel planes a distance *t=0,1* apart. The planes are perpendicular to the datum a (=A) and specified in direction .

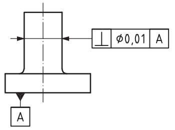
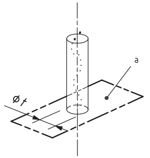
Perpendicularity tolerance – line related to a datum system

Drawing entry	Tolerance zone
	

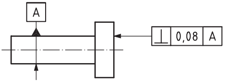
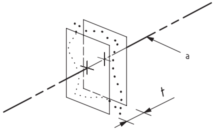
The extracted (actual) median line of the cylinder shall be contained between two pairs of parallel planes $t_1=0,2$ and $t_2=0,1$ apart. Both pairs of parallel planes shall be perpendicular to datum plane A. One pair of planes is situated parallel and the other pair perpendicular with regard to datum plane B.

The tolerance zone is limited by two pairs of parallel planes a distance $t_2=0,1$ and $t_1=0,2$ apart and perpendicular to each other. Both planes are perpendicular to the datum a (=A), one pair of planes being parallel to datum b (=B), the other pair being perpendicular to datum b (=B).

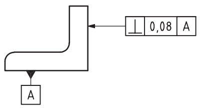
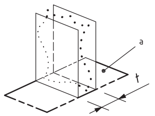
Perpendicularity tolerance - line related to a datum surface

Drawing entry	Tolerance zone
	
The extracted (actual) median line of the cylinder shall be within a cylindrical zone of diameter *t=0,01* perpendicular to datum plane A.	The tolerance zone is limited by a cylinder of diameter *t=0,01* perpendicular to the datum a (=A).

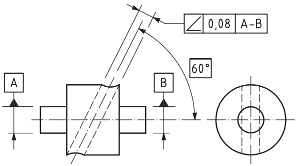
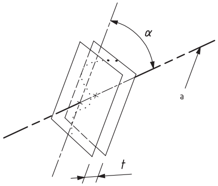
Perpendicularity tolerance - surface related to a datum line

Drawing entry	Tolerance zone
	
The extracted (actual) surface shall be contained between two parallel planes *t=0,08* apart that are perpendicular to datum axis A.	The tolerance zone is limited by two parallel planes a distance *t=0,08* apart and perpendicular to the datum axis a (=A).

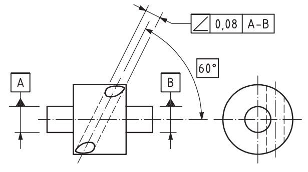
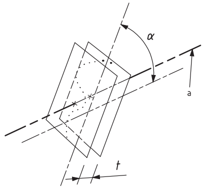
Perpendicularity tolerance - surface related to a datum surface

Drawing entry	Tolerance zone
	
The extracted (actual) surface shall be contained between two parallel planes *t=0,08* apart that are perpendicular to datum plane A.	The tolerance zone is limited by two parallel planes a distance *t=0,08* apart and perpendicular to the datum a (=A).

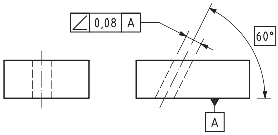
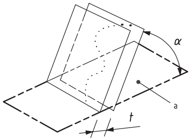
Angularity tolerance – line related to a datum line

Drawing entry	Tolerance zone
	
Line and datum line are in the same plane: The extracted (actual) median line shall be contained between two parallel planes *t=0,08* apart that are inclined with a theoretically exact angle of 60° toward the common datum axis A-B.	The tolerance zone is limited by two parallel planes a distance *t=0,08* apart and inclined with the specified angle to the datum axis a (=A-B).

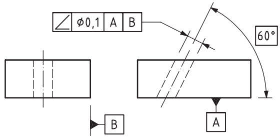
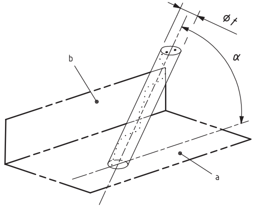
Angularity tolerance – line related to a datum line

Drawing entry	Tolerance zone
	
Line and datum line are not in the same plane: The extracted (actual) median line shall be contained between two parallel planes *t=0,08* apart that are inclined with a theoretically exact angle of 60° toward the common datum axis A-B.	The tolerance zone is limited by two parallel planes a distance *t=0,08* apart and inclined with the specified angle to the datum axis a (=A-B). The considered line and the datum line are not in the same plane.

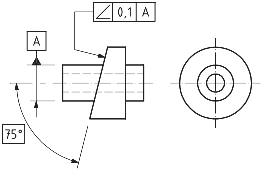
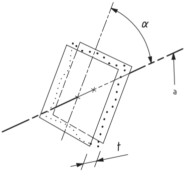
Angularity tolerance – line related to a datum surface

Drawing entry	Tolerance zone
	
The extracted (actual) median line shall be contained between two parallel planes *t=0,08* apart that are inclined with a theoretically exact angle of 60° to the datum plane A.	The tolerance zone is limited by two parallel planes a distance *t=0,08* apart and inclined with the specified angle to the datum plane a (=A).

Angularity tolerance – line related to a datum system

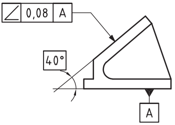
Drawing entry	Tolerance zone
	
The extracted (actual) median line shall be within a cylindrical tolerance zone of diameter *t=0,1* that is parallel to datum plane B and inclined at a theoretically exact angle of 60° to datum plane A.	The tolerance zone is limited by a cylinder of diameter *t=0,1*. The cylindrical tolerance zone is parallel to a datum plane b (=B) and inclined toward the specified angle to the datum plane a (=A).

Angularity tolerance – surface related to a datum line

Drawing entry	Tolerance zone
	
The extracted (actual) surface shall be contained between two parallel planes *t=0,1* apart that are inclined with a theoretically exact angle of 75° to the datum axis A.	The tolerance zone is limited by two planes a distance *t=0,1* apart and inclined with the specified angle to the datum a (=A).

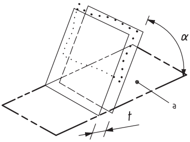
Angularity tolerance – surface related to a datum surface

Drawing entry



The extracted (actual) surface shall be contained between two parallel planes *t=0,08* apart that are inclined with a theoretically exact angle of 40° to the datum plane A.

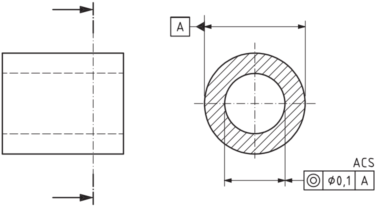
Tolerance zone



The tolerance zone is limited by two planes a distance *t=0,08* apart and inclined with the specified angle to the datum a (=A).

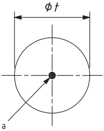
Concentricity of a point

Drawing entry



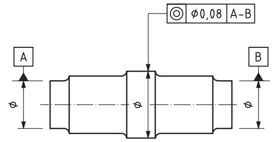
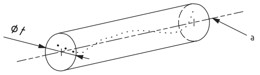
Within a circle of diameter t=0,1 the extracted (actual) center of the bore shall be concentric with any random cross section to the datum point A .

Tolerance zone

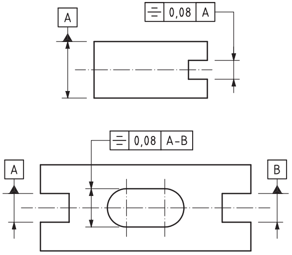
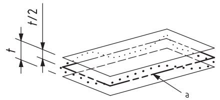


The tolerance zone is limited by a circle of diameter *t=0,1*. The centre of the circular tolerance coincides in any random cross section with the datum point a (=A).

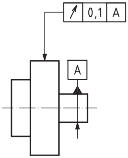
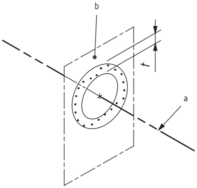
Coaxiality tolerance of an axis

Drawing entry	Tolerance zone
	
The extracted (actual) median line of the large cylinder shall be within a cylindrical zone of diameter *t=0,08* the axis of which is the common datum axis A-B.	The tolerance zone is limited by a cylinder of diameter *t=0,08*. The axis of the cylindrical tolerance zone coincides with the datum axis a (=A-B).

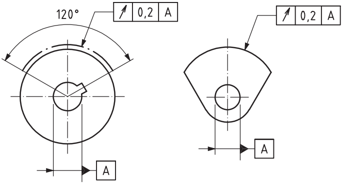
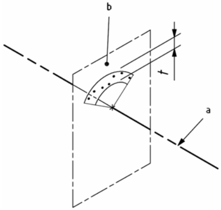
Symmetry tolerance of a median plane

Drawing entry	Tolerance zone
	
The extracted (actual) median surface shall be contained between two parallel planes *t=0,08* apart which are symmetrically disposed about the datum median plane A or A-B.	The tolerance zone is limited by two planes *t=0,08* apart, symmetrically disposed about the median plane with respect to the datum median plane a (=A or A-B).

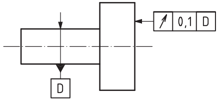
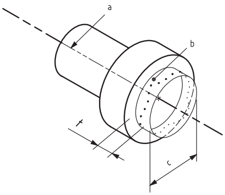
Circular run-out tolerance - radial (circular run-out)

Drawing entry	Tolerance zone
	
The extracted (actual) line in any cross-section plane perpendicular to datum axis A shall be contained between two coplanar concentric circles with a difference in radii of 0,1.	The tolerance zone is limited in any cross-section b perpendicular to the datum axis a (=A) by two concentric circles with a difference in radii of t=0,1, the centers of which coincides with the datum axis a (=A).

Circular run-out tolerance – radial, partial (circular run-out)

Drawing entry	Tolerance zone
	
The extracted (actual) line in any cross-section plane perpendicular to the datum axis A shall be contained between two coplanar concentric circles with a difference in radii of t=0,2.	Run-out tolerance usually applies to complete features, but could be applied to a restricted part of a feature.

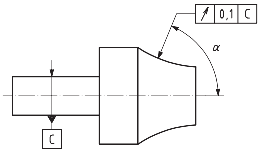
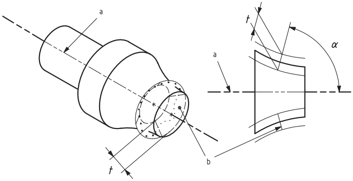
Circular run-out tolerance – axial (axial run-out)

Drawing entry	Tolerance zone
	

The extracted (actual) line, in any cylindrical section, the axis of which coincides with datum axis D, shall be contained between two circles with a distance *t=0,1*.

The axial tolerance zone b of the plane surface is limited to a distance t=0,1 for any random diameter c, the axis of which coincides with the datum axis a (=D).

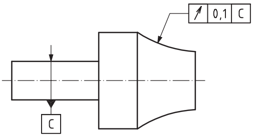
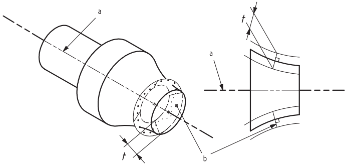
Circular run-out tolerance – specified direction

Drawing entry	Tolerance zone
	

The extracted (actual) line in any conical section (angle α), the axis of which coincides with datum axis C, shall be contained between two circles at a distance of *t=0,1* apart .

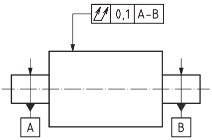
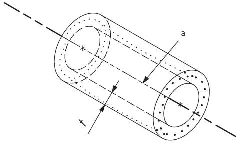
The tolerance zone b is limited within any conical section of the specified angle α by two circles a distance *t=0,1* apart, the axis of which coincides with the datum a (=C) .

Circular run-out tolerance – perpendicular to geometry

Drawing entry	Tolerance zone
	
The extracted (actual) line in any conical section, the axis of which coincides with the datum axis C, shall be contained between two circles within the conical section with a distance of *t=0,1*. When the generator line for the toleranced feature is not straight, the apex angle of the conical section will change depending on the actual position.	The tolerance zone b is limited in any conical section by two circles a distance *t=0,1* apart, the axes of which coincide with the datum axis a (=C). The width of the tolerance zone is normal to the specified geometry unless otherwise specified.

This tolerance demand requires high measuring efforts and shall therefore absolutely be avoided!

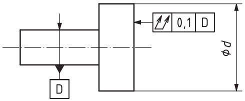
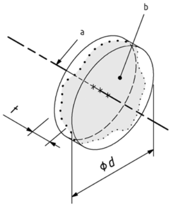
Total run-out tolerance

Drawing entry	Tolerance zone
	

The extracted (actual) surface shall be contained between two coaxial cylinders with a difference in radii of *t=0,1* and the axes coincident with the common datum axis A-B

The tolerance zone is limited by two coaxial cylinders with a difference in radii of *t=0,1*, the axes of which coincide with the datum axis a (=A-B).

Total axial run-out tolerance

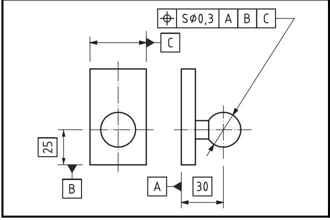
Drawing entry	Tolerance zone
	

The extracted (actual) surface (b) shall be contained between two parallel planes *t=0,1* apart which are perpendicular to datum axis D.

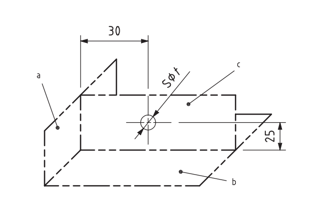
The tolerance zone is limited by two parallel planes a distance *t=0,1* apart and perpendicular to the datum axis a (=D).

Position tolerance of a point

Drawing entry



Tolerance zone

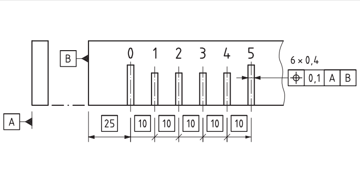


The extracted (actual) center of the sphere shall be within a spherical zone of diameter *t=0,3*, the center of which coincides with the theoretically exact position of the sphere, with respect to datums A, B, C.

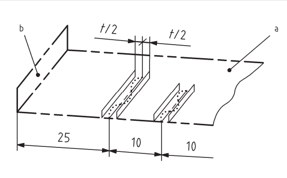
The tolerance zone is limited by a sphere of diameter *t=0,3* . The center of the spherical tolerance zone is fixed by theoretically exact dimensions with respect to the datums a (=A), b (=B) and c (=C).

Position tolerance of a line

Drawing entry



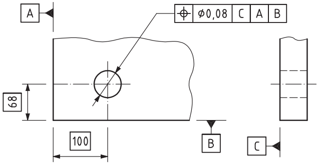
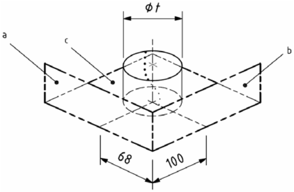
Tolerance zone



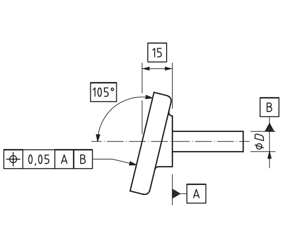
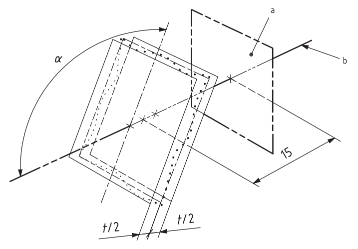
The extract (actual) median line of each of the scribe lines shall be contained between two parallel planes *t=0,1* apart that are symmetrically disposed about the theoretically exact position of the considered line, with respect to datum plane A and B.

The tolerance zone is limited by two parallel planes a distance *t=0,1* apart and symmetrically disposed about the center line. The center line is fixed by theoretically exact dimensions with respect to datums a (=A) and b (=B).

Position tolerance of a line

Drawing entry	Tolerance zone
	
The extracted (actual) median line shall be within a cylindrical tolerance zone of diameter *t=0,08*, the axis of which coincides with the theoretically exact position of the considered hole with respect to datum planes C, A and B.	The tolerance zone is limited by a cylinder of diameter *t=0,08*. The axis of the tolerance cylinder is fixed by the theoretically exact dimension with respect to the datums c (=C), a (=A), and b (=B).

Position tolerance of a flat surface or a median plane

Drawing entry	Tolerance zone
	

The extracted (actual) surface shall be contained between two parallel planes *t=0,05* apart that are symmetrically disposed about the theoretically exact position of the toleranced surface, with respect to datum plane A and datum axis B.

The tolerance zone is limited by two parallel planes a distance *t=0,05*apart and symmetrically disposed about the geometrically exact position fixed by theoretically exact dimensions with respect to datums a (=A) and b (=B).

The **maximum material requirement** is a tolerancing principle for axes and symmetrical surfaces which, by applying the symbol, Ⓜ considers the reciprocal dependency between dimensional tolerance and geometrical tolerances. It allows to enlarge the geometrical tolerance by the not used portion of the dimensional tolerance, provided that the geometrical feature does not break through the maximum material condition.

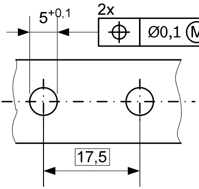
When boring a hole in a plate it applies:
If the diameter of the bore is larger than the maximum material requirement, its position may deviate by the same measure without impeding the fitting.

The maximum material requirement can be applied for the toleranced feature as well as for the datum feature or for both.

The maximum material requirement is preferred for positional tolerancing.

The maximum material requirement shall always be applied if the function of the part allows for it.

Example:



Explanation:

1. If both bores correspond to the maximum material dimension (diameter 5 mm), their axes shall be positioned in a tolerance cylinder of diameter 0,1 mm. The axes of the tolerance cylinder are at the theoretically exact position.
2. If the diameter of a bore exceeds 5,0 mm, the tolerance cylinder of this bore shall be larger by the distance that the bore diameter is apart from the maximum material size.
3. If the diameter of a bore is 5,1 mm, the diameter of the tolerance cylinder may be 0,2 mm. This corresponds to the sum of diameter tolerance and position tolerance.

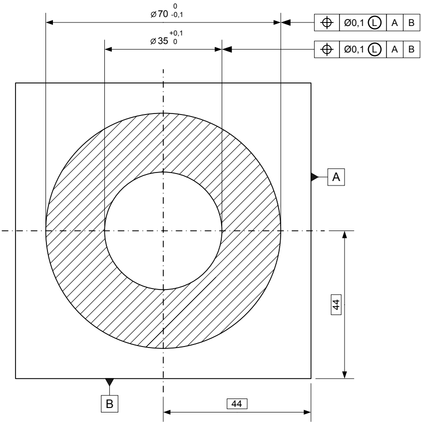
The **least material requirement** is a tolerancing principle for axes and symmetrical surfaces which, by applying the symbol Ⓛ , considers the reciprocal dependency between dimensional tolerance and geometrical tolerances. It allows to enlarge the geometrical tolerance by the not used part of the dimensional tolerance, provided that the geometrical feature does not break the least material condition.

When boring a hole in a plate it applies:
If the diameter of the bore is smaller than the least material requirement its position may deviate by the same dimension without breaking the minimum wall thickness.

The least material requirement can be applied for the toleranced feature as well as for the datum feature or for both.
It is preferred for the positional and coaxiality tolerancing in order to assure for example a minimum wall thickness or machining allowances.

The least material requirement shall always be applied if the function of the part allow for it.

Example: Assuring the minimum wall thickness s_{min}



Explanation:

1. With least material size (∅69,9 and ∅35,1) the position tolerance can be always 0,1 mm. The minimum wall thickness is calculated by:

$$s_{min} = \left(\frac{69{,}9}{2} - \frac{35{,}1}{2}\right) - 0{,}1 = 17{,}3$$

2. With the maximum material size (∅70 and ∅35) the position tolerance can be 0,2 mm in both cases (sum of positional tolerance and dimensional tolerance). The minimum wall thickness is calculated by:

$$s_{min} = \left(\frac{70}{2} - \frac{35}{2}\right) - 0{,}2 = 17{,}3$$

The **reciprocity requirement** is an additional requirement to the maximum material requirement Ⓜ or least material requirement Ⓛ and accompanied by the symbol Ⓡ. This requirement makes it possible to apply not used tolerance fractions for geometrical deviations and enlarge the respective dimensional tolerance.

In case of the **maximum material requirement** it means to enlarge the dimensional tolerance by the fraction not used for geometrical tolerancing. The least material size must not be reduced.

In case of the **least material requirement** it means also to enlarge the dimensional tolerance by the fraction not used for geometrical tolerancing. The maximum material size must not be exceeded.

The **reciprocity requirement** must only be applied to the toleranced feature.

The reciprocity requirement shall always be applied if the function of the part allows for it.

Tolerancing principle

To avoid misinterpretations please indicate on all drawings the tolerance principle for:

- the envelope principle:

tolerancing principle DIN 7167

- the principle of independency:

tolerancing principle ISO 8015 (or *DIN ISO 8015*)

The symbol Ⓔ is used only in drawings to which the principle of independency in accordance with ISO 8015 applies. It shall be indicated in the drawing explicitly for all dimensions respectively.

Complete specification

Indicate only the geometrical tolerances which are absolutely required, that is as a rule only for features that are relevant for function. For all other features the general tolerances which are on the drawing as collective indication apply. Please note that not for each manufacturing method general tolerances are specified for all geometrical deviations (cf. pages 57ff).

Datum feature / datum systems

Select the features on which depends the location and orientation of the component in mounted condition. If possible, use the same features for production and inspection.

The datum features shall be toleranced among each other, being this tolerance smaller than the smallest tolerance referring to it. It shall be controlled if the form of the datum features has to be toleranced too.
If possible, datums that have been specified once shall be maintained for all tolerances of location, orientation and run-out. This applies in particular to the primary datum.

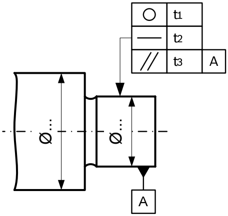
Avoid cylindricity tolerances

Cylindricity tolerances can hardly be comprehended and interpreted.
Avoid to indicate cylindricity tolerances and instead indicate tolerances for

- **roundness**
- **straightness**

  and
- **parallelism** of the generating lines.

Doing so, it is possible to identify reasons for exceeding the tolerances and to take effective countermeasures.



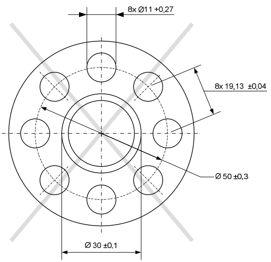
Position tolerances instead of dimensional tolerances

Apply position tolerances instead of dimensional tolerances. Advantages and/or gains in tolerance are for example:

- complete and unique tolerancing corresponding to function and requirements
- replaces several geometrical tolerances
- position tolerances applying to the whole length of the toleranced feature
- simple tolerance calculation
- with theoretically exact dimensions no tolerance accumulation for chain dimensions
- possibilities to utilize cylindrical instead of parallel-epiped tolerance zones
- the most simple possibility when applying the maximum or least material requirement
- the possibility to apply the projected tolerance zone

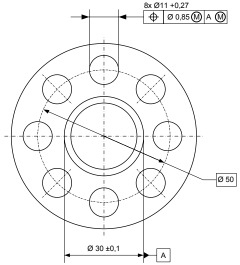
not function-adapted:

dimensional tolerancing



function-adapted:

positional tolerancing

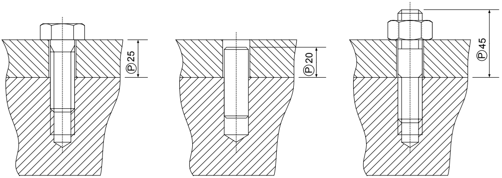


Avoid coaxiality tolerances

Avoid to indicate coaxiality tolerances and use tolerances for **circular run-out** and/or **total circular run-out** instead. This facilitates quality inspection.

Apply projected tolerance zones

Apply and indicate the **projected tolerance zone** for bolted joints in order to assure the compatibility.



Apply the maximum material requirement (MMR)

Apply the **maximum material condition**Ⓜ to profit by the not used portion of the dimensional tolerance for geometrical deviations that exceed the specified geometrical tolerances. Make sure if the total tolerance can be given as dimensional tolerance and the geometrical tolerance as "0 Ⓜ" This means functional safety by highly flexible tolerance demands.

Apply the least material requirement (LMR)

Apply the **least material condition** Ⓛ to assure minimum wall thicknesses. Always both features forming the wall thickness have to be toleranced.

Apply the **least material condition** Ⓛ to profit by the not used portion of the dimensional tolerance for geometrical deviations that exceed the specified geometrical tolerance.

Make sure if the total tolerance can be given as dimensional tolerance and the geometrical tolerance as "0 Ⓛ" This means functional safety by highly flexible tolerance demands.

Reciprocity requirement (RpR)

The **reciprocity requirement** Ⓡ is a supplement to Ⓜ and Ⓛ and allows that the dimensional tolerance being interrelated with the respective geometrical tolerance may be exceeded if the geometrical tolerance had not completely be used.

Original drawing with tolerancing principle

If you often have to design similar parts, create an **original drawing** on the basis of approved dimensioning and tolerancing. This original drawing shall be agreed with authorities in production and quality inspection. If such similar parts occur repeatedly, you may create a constructional catalog containing agreed and approved solutions.

In **series production** the following values for geometrical tolerances can be met without taking specific measures.[1]

In material removing production the values apply to production with one clamping, i.e. without re-clamping.

mm

Flatness tolerance						
Length[2] Over	**To**	**Lap-ping**	**Grinding**	**Milling**	**Tur-ning**	**Leveling**
	10	0,002	0,005	0,015	0,02	0,04
10	25	0,004	0,015	0,03	0,04	0,08
25	50	0,006	0,03	0,045	0,08	0,16
50	120	0,01	0,05	0,06	0,12	0,28
120	250	0,012	0,06	0,07	0,14	0,36

[1] Extract of N13 A21/3:1996-04

[2] Maximum length of the machined element

mm

Parallelism tolerance

Length[1] Over	To	Turning	Milling	Grinding	Pressed insulation parts
	10	0,03	0,05	0,01	0,06
10	25	0,05	0,05	0,02	0,1
25	50	0,1	0,1	0,05	0,2
50	120	0,1	0,15	0,08	0,2
120	250	0,15	0,2	0,1	0,3

mm

Roundness tolerance

Diameter		Turning		Grinding	
Over	To	between centers	in chuck/ in tongs	between centers	w/o centers/ in chuck/ in tongs
	10	0,003	0,005	0,002	0,003
10	50	0,005	0,015	0,002	0,005
50	120	0,008	0,03	0,003	0,008
120	250	0,01	0,05	0,005	0,01

[1] Maximum length of the machined element

mm

Cylindricity tolerance

Length[1] Over	To	Shafts Turning	Shafts Grinding	Holes Turning	Holes Grinding
	50	0,01	0,003	0,02	0,003
50	120	0,02	0,005	0,03	0,005
120	250	0,04	0,008	0,05	0,008
250	500	0,05	0,01	-	-

mm

Circular and run-out tolerance

Diameter Over	To	Turning between centers	Turning in chuck/ in tongs	Grinding between centers	Grinding w/o centers/ in chuck/ in tongs
	6	0,03	0,05	0,005	0,03
6	10	0,05	0,08	0,01	0,05
10	50	0,08	0,1	0,015	0,1
50	120	0,1	0,15	0,02	0,15
120	250	0,15	0,2	0,025	0,2

[1] Maximum length of the machined element

Document	Linear	Roundings	Angular	Straightness	Flatness	Roundness	Cylindrical form	Parallelism	Perpendicularity	Symmetry	Coaxiality	Run-out	Position	Angularity
Material-removing and reshaping														
ISO 2768-1: 1989 Gen. tolerances for linear and angular dimensions	X	X	X											
ISO 2768-2:1989 Gen. tolerances; Geometrical tolerances				X	X	X	X	X	X	X	X	X		
DIN 6930-2:1989 Steel stamping	X	X	X	X						X	X			
DIN 6935:1975 (hist.) Cold bending		X	X											

Document	Linear	Roundings	Angular	Straightness	Flatness	Roundness	Cylindrical form	Parallelism	Perpendicularity	Symmetry	Coaxiality	Run-out	Position	Angularity
EN 10243-1:1999 Steel die forgings – Tolerances on dimensions – Part 1: Drop and vertical press forgings	X	X			X	X	X	X						X
EN 10243-2:1999 Steel die forgings – Tolerances on dimensions – Part 2: Upset forgings made on horizontal forging machines	X	X			X	X	X	X						X

Document	Linear	Roundings	Angular	Straightness	Flatness	Roundness	Cylindrical form	Parallelism	Perpendicularity	Symmetry	Coaxiality	Run-out	Position	Angularity
Welding and thermal cutting														
ISO 9013:2002 Classification of thermal cuts	X								X					X
ISO 13920: 1996 General tolerances for welded constructions	X		X	X	X			X						
Rough castings														
DIN 1680-2:1980 Rough castings; Gen. tolerance system	X													

Document	Linear	Roundings	Angular	Straightness	Flatness	Roundness	Cylindrical form	Parallelism	Perpendicularity	Symmetry	Coaxiality	Run-out	Position	Angularity
DIN 1683-1:1998 Cast steel	X	X		In accordance with DIN 1680-1:1980 the geometrically exact envelopes of the maximum and least material dimension must not be broken.										
DIN 1684-1:1998 Malleable cast iron	X	X												
DIN 1685-1:1998 Cast iron with nodular graphite	X	X												
DIN 1686-1:1998 Cast iron with lamellar graphite	X	X												
DIN 1687-1:1998 Heavy metal alloys; sand moldings	X	X												
DIN 1687-3:1980 Heavy metal alloys; permanent mold casting	X	X												

Document	Linear	Roundings	Angular	Straightness	Flatness	Roundness	Cylindrical form	Parallelism	Perpendicularity	Symmetry	Coaxiality	Run-out	Position	Angularity
DIN 1687-4:1986 Heavy metal alloys; pressure die casting	X	X		In accordance with DIN 1680-1:1980 the geometrically exact envelopes of the maximum and least material dimension must not be broken.										
DIN 1688-1:1998 Light metal alloys; sand moldings	X	X												
DIN 1688-3:1980 Light metal alloys; permanent mold casting	X	X												
DIN 1688-4:1986 Light metal alloys; pressure die casting	X	X												
ISO 8062-3: 2007 Tolerances for moulded parts	X			X	X	X		X	X	X	X			

Document	Linear	Roundings	Angular	Straightness	Flatness	Roundness	Cylindrical form	Parallelism	Perpendicularity	Symmetry	Coaxiality	Run-out	Position	Angularity
Rubber and plastic														
DIN 7715-1:1977 Rubber products, ebonite products	X													
DIN 7715-5:1979 Soft rubber	X													
DIN 16901:1982 Molded plastic parts	X	X		In accordance with ISO 2768-2 for molded parts with or without material removing										
DIN 16941:1986 Thermoplastics extruded profiles	X	X	X	X				X						

Document	Linear	Roundings	Angular	Straightness	Flatness	Roundness	Cylindrical form	Parallelism	Perpendicularity	Symmetry	Coaxiality	Run-out	Position	Angularity
ISO 1307:2006 Rubber and plastics hoses	X													
ISO 3302-1:1996 Rubber products; Dimensional tolerances	X													
ISO 3302-2:1998 Rubber products; Form tolerances					X			X	X		X		X	
Other standards														
DIN 40680-1:1983 Ceramic components f. electrical purposes	X													
DIN 40680-2:1983 Ceramic components f. electrical purposes				X	X		X							

Number[1]	Year	Title
DIN 7167	1987	Relationship between tolerances of size, form, and parallelism; envelope requirement without individual indication on the drawing
DIN 30630	2008	Technical drawings - General tolerances in mechanical engineering - Tolerance rules and general plan
ISO 1101	2004	Geometrical Product Specifications (GPS) - geometrical tolerancing - tolerances of form, orientation, location and run-out
ISO 1660	1987	Technical drawings – dimensioning and tolerancing of profiles
ISO 2692	2006	Geometrical product specifications (GPS) - geometrical tolerancing - maximum material requirement (MMR), least material requirement (LMR) and reciprocity requirement (RPR)

[1] For all listed ISO standards corresponding DIN standards with identical numbers (DIN ISO ... or DIN EN ISO ...) are available.

Number[1]	Year	Title
ISO 3040	1990	Technical drawings; Dimensioning and tolerancing; Cones
ISO 5458	1998	Geometrical product specifications (GPS) - geometrical tolerancing - positional tolerancing
ISO 5459	1981	Technical drawings; geometrical tolerancing; datums and datum-systems for geometrical tolerances
ISO 7083	1983	Technical drawings; symbols for geometrical tolerancing; proportions and dimensions
ISO 8015	1985	Technical drawings; fundamental tolerancing principle (principle of independency)
ISO 10578	1992	Technical drawings; tolerancing of orientation and location; projected tolerance zone
ISO 10579	1993	Technical drawings; dimensioning and tolerancing; non-rigid parts
ISO 14660-1:	1999	Geometrical Product Specifications (GPS) - geometrical features - Part 1: General terms and definitions

Number[1]	Year	Title
ISO 14660-2:	1999	Geometrical Product Specifications (GPS) - geometrical features - Part 2: Extracted median line of a cylinder and a cone, extracted median surface, local size of an extracted feature
ISO/TR 16570	2004	Geometrical product specification (GPS) – linear and angular dimensioning and tolerancing: ± limit specifications – Step dimensions, distances, angular sizes and radii
ISO/TS 12180-1	2003	Geometrical Product Specifications (GPS) - cylindricity - Part 1: Vocabulary and parameters of cylindrical form
ISO/TS 12180-2	2003	Geometrical Product Specifications (GPS) - cylindricity - Part 2: Specification operators
ISO/TS 12181-1	2003	Geometrical Product Specifications (GPS) - roundness - Part 1: Vocabulary and parameters of roundness
ISO/TS 12181-2	2003	Geometrical Product Specifications (GPS) - roundness - Part 2: Specification operators

Number[1]	Year	Title
ISO/TS 12780-1	2003	Geometrical Product Specifications (GPS) – straightness - Part 1: Vocabulary and parameters of straightness
ISO/TS 12780-2	2003	Geometrical Product Specifications (GPS) – Straightness – Part 2: Specification operators
ISO/TS 12781-1	2003	Geometrical Product Specifications (GPS) - flatness - Part 1: Vocabulary and parameters of roundness
ISO/TS 12781-2	2003	Geometrical Product Specifications (GPS) - flatness - Part 2: Specification operators

Author	Title
Henzold, Georg	DIN Normenheft 7; Anwendung der Normen über Form- und Lagetoleranzen in der Praxis – Beuth 2002
Henzold, Georg	Beuth-Kommentare; Form und Lage – Beuth 1999
Henzold, Georg	Examples of Geometrical Tolerancing (Bosch GlobalNet ► Organization ► Corporate Departments ► C/CT ► Organization ► C/CTN ► Topics ► Examples of Geometrical Tolerancing)
Aberle / Brinkmann / Müller	Beuth-Kommentare; Prüfverfahren für Form- und Lageabweichungen – Beuth 1990
Jorden, Walter	Form- und Lagetoleranzen, Handbuch für Studium und Praxis – Hanser 2008
Trumpold / Beck / Richter	Toleranzsysteme und Toleranzdesign, Qualität im Austauschbau – Hanser 1997

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