BS 4500:2009

BSI British Standards

Limits and fits – Guidance for system of cone (taper) fits and tolerances for cones from C = 1:3 to 1:500, lengths from 6 mm to 630 mm and diameters up to 500 mm

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Contents

List of tables

Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 42, an inside back cover and a back cover.

Foreword

Publishing information

This British Standard is published by BSI and came into effect on 30 September 2009. It was prepared by Technical Committee TDW/4, *Technical product realization*. A list of organizations represented on this committee can be obtained on request to its secretary.

Supersession

This British Standard supersedes BS 4500-4:1985 and BS 4500-5:1988, which are withdrawn.

Relationship with other publications

This British Standard is derived from the ISO 286 (BS EN 20286) series, which establishes the ISO code-system for tolerances of linear sizes and is published in the following parts:

- ISO 286-1 (BS EN 20286-1), *ISO system of limits and fits – Part 1: Bases of tolerances, deviations and fits*;
- ISO 286-2 (BS EN 20286-2), *ISO system of limits and fits – Part 2: Tables of standard tolerance grades and limit deviations for holes and shafts*.

The ISO 286 series covers the metric system of limits and fits and replaced the original national limits and fits standard BS 4500-1:1969.

The BS 1916 series provides guidance and recommendations on the equivalent inch system (imperial) of limits and fits and is published in the following parts:

- BS 1916-1, *Limits and fits for engineering – Part 1: Guide to limits and tolerances*;
- BS 1916-2, *Limits and fits for engineering – Part 2: Guide to the selection of fits in BS 1916-1*;
- BS 1916-3, *Limits and fits for engineering – Part 3: Guide to tolerances, limits and fits for large diameters*.

This British Standard complements BS EN ISO 1119, *Geometrical product specifications (GPS) – Series of conical tapers and taper angles*.

Information about this document

In view of the time elapsed since the publication of BS 4500-4 in 1985 and BS 4500-5 in 1988, these British Standards were reviewed in detail in 2009 and amalgamated into one Standard. It was decided that the technical provisions of the previous editions were still generally applicable but the figures have been redrawn for ease of use, the wording of some guidance updated for clarity, and the opportunity was taken to update references to other standards.

Use of this document

As a guide, this British Standard takes the form of guidance and recommendations. It should not be quoted as if it were a specification or a code of practice and claims of compliance cannot be made to it.

Contractual and legal considerations

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard cannot confer immunity from legal obligations.

Section 1: General

1 Scope

This British Standard gives guidance on a system of cone fits and tolerances for cones from C = 1:3 to 1:500 and lengths from 6 mm to 630 mm.

The appropriate tolerances of this British Standard can also be used for prismatic workpieces, for example wedges.

This British Standard applies to cones which are dimensioned and toleranced according to BS ISO 3040, Method 1, Basic Taper method. This means that the tolerances limit the variation of penetration of mating surfaces, each surface being within two limiting profiles of the same taper corresponding to the maximum material condition (MMC) and the least material condition (LMC).

This British Standard is derived from BS EN 20286, and is a complement to BS EN ISO 1119.

NOTE For dimensioning and tolerancing cones on drawings, see BS ISO 3040.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

BS EN 20286-1, *ISO system of limits and fits – Part 1: Bases of tolerances, deviations and fits*

3 Terms and definitions

For the purposes of this British Standard, the terms and definitions used for cylindrical fits given in BS EN 20286-1 and the following apply.

3.1 cones

3.1.1 actual cone
cone, the conical surface of which has been found by measurement

NOTE See Figure 1.

3.1.2 basic cone
geometrically ideal conical surface which is given by its geometrical dimensions

NOTE These dimensions are either: a basic cone diameter, the basic cone length and the basic rate of taper or the basic cone angle; or two basic cone diameters and the basic cone length. See Figure 2.

3.1.3 cone
conical surface or conical workpiece, defined by its geometrical dimensions

NOTE See Figure 3. In the absence of any indication concerning the geometrical form, "cone" is understood to mean a straight circular cone or truncated cone.

3.1.4 conical surface
surface of revolution formed by rotating a straight line (generator) around an axis with the straight line intersecting this axis at the apex

NOTE See Figure 3. The parts of this infinite conical surface are also known as conical surfaces or cones. Similarly, "cone" is also the abbreviated designation of a truncated cone.

3.1.5 conical workpiece
workpiece or portion of a workpiece the main part of which is a conical surface

NOTE See Figure 4 and Figure 5.

3.1.6 external cone
cone which limits the outside form of a conical feature of a workpiece

NOTE See Figure 4 and Figure 6.

3.1.7 generator
line of intersection of the conical surface with a section in the axial plane

NOTE See Figure 3 and Figure 6.

3.1.8 internal cone
cone which limits the inside form of a conical feature of a workpiece

NOTE See Figure 5 and Figure 6.

3.1.9 limit cones
geometrically ideal coaxial surfaces, having the same basic cone angle, which result from the basic cone and the cone diameter tolerances

NOTE 1 The difference between the largest and the smallest cone diameters is the same in all sections normal to the cone axis. See Figure 7.

NOTE 2 The surfaces of the limit cones can be made to coincide by axial displacement.

3.2 sizes on cones

3.2.1 actual cone diameter (d_a)
distance between two parallel tangents to the intersection line of the surface of the actual cone with a defined plane normal to the cone axis

NOTE See Figure 1.

3.2.2 basic cone angle (α)
angle formed by the two generators of the basic cone in a section in the axial plane

NOTE See Figure 8.

3.2.3 basic cone diameters

a) largest cone diameter D; or

b) smallest cone diameter d; or

c) cone diameter d_x at a place determined by its position in the axial direction

NOTE See Figure 2.

3.2.4 basic cone length (L)
distance in the axial direction between two limiting ends of a cone

NOTE See Figure 2 and Figure 6.

3.2.5 cone diameter
distance between two parallel lines tangent to the intersection of the circular conical surface with a plane normal to the cone axis

3.2.6 cone generating angle (α/2)
angle contained between a generator and the cone axis

NOTE See Figure 8. The generating angle is equal to half the basic cone angle α.

3.2.7 limit cone angles
largest and smallest cone angles resulting from the basic cone angle α and the *d* position and magnitude of the cone angle tolerance

NOTE See Figure 9.

3.2.8 limit cone diameters
diameters of the limit cones in each section in a plane normal to the axis

NOTE See Figure 7.

3.2.9 rate of taper (*C*)
ratio of the difference between the cone diameters *D* and *d* to the cone length *L*

NOTE $C = \frac{D-d}{L} = 2\tan\frac{\alpha}{2}$

The rate of taper is often indicated by the expressions 1:x or 1/x and "Cone 1:x" for short. For example, C = 1:20 means that a diameter difference D – d of 1 mm occurs an axial distance L of 20 mm between the cone diameters D and d.

3.3 cone fit

3.3.1 character of a cone fit
clearances or interferences measured normal to the cone axis

NOTE The clearances and interferences are effective normal to the conical surfaces, but are indicated and measured normal to the cone axis. The differences between the values shown normal to the cone surface and normal to the cone axis are negligible for cones with rates of taper up to 1:3 and can be ignored for practical purposes.

3.3.2 cone fit
relationship resulting from the difference in assembly between the cone diameters of conical workpieces (internal cone and external cone) having circular sections and the same basic cone angle α or the same rate of taper *C*

NOTE The definition for a cone fit with a circular section is also applicable for taper workpieces with other sections, for example, prismatic parts, wedges, etc.

3.4 axial displacement for single conical workpieces

3.4.1 axial displacement (*EN*)
calculated axial distance of the cone with regard to the basic cone

*NOTE See Figure 21a). This has importance only for the calculation of the axial displacement for cone assemblies (see **3.5.1**).*

3.4.2 maximum axial displacement (EN_{max})
displacement relative to the basic cone which is calculated from the fundamental deviation and the tolerance for the basic cone diameter

3.4.3 minimum axial displacement (EN_{min})
displacement relative to the basic cone which is calculated from the fundamental deviation for the basic cone diameter

3.5 constructional and dimensional location cone fits

3.5.1 axial displacement for cone assemblies (EP)
axial displacement of the conical workpieces to be assembled with respect to each other

NOTE This is the algebraic sum of the calculated displacements EN_i of the internal cone and EN_e of the external cone (referred to the basic cone).

3.5.2 maximum axial displacement for cone assemblies (EP_{max})
displacement which is calculated from the sum EN_{imax} of the internal cone and EN_{emax} of the external cone

NOTE $EP_{max} = EN_{imax} + EN_{emax}$

For the basic hole system, $EN_{imax} = \frac{1}{C} \times IT$.

3.5.3 minimum axial displacement for cone assemblies (EP_{min})
displacement which is calculated from the sum of EN_{imin} of the internal cone and EN_{emin} of the external cone

NOTE $EP_{min} = EN_{imin} + EN_{emin}$

For the basic hole system, $EN_{imin} = 0$.

3.5.4 variation of cone diameter fit (T_{DP})
possible variation of the diametral clearance and/or interference between the conical workpieces to be assembled and the absolute value of the difference between the maximum and minimum clearances and interferences respectively

NOTE 1 See Figure 10, Figure 17, Figure 18, Figure 19, Figure 20 and Figure 21.

NOTE 2 $T_{DP} = S_{max} - S_{min}$ *or* $U_{max} - U_{min}$

where S_{max} and S_{min} are the maximum and minimum diametral clearances respectively and U_{max} and U_{min} are the maximum and minimum diametral interferences respectively.

The variation of cone diameter fit is equal to the sum of the cone diameter tolerances of the internal cone T_{Di} and the external cone T_{De}, i.e.:

$T_{DP} = T_{Di} + T_{De}$.

3.6 axial displacement type cone fits

3.6.1 assembly force (F_s)
force to be applied axially in the assembly of the conical workpieces starting from the actual starting position (P_a) in order to reach a defined interference cone fit in the final position (P_f) of the cones

NOTE See Figure 20.

3.6.2 axial displacement for assembled cones (E_a)
algebraic difference measured axially between the separation of the reference planes of the internal and external cones respectively at the actual starting position (P_a), and the separation of the reference planes at the final position (P_f) required for the cone fit

NOTE Figure 19 gives an example of an interference cone fit. The amount of the axial displacement E_a depends on the rate of taper C of both conical workpieces to be assembled.

3.6.3 maximum axial displacement (E_{amax})
measured axial displacement giving the maximum clearance or the maximum interference respectively in the final position of the conical workpieces

NOTE Figure 10 gives an example of an interference cone fit.

3.6.4 minimum axial displacement (E_{amin})
axial displacement giving the minimum clearance and the minimum interference respectively in the final position of the conical workpieces

NOTE Figure 10 gives an example of an interference cone fit.

3.6.5 tolerance on the axial displacement (T_E)
difference between the minimum and maximum axial displacements

NOTE $T_E = E_{amax} - E_{amin}$. See Figure 10.

3.6.6 final position (P_f)
axial position prescribed for the conical workpieces with respect to each other in the final state in which the required clearances or interferences exist

3.6.7 starting positions

3.6.7.1 starting position (P)
axial position of the conical workpieces with respect to each other at which the cones contact without force

3.6.7.2 actual starting position (P_a)
axial position of the actual cones (internal cone and external cone) relative to each other at which they contact without force

NOTE See Figure 19 and Figure 20. This parameter is important in the production of cone fits and should lie within the limit starting positions P_1 and P_2 (see Figure 11).

3.6.7.3 limit starting positions (P_1 and P_2)
extreme axial positions of the conical workpieces to be assembled with respect to each other which are calculated from the limit cones at contact without force

NOTE 1 The limit cones are those (extreme) cones having basic cone angle and cone diameter tolerances T_{Di} and T_{De} respectively.

NOTE 2 The limit starting positions are calculated from the assembly of the smallest possible internal cone with the largest possible external cone on the one hand, and the largest possible internal cone with the smallest possible external cone on the other hand (see Figure 11).

3.6.7.4 tolerance on the starting positions (T_p)
maximum axial distance between the reference planes of the internal cone and the external cone relative to each other, resulting from the calculated limit starting positions P_1 and P_2

NOTE See Figure 11. The tolerance T_p of the starting position is calculated from: $T_p = \frac{1}{C} \ (T_{Di} + T_{De})$

3.7 cone tolerances

3.7.1 cone angle tolerance (AT)
difference between the largest and smallest permissible cone angles

NOTE See Figure 9 and Figure 12.

3.7.2 cone diameter tolerance (T_D)
difference between the largest and smallest permissible cone diameters in any section, i.e. between the limit cones

NOTE See Figure 7.

3.7.3 cone form tolerances (T_F)

3.7.3.1 tolerance on the roundness of the section
distance between two coplanar concentric circles in a section normal to the axis between which the actual cone section is situated

NOTE See Figure 13. The actual value for the error on roundness is taken as the distance between two coplanar concentric circles which touch the actual line of any section normal to the axis.

3.7.3.2 tolerance on the straightness of the generator
distance between two parallel, straight lines between which the actual generator lies

NOTE See Figure 7. The actual value for the error on straightness is taken as the distance between two parallel straight lines touching the actual generator, and so placed that the distance between them is a minimum.

3.7.4 cone section diameter tolerance (T_{DS})
difference between the largest and smallest permissible cone diameters in a defined section

NOTE See Figure 14.

3.7.5 cone tolerance system
system containing the cone diameter tolerances, the cone angle tolerances and the tolerances on the cone form of the generator and the circumferential line of the section normal to the cone axis

3.7.6 cone tolerance space
space between the two limit cones, for the conical surface

*NOTE Cone tolerance space includes all the tolerances referred to in **3.7**. It can be represented by tolerance zones in two plane sections. See Figure 7 and Figure 13.*

3.8 actual cone angles

3.8.1 actual cone angle
in any axial plan section, the angle between the two pairs of parallel straight lines that enclose the form errors of the two generators in such a way that the maximum distance between them is the least possible value

NOTE See Figure 15. For a given cone, there is not only one actual cone angle; for cones having deviations of roundness, the actual cone angle will be in different axial planes (see α_1 and α_2 in Figure 15).

3.8.2 average actual cone angle
arithmetical average value of the actual cone angle in several equally distributed axial plane sections

NOTE Amongst the axial planes chosen, one at least should cover the greatest deviation of roundness from the circle line of the cone diameter.

3.9 cone tolerance zones

3.9.1 cone diameter tolerance zone (in a graphic representation)
zone, lying in the plane section of the cone axis, which is limited by the limit cones

NOTE The total tolerances zone is represented in Figure 7 and Figure 13 by the hatched portions, which also indicate the cone tolerance space. It includes the tolerances for the cone diameter, the cone angle, the roundness and the straightness which can occupy the whole cone tolerance zone. In general, each of these particular deviations occupies a part of the cone diameter tolerance zone only.

3.9.2 cone section diameter tolerance zone
tolerance zone for the cone diameter in a defined section

NOTE It applies where the cone diameter tolerance is indicated for a fixed diameter only.

3.9.3 tolerance zone for the cone angle
fan-shaped zone within the limit cone angles

NOTE The inclination of the limit cones can be indicated by plus, minus or plus/minus for the cone angle tolerances. See Figure 16. For the indication of plus/minus, the values can be different.

3.9.4 tolerance zone for the roundness of the section (in a graphic representation)
zone lying in a section normal to the cone axis and formed by concentric circles

*NOTE See Figure 13. As this zone is narrower than that referred to in **3.9.1**, it only applies if the tolerance for the roundness of the section is reduced with respect to the cone diameter tolerance zone. The contour is situated anywhere with a tolerance zone given by the tolerance for the roundness of the section.*

3.9.5 tolerance zone for the straightness of the generator (in a graphic representation)
zone (band), situated in any axial plane section and disposed on each side of the cone axis, which is determined by the form tolerance of the generators

*NOTE See Figure 7. As this zone is smaller than that referred to in **3.9.1**, it only applies if the tolerance on the straightness of the generator is reduced with respect to the cone diameter tolerance zone. The actual generator is situated anywhere with a tolerance zone given by the tolerance for the straightness.*

Figure 1 **Actual cone**

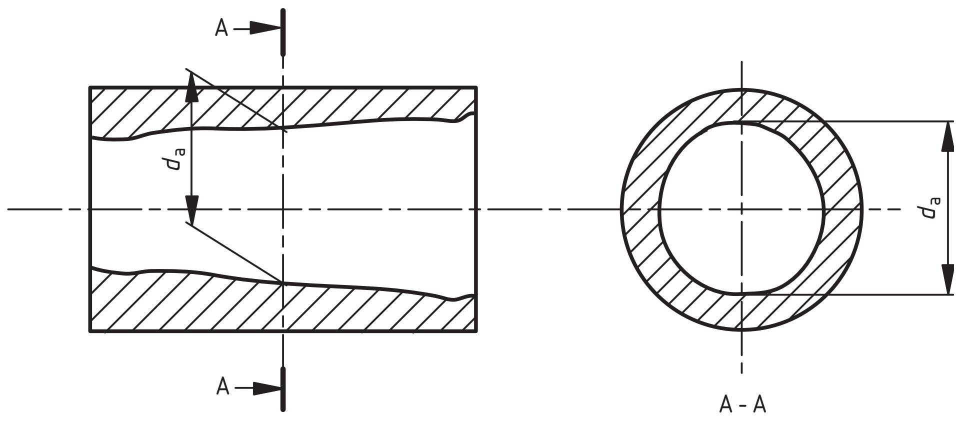


Figure 2 **Basic cone**

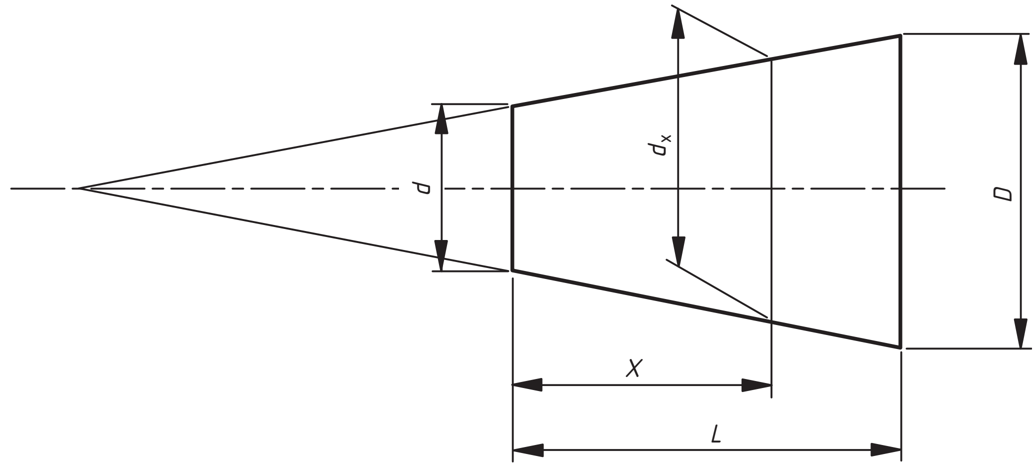
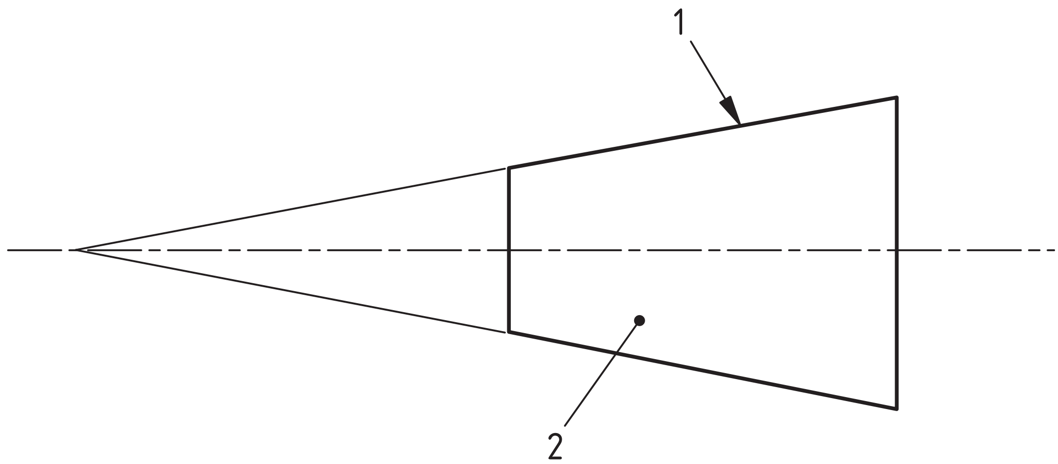


Figure 3 **Cone**



Key

1 Generator

2 Conical surface and conical workpiece

Figure 4 **Conical workpiece – external cone**

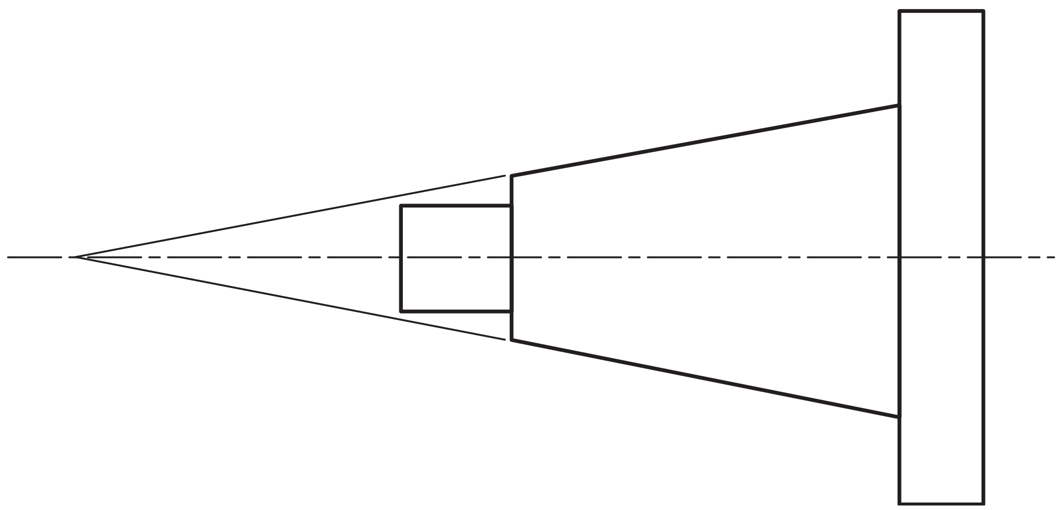


Figure 5 **Conical workpiece – internal cone**

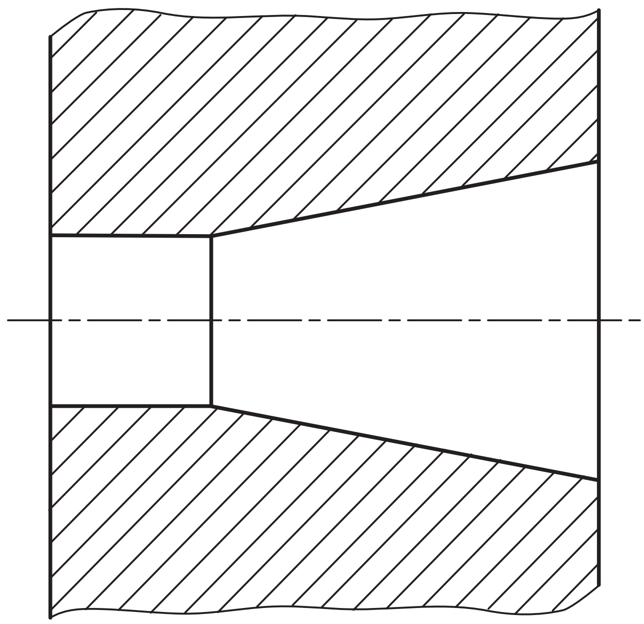
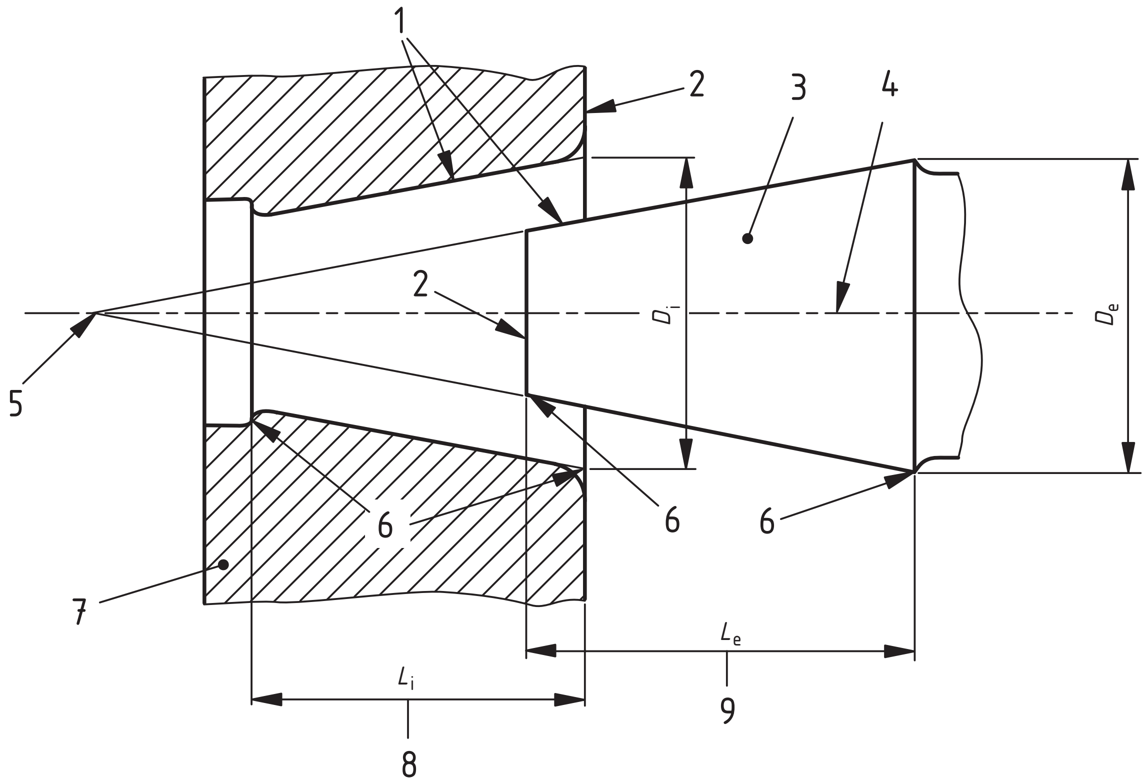


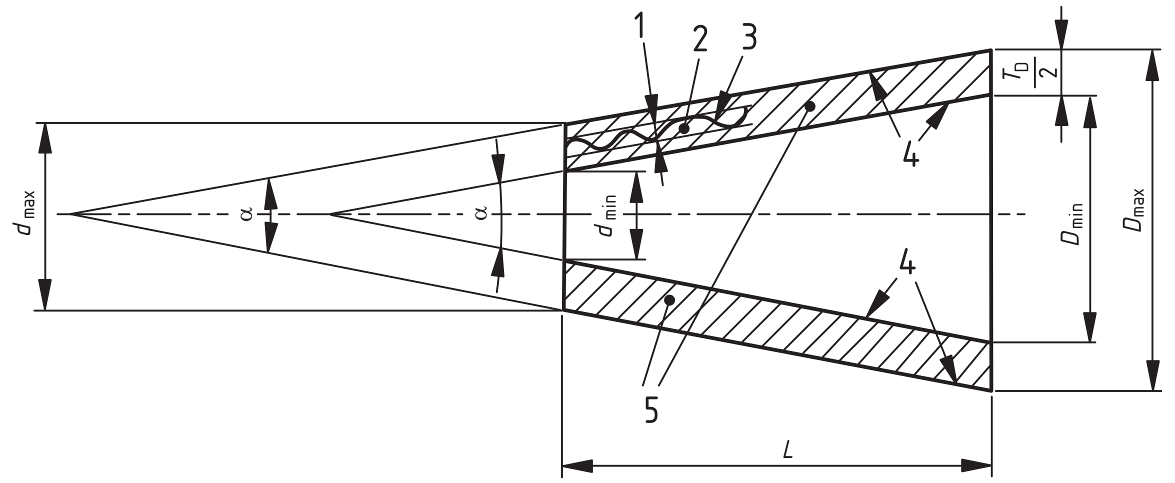
Figure 6 **General definitions**



Key

1 Conical surface and generator
2 Face
3 External cone
4 Cone axis
5 Basic point
6 Limit edges
7 Internal cone
8 Cone length L_i
9 Cone length L_e

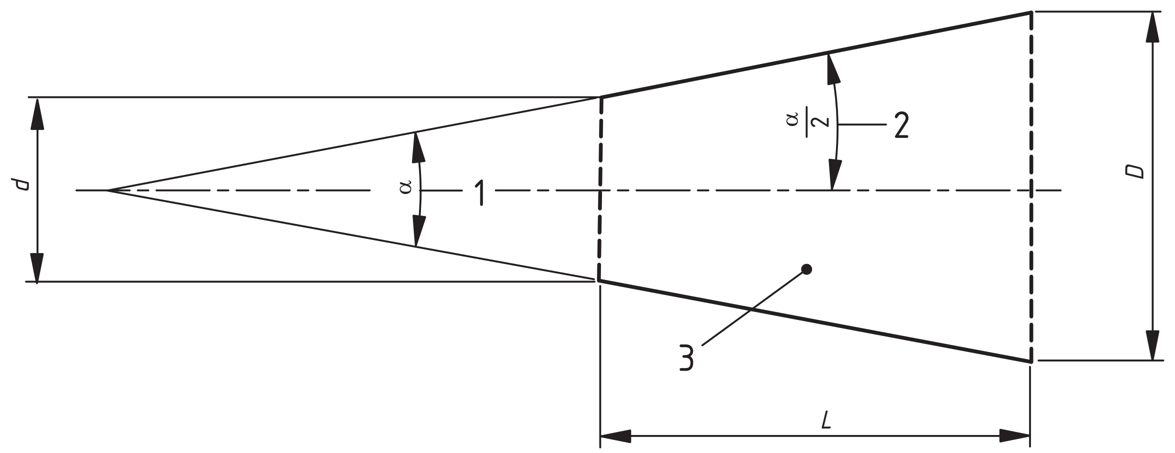
Figure 7 **Limit cones, cone diameter, tolerance zone and straightness of the generator tolerance zone**



Key

1 Tolerance on the straightness
2 Form tolerance zone of the generator
3 Actual cone
4 Limit cones
5 Cone diameter tolerance zone

Figure 8 **Angles on cones**



Key

1 Basic angle
2 Generating angle
3 Basic cone

Figure 9 **Limit cone angles**

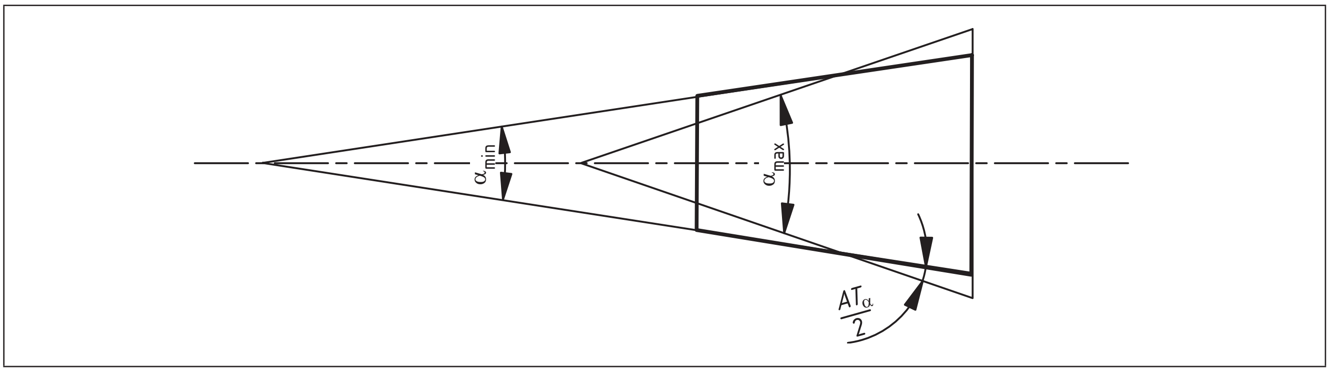


Figure 10 **Maximum and minimum interference of a cone interference fit made by a defined axial displacement of the cones with respect to each other from the actual starting position P_a (pressing in and on respectively by displacement E_{amin} and E_{amax} respectively)**

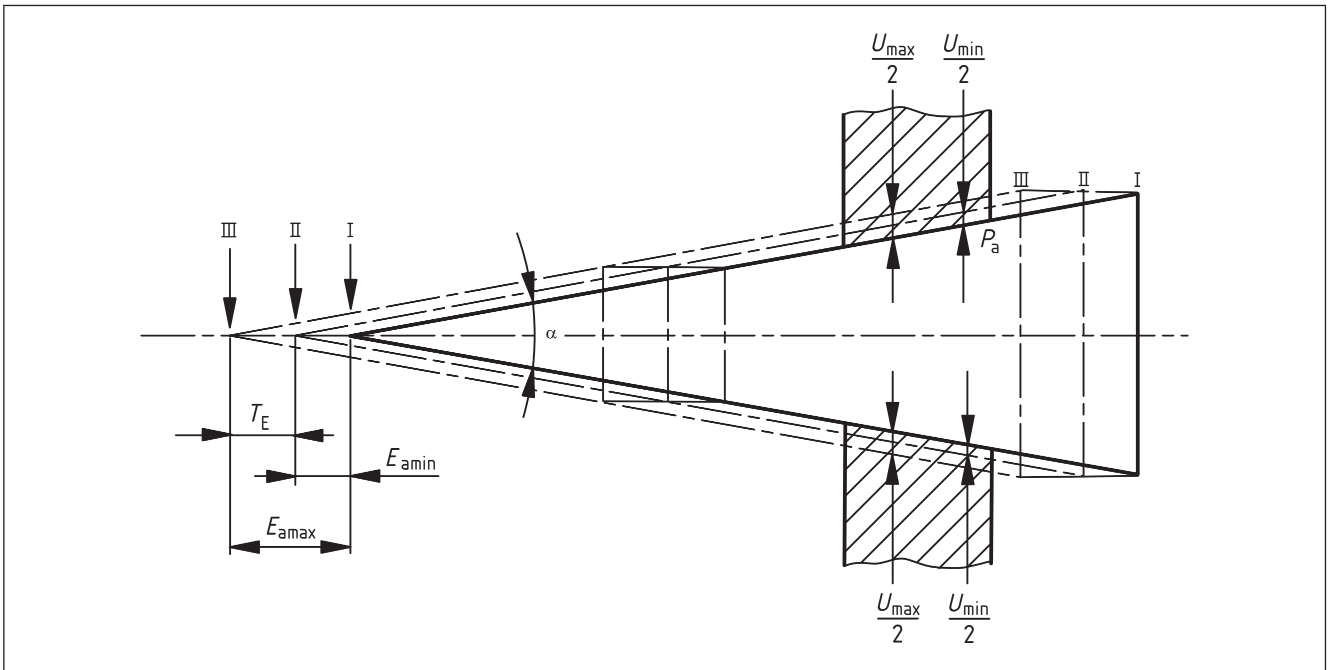
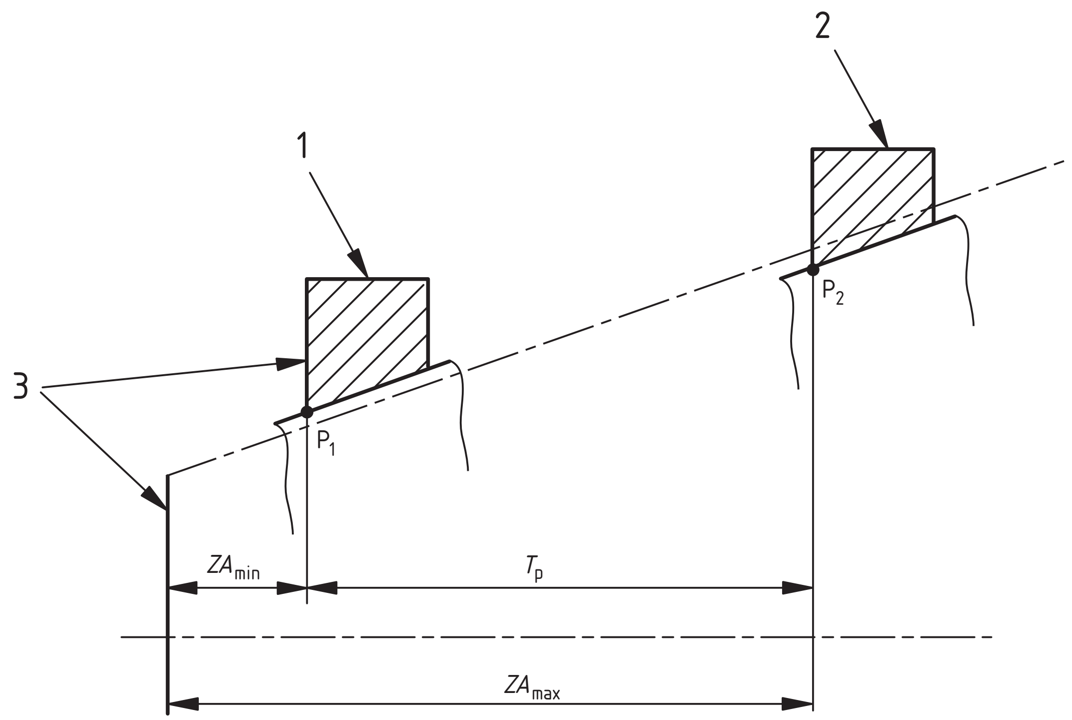


Figure 11 **Limit starting positions**



Key

1 Limit starting position P_1 (smallest internal cone on largest external cone)

2 Limit starting position P_2 (largest internal cone on smallest external cone)

3 Datum planes

Figure 12 **Admissible limit cone angles resulting from the cone diameter tolerance**

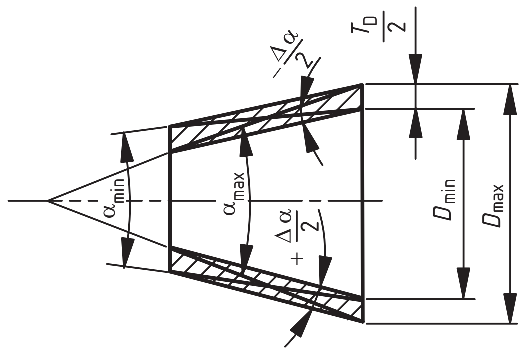
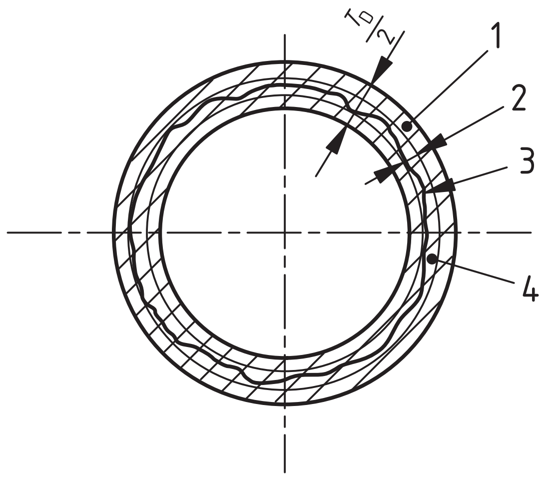


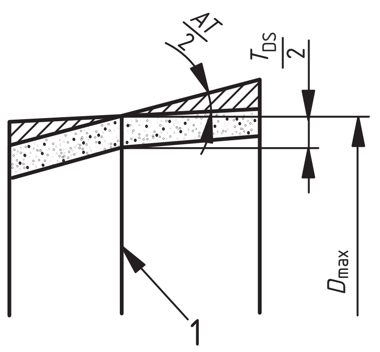
Figure 13 **Cone diameter tolerance zone and roundness tolerance zone**



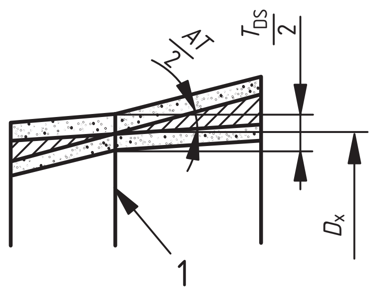
Key

1 Cone diameter tolerance zone
2 Tolerance on the roundness
3 Actual cone
4 Form tolerance zone of the section

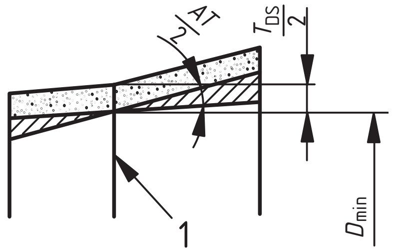
Figure 14 **Cone section diameter tolerance (T_{DS}) and cone angle tolerance (*AT*)**



a) The actual cone diameter in the defined section has the maximum permissible size of the cone diameter.



b) The actual cone diameter in the defined section lies between the limit sizes of the cone diameter.

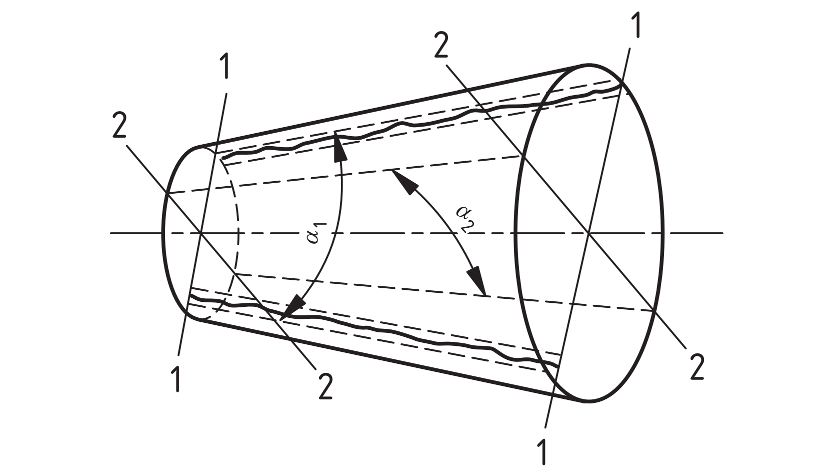


c) The actual cone diameter in the defined section has the minimum size of the cone diameter.

Key

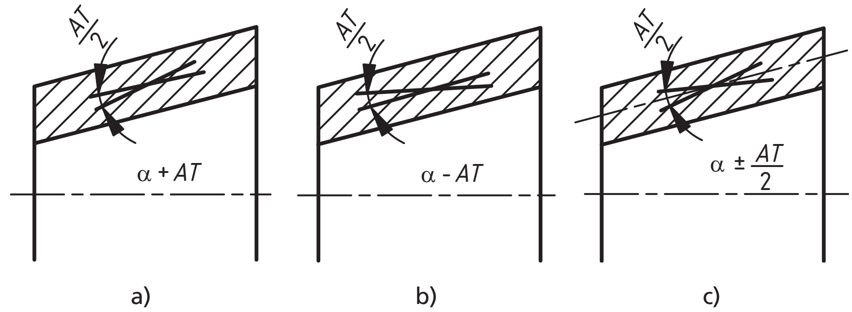
1 Defined section

Figure 15 **Actual cone angles**



NOTE The parallel straight lines shown in this figure lie in plane 1.

Figure 16 **Position of the cone angle within the cone diameter tolerance zone**



Section 2: System of cone fits

4 Formation of cone fits

4.1 General

A special feature of cone fits is that clearances and interferences are made by defining the axial position of the assembled internal and external cones with respect to each other. The conical workpieces to be assembled are manufactured separately according to the tolerance zones indicated for their common basic cone diameter. Because of the methods of manufacture, a hole basis system of fits is recommended.

The axial position of the conical workpieces with respect to each other for obtaining the required clearance or interference of the cone fit in the final position of the assembled conical workpieces can be made by different methods. These are:

a) by constructional formation (see **4.2**);

b) by dimensional location (see **4.3**);

c) by an actual axial displacement (see **4.4**);

d) by an actual axial displacement with a defined assembly force (see **4.5**).

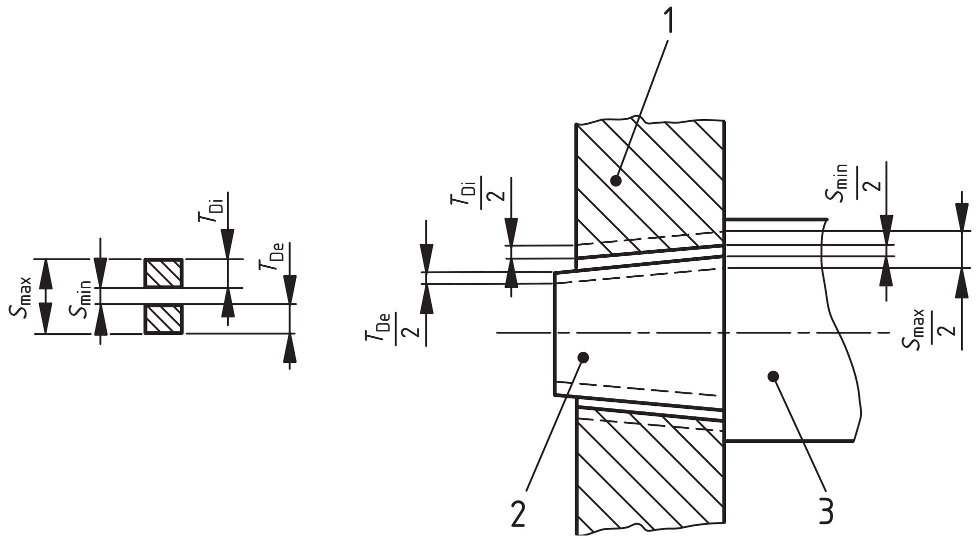
NOTE Information on the effect on the cone fit of departures of the internal and external cones from the basic cone is given in Annex A.

4.2 Constructional formation

This is a cone fit resulting from the constructional formation of the workpieces to be assembled (see Figure 17).

The axial position of the cones relative to each other in the final position (see **3.6.6**) is determined by the form of the conical workpieces. Figure 17 shows a clearance cone fit in which the workpiece with the external cone has a collar which contacts the surface of the workpiece with the internal cone. This type of construction is also valid for an interference cone fit when the workpiece with the internal cone is pressed on to the workpiece with the external cone in order to make contact at the collar.

Figure 17 **Cone clearance fit made by constructional formation (final position P_f fixed by contact at a collar)**



Key

1 Internal cone

2 External cone

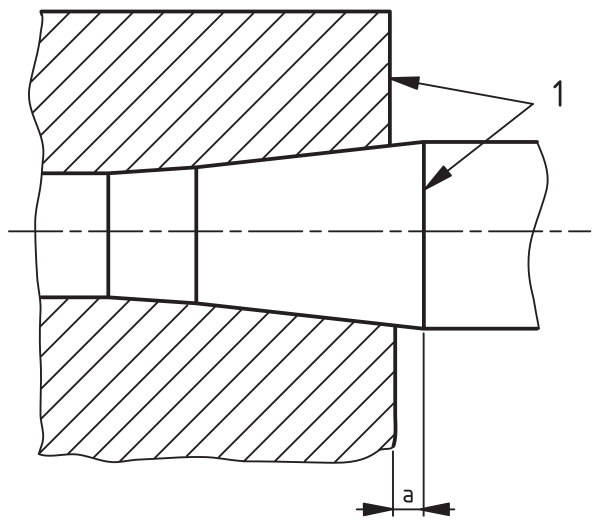
3 Collar

4.3 Dimensional location

This is a cone fit made by the assembly of the conical workpieces to a predetermined axial position relative to each other, irrespective of the actual size of the mating cones (see Figure 18).

The final position of the conical workpieces relative to each other is specified on the drawing (see Figure 18) and, if need be, marked on the internal cone and on the external cone.

Figure 18 **Cone interference fit made by pressing in to a defined dimension (final position P_f fixed by distance *a*)**



Key

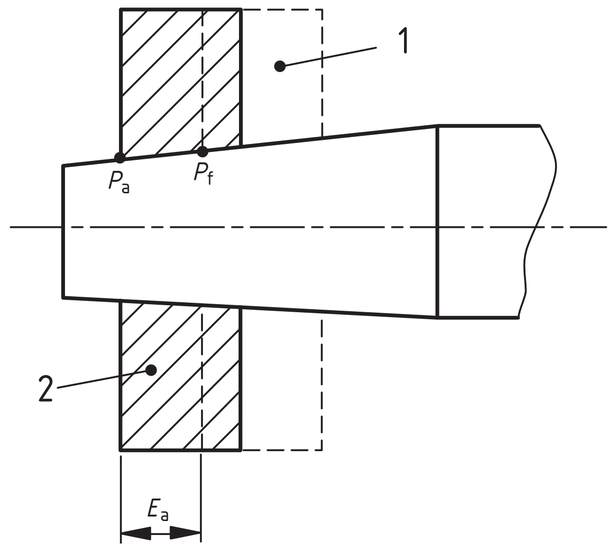
1 Datum planes

4.4 Axial displacement

This is a cone fit made by axial displacement of the (actual) cones with respect to each other by a fixed amount, starting from the actual starting position (see **3.6.7.2**).

In order to reach the required clearances or interferences of the cone fit, the necessary axial displacement (dimension E_a in Figure 19 for the example of an interference cone fit) is indicated from the actual starting position.

Figure 19 **Cone interference fit made by a defined axial displacement of the cones with respect to each other from the actual starting position P_a (pressing in and on respectively by a defined displacement E_a)**



Key

1 Final position

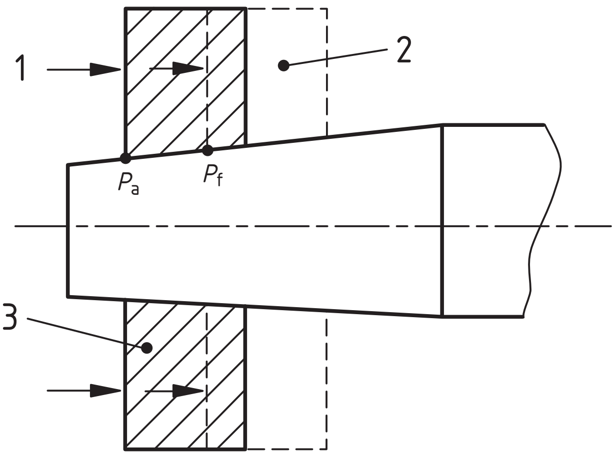
2 Actual starting position

4.5 Axial displacement with a defined assembly force

This is a cone fit made by displacement of the actual cones using a defined assembly force from the actual starting position (see Figure 20).

For an interference cone fit, the final position of the assembled conical workpieces relative to each other is reached on assembly by a defined axial force (F_s).

Figure 20 **Cone interference fit made by a defined force of assembly from the actual starting position P_a (pressing in and on respectively by a defined force of assembly F_s)**



Key

1 Force F_s

2 Final position

3 Actual starting position

5 Calculation of axial displacements for the hole basis system of cone fits

5.1 Axial displacement of the single conical workpiece (*EN*) with regard to the basic cone

For each of the conical workpieces to be assembled, the upper and lower deviation and the geometrical symbol should be indicated for the basic cone diameter in a reference plane normal to the cone axis.

Figure 21a), Figure 21b) and Figure 21c) show for the hole basis fit system the possibilities of axial displacements *EN* of the external cones relative to the basic cone for each of the symbols for the cone diameter tolerance zones. Figure 21d) shows the axial displacement for an internal cone with tolerance position *H* (i.e. basic hole).

These displacements (*EN*) are of importance for the calculation of the axial displacement of two conical workpieces relative to each other. Using the tolerance system of BS EN 20286 for the basic cone diameter of a cone fit, the following axial displacements (*EN*) result.

a) A displacement EN_T [see Figure 21b), Figure 21d) and Table 1] resulting from the standard tolerance *IT*.

$$EN_T = \frac{1}{C} \times IT$$

b) Minimum and maximum displacements EN_{emin} and EN_{emax} [see Figure 21a), Figure 21c), Table 1 and Table 2], a combination of the fundamental deviation and the standard tolerance.

$$EN_{emin} = \frac{1}{C} \times \text{ fundamental deviation}$$

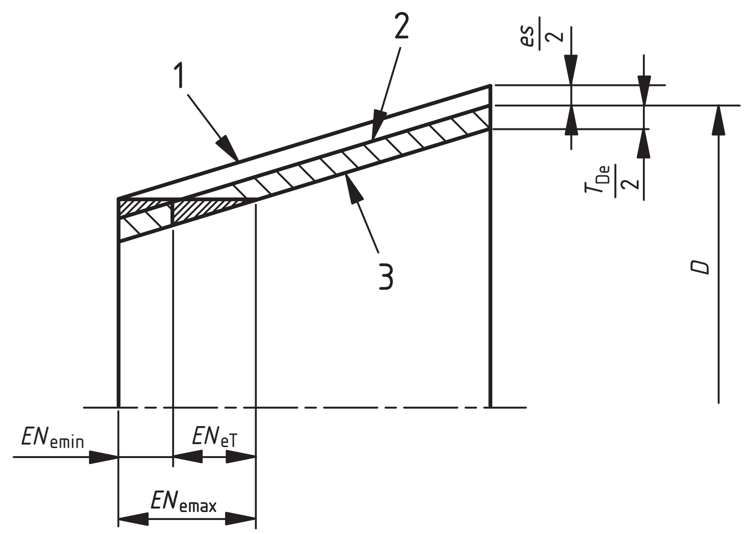
$$EN_{emax} = EN_{emin} + EN_{eT}$$

c) Minimum and maximum displacements EN_{imin} and EN_{imax} [see Figure 21d) and Table 1] for the internal cone resulting from the standard tolerance IT only since the fundamental deviation for the basic hole is zero.

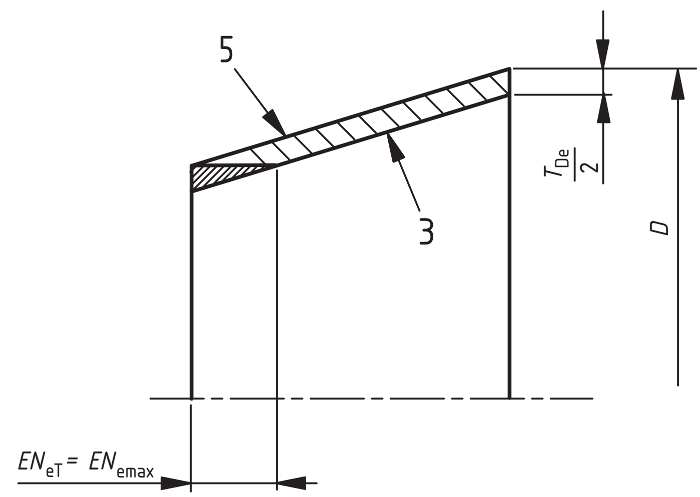
$EN_{imin} = 0$

$EN_{imax} = EN_{iT}$

Figure 21 **Axial displacements *EN* of the single conical workpiece with regard to the basic cone (basic displacement)**

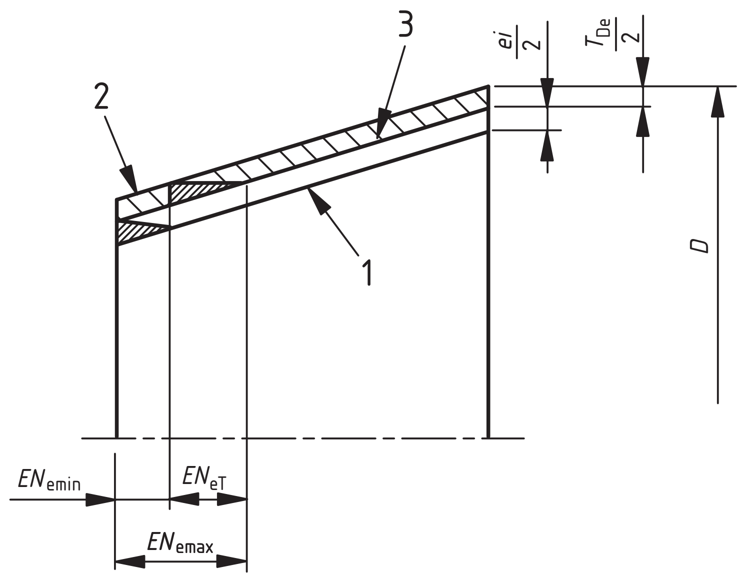


a) External cone – Positions of deviations a to g

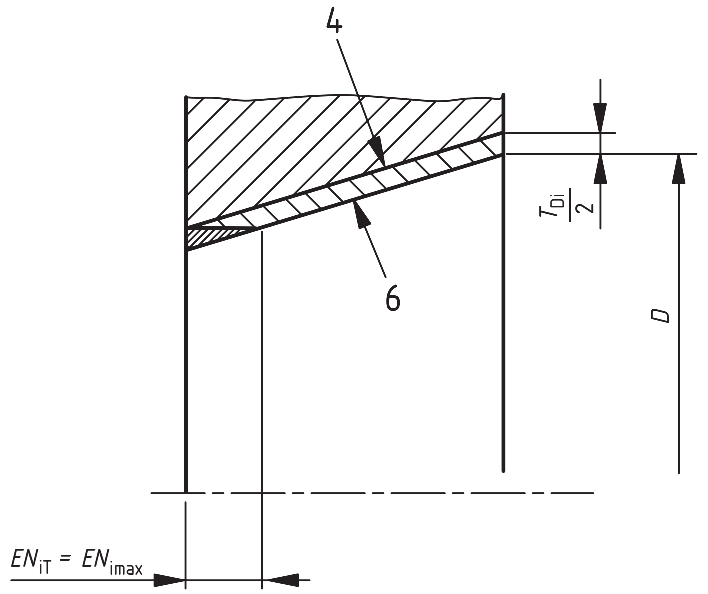


b) External cone – Position of deviation h

Figure 21 **Axial displacements *EN* of the single conical workpiece with regard to the basic cone (basic displacement)** *(continued)*



c) External cone – Positions of deviations n to zc



d) Internal cone – Position of deviation *H*

Fundamental deviations:
es = upper deviation
ei = lower deviation

Key

1 Basic cone
2 Largest external cone
3 Smallest external cone
4 Largest internal cone
5 Basic cone and largest external cone
6 Basic cone and smallest internal cone

5.2 Axial displacement type cone fits

5.2.1 Axial displacements (E_a) from the actual starting position (P_a)

From the actual starting position (P_a), the axial displacement of the internal cone relative to the external cone results in a clearance fit (positive displacement, i.e. moving apart) or an interference fit (negative displacement, i.e. forcing together).

For a clearance fit, the minimum axial displacement giving the minimum clearance is:

$$E_{amin} = \frac{1}{C} \times S_{min}$$

and the maximum axial displacement giving the maximum clearance is:

$$E_{amax} = \frac{1}{C} \times S_{max}.$$

For an interference fit, the minimum axial displacement giving the minimum interference (to obtain the necessary securing force) is:

$$E_{amin} = \frac{1}{C} \times U_{min}$$

and the maximum axial displacement giving the maximum interference with regard to the strength of the cone fit is:

$$E_{amax} = \frac{1}{C} \times U_{max}.$$

NOTE The maximum interference (U_{max}) can be reduced in order to avoid an excessive maximum displacement (E_a) in regard to fabrication.

5.2.2 Tolerance (T_E) of the axial displacement (E_a)

Starting from the actual starting position (P_a), the displacement to be used in order to reach the required cone fit should lie between E_{amin} and E_{amax} calculated according to **5.2.1**, i.e. the tolerance $T_E = E_{amax} - E_{amin}$.

Because of the uncertainties in manufacturing the cones and in measuring the displacement, it is recommended that the calculated displacement E_{amin} be slightly increased, and also E_{amax} slightly reduced. In so doing, the actual tolerance (T_E), resulting from $E_{amax} - E_{amin}$, is reduced in practice.

5.3 Dimensional location type cone fits: Axial displacement (*EP*) of the conical workpieces to be assembled with each other (fit displacement)

The axial displacement (*EP*) of the conical workpieces with respect to each other is the algebraic sum of the calculated displacements (EN_i) referred to the basic cone, of the internal cone and (EN_e) of the external cone.

Minimum displacement $EP_{min} = EN_{emin}$

Maximum displacement $EP_{max} = EN_{imax} + EN_{emax}$

$$= EN_{iT} + EN_{eT} + EN_{emin}$$

The values given in Table 1 and Table 2 for EN_T and EN_{emin} respectively are derived for cones with a rate of taper C = 1:10 from the values of IT grades and fundamental deviations given in BS EN 20286.

For cones with rates of taper other than C = 1:10, the appropriate axial displacement for the required tolerance class is calculated from Table 1 and Table 2 and then multiplied by the conversion factor for the required rate of taper given in Table 3.

Table 1 gives the axial displacement (EN_T) of the internal and external cones with regard to the basic cone resulting from tolerance grades IT0 to IT16 given in BS EN 20286. The values apply for cone rates of taper C = 1:10; they are given in micrometres for tolerance grades up to IT5 and millimetres for tolerance grades IT6 to IT16 inclusive.

Table 2 gives the axial displacement (EN_{emin}) of the external cone with regard to the basic cone resulting from the fundamental deviations a to zc given in BS EN 20286 for the basic cone diameter of an external cone with a rate of taper C = 1:10.

Table 3 gives the conversion factors to be applied to the values given in Table 1 and Table 2 for the axial displacement of all rates of taper (other than C = 1:10) given in BS EN ISO 1119.

Table 1 **Axial displacement EN_T of the internal cone and the external cone respectively, with regard to the basic cone resulting from the standard tolerances IT01 to IT16 according to BS EN 20286 for the basic cone diameter – for rate of taper C = 1:10**

Cone diameter range mm		Values for ENT in micrometres for							Values for ENT in millimetres for											
From	**To**	**IT01**	**IT0**	**IT1**	**IT2**	**IT3**	**IT4**	**IT5**	**IT6**	**IT7**	**IT8**	**IT9**	**IT10**	**IT11**	**IT12**	**IT13**	**IT14**	**IT15**	**IT16**
	3	3	5	8	12	20	30	40	0.06	0.10	0.14	0.25	0.40	0.60	1	1.4	2.5	4	6
3	6	4	6	10	15	25	40	50	0.08	0.12	0.18	0.30	0.48	0.75	1.2	1.8	3	4.8	7.5
6	10	4	6	10	15	25	40	60	0.09	0.15	0.22	0.36	0.58	0.90	1.5	2.2	3.6	5.8	9
10	18	5	8	12	20	30	50	80	0.11	0.18	0.27	0.43	0.70	1.1	1.8	2.7	4.3	7	11
18	30	6	10	15	25	40	60	90	0.13	0.21	0.33	0.52	0.84	1.3	2.1	3.3	5.2	8.4	13
30	50	6	10	15	25	40	70	110	0.16	0.25	0.39	0.62	1	1.6	2.5	3.9	6.2	10	16
50	80	8	12	20	30	50	80	130	0.19	0.30	0.46	0.74	1.2	1.9	3	4.6	7.4	12	19
80	120	10	15	25	40	60	100	150	0.22	0.35	0.54	0.87	1.4	2.2	3.5	5.4	8.7	14	22
120	180	12	20	35	50	80	120	180	0.25	0.40	0.63	1	1.6	2.5	4	6.3	10	16	25
180	250	20	30	45	70	100	140	200	0.29	0.46	0.72	1.15	1.85	2.9	4.6	7.2	11.5	18.5	29
250	315	25	40	60	80	120	160	230	0.32	0.52	0.81	1.3	2.1	3.2	5.2	8.1	13	21	32
315	400	30	50	70	90	130	180	250	0.36	0.57	0.89	1.4	2.3	3.6	5.7	8.9	14	23	36
400	500	40	60	80	100	150	200	270	0.40	0.63	0.97	1.55	2.5	4	6.3	9.7	15.5	25	40

NOTE For cones other than C = 1:10, the above values for the respective IT grades should be multiplied by the appropriate conversion factor given in Table 3.

Table 2 **Axial displacement EN_{emin} of the external cone with regard to the basic cone resulting from the fundamental deviations a to zc according to BS EN 20286 for the basic cone diameter of the external cone for rate of taper C = 1:10**

Deviation		a	b	c	cd	d	e	ef	f	fg	g	h	js	j		
Range of cone diameters		Tolerance grade														
Over	To	All IT grades												IT5 and IT6	IT7	IT8
	3	+2.7	+1.4	+0.6	+0.34	+0.20	+0.14	+0.1	+0.06	+0.04	+0.02	0	$EN_e = \pm \frac{EN_T}{2}$	+0.02	+0.04	+0.06
3	6	+2.7	+1.4	+0.7	+0.46	+0.30	+0.2	+0.14	+0.1	+0.06	+0.04	0		+0.02	+0.04	—
6	10	+2.8	+1.5	+0.8	+0.56	+0.40	+0.25	+0.18	+0.13	+0.08	+0.05	0		+0.02	+0.05	—
10	14	+2.9	+1.5	+0.95	—	+0.50	+0.32	—	+0.16	—	+0.06	0		+0.03	+0.06	—
14	18															
18	24	+3	+1.6	+1.1	—	+0.65	+0.4	—	+0.2	—	+0.07	0		+0.04	+0.08	—
24	30															
30	40	+3.1	+1.7	+1.2	—	+0.80	+0.5	—	+0.25	—	+0.09	0		+0.05	+0.1	—
40	50	+3.2	+1.8	+1.3												
50	65	+3.4	+1.9	+1.4	—	+1	+0.6	—	+0.3	—	+0.1	0		+0.07	+0.12	—
65	80	+3.6	+2	+1.5												
80	100	+3.8	+2.2	+1.7	—	+1.2	+0.72	—	+0.36	—	+0.12	0		+0.09	+0.15	—
100	120	+4.1	+2.4	+1.8												
120	140	+4.6	+2.6	+2	—	+1.45	+0.85	—	+0.43	—	+0.14	0		+0.11	+0.18	—
140	160	+5.2	+2.8	+2.1												
160	180	+5.8	+3.1	+2.3												
180	200	+6.6	+3.4	+2.4	—	+1.7	+1	—	+0.5	—	+0.15	0		+0.13	+0.21	—
200	225	+7.4	+3.8	+2.6												
225	250	+8.2	+4.2	+2.8												
250	280	+9.2	+4.8	+3	—	+1.9	+1.1	—	+0.56	—	+0.17	0		+0.16	+0.26	—
280	315	+10.5	+5.4	+3.3												
315	355	+12	+6	+3.6	—	+2.1	+1.25	—	+0.62	—	+0.18	0		+0.18	+0.28	—
355	400	+13.5	+6.8	+4												
400	450	+15	+7.6	+4.4	—	+2.3	+1.35	—	+0.68	—	+0.2	0		+0.20	+0.32	—
450	500	+16.5	+8.4	+4.8												

Table 2 **Axial displacement EN_{emin} of the external cone with regard to the basic cone resulting from the fundamental deviations a to zc according to BS EN 20286 for the basic cone diameter of the external cone for rate of taper C = 1:10** *(continued)*

Deviation		k		m	n	p	r	s	t	u	v	x	y	z	za	zb	zc
Range of cone diameters		Tolerance grade															
Over	To	IT01 to IT3	IT4 to IT7	All IT grades													
	3	0	0	–0.02	–0.04	–0.06	–0.1	–0.14	—	–0.18	—	–0.2	—	–0.26	–0.32	–0.4	–0.6
3	6	0	–0.01	–0.04	–0.08	–0.12	–0.15	–0.19	—	–0.23	—	–0.28	—	–0.35	–0.42	–0.5	–0.8
6	10	0	–0.01	–0.06	–0.1	–0.15	–0.19	–0.23	—	–0.28	—	–0.34	—	–0.42	–0.52	–0.67	–0.97
10	14	0	–0.01	–0.07	–0.12	–0.18	–0.23	–0.28	—	–033	—	–0.4	—	–0.5	–0.64	–0.9	–1.3
14	18									–0.33	–0.39	–0.45	—	–0.6	–0.77	–1.08	–1.5
18	24	0	–0.02	–0.08	–0.15	–0.22	–0.28	–0.35	—	–0.41	–0.47	–0.54	–0.63	–0.73	–0.98	–1.36	–1.88
24	30								–0.41	–0.48	–0.55	–0.64	–0.75	–0.88	–1.18	–1.6	–2.18
30	40	0	–0.02	–0.9	–0.17	–0.26	–0.34	–0.43	–0.48	–0.6	–0.68	–0.8	–0.94	–1.12	–1.48	–2	–2.74
40	50								–0.54	–0.7	–0.81	–0.97	–1.14	–1.36	–1.80	–2.42	–3.25
50	65	0	–0.02	–0.11	–0.2	–0.32	–0.41	–0.53	–0.66	–0.87	–1.02	–1.22	–1.44	–1.72	–2.25	–3	–4.05
65	80						–0.43	–0.59	–0.75	–1.02	–1.2	–1.46	–1.74	–2.1	–2.74	–3.6	–4.8
80	100	0	–0.03	–0.13	–0.23	–0.37	–0.51	–0.71	–0.91	–1.24	–1.46	–1.78	–2.14	–2.58	–3.35	–4.45	–5.85
100	120						–0.54	–0.79	–1.04	–1.44	–1.72	–2.10	–2.54	–3.1	–4	–5.25	–6.9
120	140	0	–0.03	–0.15	–0.27	–0.43	–0.63	–0.92	–1.22	–1.7	–2.02	–2.48	–3	–3.65	–4.7	–6.2	–8
140	160						–0.65	–1	–1.34	–1.9	–2.28	–2.8	–3.4	–4.15	–5.35	–7	–9
160	180						–0.68	–1.08	–1.46	–2.1	–2.52	–3.1	–3.8	–4.65	–6	–7.8	–10
180	200	0	–0.04	–0.17	–0.31	–0.5	–0.77	–1.22	–1.66	–2.36	–2.84	–3.5	–4.25	–5.2	–6.7	–8.8	–11.5
200	225						–0.80	–1.3	–1.8	–2.58	–3.1	–3.85	–4.7	–5.75	–7.4	–9.6	–12.5
225	250						–0.84	–1.4	–1.96	–2.84	–3.4	–4.25	–5.2	–6.4	–8.2	–10.5	–13.5
250	280	0	–0.04	–0.2	–0.34	–0.56	–0.94	–1.58	–2.18	–3.15	–3.85	–4.75	–5.8	–7.1	–9.2	–12	–15.5
280	315						–0.98	–1.7	–2.4	–3.5	–4.25	–5.25	–6.5	–7.9	–10	–13	–17
315	355	0	–0.04	–0.21	–0.37	–0.62	–1.08	–1.9	–2.68	–3.9	–4.75	–5.9	–7.3	–9	–11.5	–15	–19
355	400						–1.14	–2.08	–2.94	–4.35	–5.3	–6.6	–8.2	–10	–13	–16.5	–21
400	450	0	–0.05	–0.23	–0.4	–0.68	–1.26	–2.32	–3.3	–4.9	–5.95	–7.4	–9.2	–11	–14.5	–18.5	–24
450	500						–1.32	–2.52	–3.6	–5.4	–6.6	–8.2	–10	–12.5	–16	–21	–26

NOTE 1 The signs associated with the value given in this table are reversed with respect to the relevant diametral values given in BS EN 20286.

Therefore:
+ means the external cone has an axial clearance with regard to the basic cone;
– means the external cone has an axial interference with regard to the basic cone.

NOTE 2 For cones other than C = 1:10, the above values for the fundamental deviations should be multiplied by the appropriate conversion factor given in Table 3.

Table 3 **Conversion factors to be applied to the values given in Table 1 and Table 2 for the axial displacement of all rates of taper other than *C* = 1:10**

Cones for general use				Cones for special cases		
Nominal value		Rate of taper	Conversion factor	Nominal value	Rate of taper	Conversion factor
Series 1	Series 2	*C*			*C*	
120°	—	1:0.288 675	0.029	18° 30′	1:3.070 115	0.3
90°	—	1:0.500 000	0.05	11° 54′	1:4.797 451	0.48
—	75°	1:0.651 613	0.065	8° 40′	1:6.598 442	0.66
60°	—	1:0.866 025	0.086	7°	1:8.174 928	0.82
45°	—	1:1.207 107	0.12	7:24	1:3.428 571	0.34
30°	—	1:1.866 025	0.186	1:9	—	0.9
1:3	—	—	0.3	1:12.262	—	1.2
—	1:4	—	0.4	1:12.972	—	1.3
1:5	—	—	0.5	1:15.748	—	1.57
—	1:6	—	0.6	1:18.779	—	1.8
—	1:7	—	0.7	1:19.002	—	1.9
—	1:8	—	0.8			
				1:19.180	—	1.92
—	1:12	—	1.2	1:19.212	—	1.92
—	1:15	—	1.5	1:19.254	—	1.92
1:20	—	—	2	1:19.264	—	1.92
—	1:30	—	3	1:19.922	—	1.99
1:50	—	—	5	1:20.020	—	2
1:100	—	—	10	1:20.047	—	2
1:200	—	—	20	1:20.288	—	2
1:500	—	—	50	1:23.904	—	2.4

NOTE The rates of taper correspond to BS EN ISO 1119.

Section 3: System of cone tolerances

6 Basis of the system

6.1 Types of cone tolerance

The following four types of tolerance provide the basis of the cone tolerance system.

a) Cone diameter tolerance (T_D), valid for all cone diameters within the cone length (L).

b) Cone angle tolerance (AT), given in angular or linear dimensions (AT_α or AT_D).

c) Cone form tolerance (T_F) (tolerances for the straightness of the generator and for the roundness of the section).

d) Cone section diameter tolerance (T_{DS}), given for the cone diameter in a defined section. It is valid for the cone diameter of this section only.

6.2 Cone diameter tolerance, cone angle tolerance and cone form tolerance

Normal cases will be handled by application of the cone diameter tolerance (T_D) only. It includes the two tolerances of the types **6.1**b) and **6.1**c). This means that the deviations of these two types might, in principle, utilize the whole tolerance space given by the cone diameter tolerance (T_D).

In case of stronger requirements, the cone angle tolerance and the cone form tolerance may be reduced within the cone diameter tolerance (T_D) by means of supplementary instructions. In this case likewise, no point on the conical surface is permitted to lie outside the limit cones given by T_D.

In practice, all types of tolerance generally exist at the same time and, as far as normal cases are concerned, each tolerance may occupy a part of the cone diameter tolerance (T_D) only in such a way that no point on the conical surface lies outside the tolerance space. In other words, no point on the conical surface is permitted to lie outside the limit cones.

6.3 Cone section diameter tolerance

If for functional reasons the cone diameter tolerance is required in a defined section, the cone diameter tolerance (T_{DS}) [tolerance type **6.1**d)] should be indicated. In this case, it is also necessary to indicate the cone angle tolerance.

If general tolerances for the cone angle are specified, for example in an international document, and if it is referred to this tolerance, it is not necessary to indicate special cone angle tolerances.

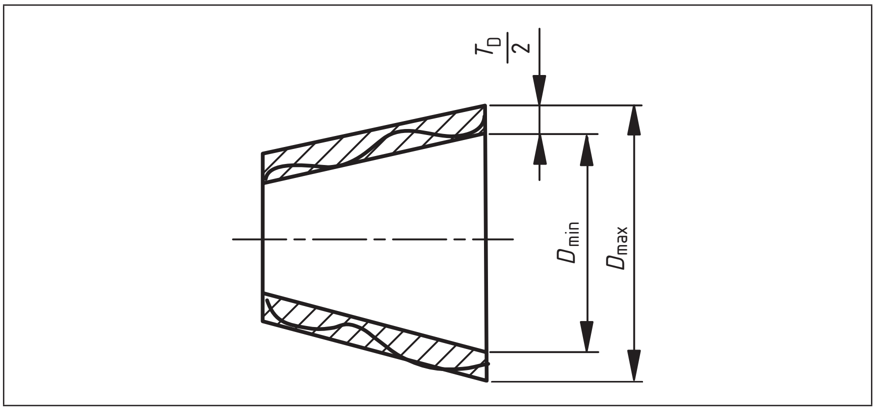
7 Cone diameter tolerance (T_D)

In general, the choice of the cone diameter tolerance (T_D) is based on the large cone diameter (D). It is selected from the IT tolerances and applies over the whole of the cone length (L).

If it is not necessary to indicate smaller tolerances of angle and form, a cone diameter tolerance (T_D), given on the drawing, applies also to the angle and form deviations. However, in this case all workpieces that conform to Figure 12 and Figure 22 should be accepted.

The symbols of the geometric tolerance system should be used to indicate the cone diameter tolerances referred to the corresponding cone diameter. If the conical surface of the conical workpiece is not intended for a cone fit, the tolerance positions J_s and j_s should be chosen for preference, for example, 40 j_s10.

Figure 22 **Admissible cone form deviation resulting from the cone diameter tolerance**



8 Cone angle tolerance (AT)

8.1 Cone angle tolerance resulting from the cone diameter tolerance (T_D)

The actual cone angle lies within the cone diameter tolerance zone in case of absence of any special indication of cone angle tolerances. The cone angles α_{max} and α_{min} (see Figure 12) are thus the limit cone angles resulting from the cone diameter tolerance (T_D). Consequently, the actual cone angle is permitted to be disposed with respect to the basic cone angle (α) from $+\Delta\alpha$ to $-\Delta\alpha$ (for values of $\Delta\alpha$, see Annex B).

8.2 Fixed cone angle tolerance

If the cone angle tolerance has to be smaller than that given by the cone diameter tolerance, it is necessary to establish the cone angle limits. For the cone angle tolerances, the deviations should be indicated by plus, minus or plus/minus, for example $+AT$, $-AT$, $\pm AT/2$.

For the indication of plus/minus, the values can be different.

9 Cone form tolerances (T_F)

Cone form tolerances comprise the tolerances on:

a) the straightness of the generator (see Figure 7);

b) the roundness of the cone section (see Figure 13).

Cone form tolerances should be especially indicated (in micrometres) if they are smaller than half of the cone diameter tolerance.

10 Cone section diameter tolerance (T_{DS})

If the cone diameter tolerance is reduced locally and is given for a defined section only, for functional or manufacturing reasons, the cone diameter tolerance should be indicated for this section only.

11 Table of cone angle tolerances – structure of the table

As the cone angle tolerances (*AT*) have different functions, they are stepped in grades represented by numbers, for example AT 5. Table 4 shows these cone angle tolerance grades. They are expressed in microradians (μrad) [1] for AT_α or in micrometres (μm) for AT_D, calculated from the constant AT_α value within a range of cone lengths. AT_D is valid normal to the axis [2] in the form of a diameter difference. It should be smaller with respect to the cone diameter tolerance T_D. Taking account of the units (micrometres, microradians), the following relationship exists (see also Figure 23):

$$AT_D = AT_\alpha \times L.$$

The grade numbers for IT (diameter) and AT (angle) tolerances are chosen in such a way that the same numbers correspond to approximately the same difficulties of manufacture. No direct relation is given, however, because the IT values are stepped in accordance with the diameter of cylindrical workpieces, whereas the AT values are stepped in accordance with the cone length (*L*).

The ratio for the cone angle tolerances from an AT grade to the next higher grade is 1:6. It is necessary to relate the cone and tolerance (*AT*) to the cone length (*L*), because the longer the length of cone, the better the angle can be met. The cone lengths (*L*) from 6 to 630 mm are divided into ten ranges with a stepped ratio of 1:6.

The AT_α values decrease from one range of length to the next higher range by a step of 0.8, which corresponds to the experimental relationship:

$$AT_\alpha \sim \frac{1}{\sqrt{L}}.$$

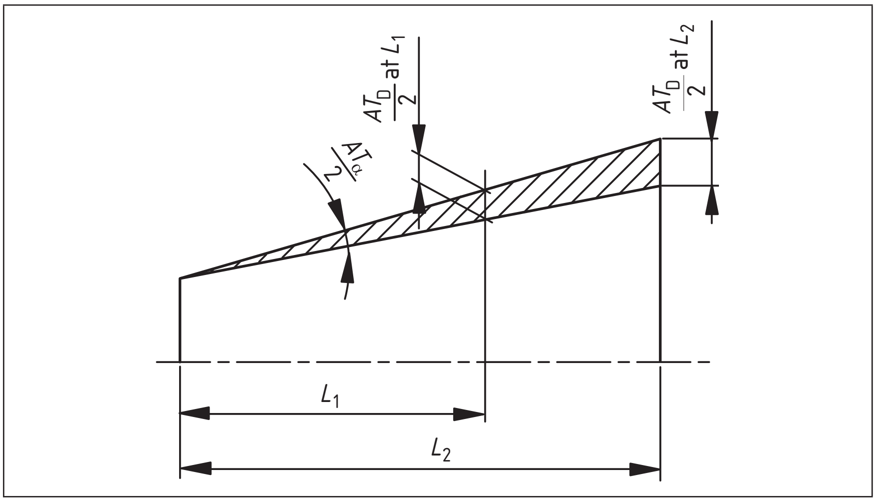
[1] 1 μrad = an angle producing an arc of length 1 μm at a radial distance of 1 m. 5 μrad ≈ 1″ (1 second); 300 μrad ≈ 1′ (1 minute).

[2] The measurement normal to the cone axis is regarded as equivalent to the theoretical correct measurement normal to the generator as the difference of the measured AT_D values is only 2% even for a cone 1:3.

As the AT_{α} values are held constant in a cone length range, it is the corresponding AT_D values that vary. They are given for the limits of the ranges of lengths and increase from one length range to the next with a ratio of 1:25.

Figure 23 shows the largest and smallest values for AT_D resulting from the largest (L_{max}) and smallest (L_{min}) basic lengths of a length range at a constant AT_{α} value.

Figure 23 **Variation of AT_D within a range of cone length with the limits of the length range L_1 and L_2**



No relationship is provided for between the cone angle tolerance and the cone diameter because of lack of experience. The introduction of such a relationship will be made in future if sufficient experience is available. In the case of conical workpieces with large cone diameters, it is left to the user to select a higher AT grade than that used for conical workpieces of small diameter.

If finer or coarser angle tolerances are necessary, they should be calculated by division or multiplication by 1.6 from the AT_1 and AT_{12} values respectively. The finer AT grades should be designated AT 0, AT 01.

Table 4 **Cone angle tolerance grades**

Range of cone length L mm		Cone angle tolerance grades								
		AT 1			AT 2			AT 3		
		AT_{α}		AT_D	AT_{α}		AT_D	AT_{α}		AT_D
Over	**Up to**	μrad	Seconds	μm	μrad	Seconds	μm	μrad	Seconds	μm
6	10	50	10"	0.3–0.5	80	16"	0.5–0.8	125	26"	0.8–1.3
10	16	40	8"	0.4–0.6	63	13"	0.6–1	100	21"	1–1.6
16	25	31.5	6"	0.5–0.8	50	10"	0.8–1.3	80	16"	1.3–2
25	40	25	5"	0.6–1	40	8"	1–1.6	63	13"	1.6–2.5
40	63	20	4"	0.8–1.3	31.5	6"	1.3–2	50	10"	2–3.2
63	100	16	3"	1–1.6	25	5"	1.6–2.5	40	8"	2.5–4
100	160	12.5	2.5"	1.3–2	20	4"	2–3.2	31.5	6"	3.2–5
160	250	10	2"	1.6–2.5	16	3"	2.5–4	25	5"	4–6.3
250	400	8	1.5"	2–3.2	12.5	2.5"	3.2–5	20	4"	5–8
400	630	6.3	1"	2.5–4	10	2"	4–6.3	16	3"	6.3–10

Table 4 **Cone angle tolerance grades** *(continued)*

Range of cone length L mm		Cone angle tolerance grades								
		AT 4			AT 5			AT 6		
		AT_{α}		AT_D	AT_{α}		AT_D	AT_{α}		AT_D
Over	**Up to**	μrad	Seconds	μm	μrad	Minutes seconds	μm	μrad	Minutes seconds	μm
6	10	200	41"	1.3–2	315	1'05"	2–3.2	500	1'43"	3.2–5
10	16	160	33"	1.6–2.5	250	52"	2.5–4	400	1'22"	4–6.3
16	25	125	26"	2–3.2	200	41"	3.2–5	315	1'0.5"	5–8
25	40	100	21"	2.5–4	160	33"	4–6.3	250	52"	6.3–10
40	63	80	16"	3.2–5	125	26"	5–8	200	41"	8–12.5
63	100	63	13"	4–6.3	100	21"	6.3–10	160	33"	10–16
100	160	50	10"	5–8	80	16"	8–12.5	125	26"	12.5–20
160	250	40	8"	6.3–10	63	13"	10–16	100	21"	16–25
250	400	31.5	6"	8–12.5	50	10"	12.5–20	80	16"	20–32
400	630	25	5"	10–16	40	8"	16–25	63	13"	25–40

Table 4 **Cone angle tolerance grades** *(continued)*

Range of cone length *L* mm		Cone angle tolerance grades								
		AT 7			AT 8			AT 9		
		AT_α		AT_D	AT_α		AT_D	AT_α		AT_D
Over	**Up to**	μrad	Minutes seconds	μm	μrad	Minutes seconds	μm	μrad	Minutes seconds	μm
6	10	800	2'45"	5–8	1 250	4'18"	8–12.5	2 000	6'52"	12.5–20
10	16	630	2'10"	6.3–10	1 000	3'26"	10–16	1 600	5'30"	16–25
16	25	500	1'43"	8–12.5	800	2'45"	12.5–20	1 250	4'18"	20–32
25	40	400	1'22"	10–16	630	2'10"	16–25	1 000	3'26"	25–40
40	63	315	1'05"	12.5–20	500	1'43"	20–32	800	2'45"	32–50
63	100	250	52"	16–25	400	1'22"	25–40	630	2'10"	40–63
100	160	200	41"	20–32	315	1'05"	32–50	500	1'43"	50–80
160	250	160	33"	25–40	250	25"	40–63	400	1'22"	63–100
250	400	125	26"	32–50	200	41"	50–80	315	1'05"	80–125
400	630	100	21"	40–63	160	33"	63–100	250	52"	100–160

Table 4 **Cone angle tolerance grades** *(continued)*

Range of cone length *L* mm		Cone angle tolerance grades								
		AT 10			AT 11			AT 12		
		AT_α		AT_D	AT_α		AT_D	AT_α		AT_D
Over	**Up to**	μrad	Minutes seconds	μm	μrad	Minutes seconds	μm	μrad	Minutes seconds	μm
6	10	3 150	10'49"	20–32	5 000	17'10"	32–50	8 000	27'28"	50–80
10	16	2 500	8'35"	25–40	4 000	13'44"	40–63	6 300	21'38"	63–100
16	25	2 000	6'52"	32–50	3 150	10'49"	50–80	5 000	17'10"	80–125
25	40	1 600	5'30"	40–63	2 500	8'35"	63–100	4 000	13'44"	100–160
40	63	1 250	4'18"	50–80	2 000	6'52"	80–125	3 150	10'49"	125–200
63	100	1 000	3'26"	63–100	1 600	5'30"	100–160	2 500	8'35"	160–250
100	160	800	2'45"	80–125	1 250	4'18"	125–200	2 000	6'52"	200–320
160	250	630	2'10"	100–160	1 000	3'26"	160–250	1 600	5'30"	250–400
250	400	500	1'43"	125–200	800	2'45"	200–320	1 250	4'18"	320–500
400	630	400	1'22"	160–250	630	2'10"	250–400	1 000	3'26"	400–630

Annex A (informative) Effect on the cone fit of departures of the internal and external cones from the basic cone

A.1 Effect of cone diameter tolerances

A.1.1 Cone diameter tolerance (T_D)

Application of the cone diameter tolerance (**3.7.2**) means that each individual internal and external cone should conform to their respective maximum material condition (MMC) and least material condition (LMC) boundaries over the whole length of the cone, and therefore the designed fit will be achieved throughout the whole cone length.

A.1.2 Cone diameter tolerance (T_{DS}) in a defined section

Application of the cone diameter tolerance in a defined section (**3.7.4**) means that each individual internal and external cone should conform to the maximum and minimum (diametral) limits in a specifically defined section only, and therefore the maximum material condition (MMC) and least material condition (LMC) boundaries might be exceeded in other sections of the cones.

A.2 Effect of cone form tolerances

All departures from circular form of the section and from the straightness of the generator are included in the cone diameter tolerance (T_D). They affect the quality of the contact of the assembled conical workpieces at the conical surfaces and should be taken into account in design. If the possible extremes of circular form and straightness cannot be tolerated for functional reasons, the cone diameter limits should be reduced, either by changing the cone diameter tolerance appropriately or by separately specifying tolerances on circular form and straightness.

A.3 Variation of cone angle fit (AT_p)

This is the tolerance of the cone angle between the conical workpieces of the cone fit; it is the possible variation of the (cone) angle clearance and/or interference between the conical workpieces to be assembled and is the absolute value of the difference between the maximum and minimum (cone) angle clearance and interferences respectively.

"Maximum cone angle clearance" = "maximum internal cone angle" minus "minimum external cone angle".

$$S_{amax} = \alpha_{imax} - \alpha_{emin}$$

"Minimum cone angle clearance" = "minimum internal cone angle" minus "maximum external cone angle".

$$S_{amin} = \alpha_{imin} - \alpha_{emax}$$

$$AT_P = (\alpha_{imax} - \alpha_{emin}) - (\alpha_{imin} - \alpha_{emax})$$

thus:

$$AT_P = S_{amax} - S_{amin}.$$

The variation of cone angle is equal to the sum of the cone angle tolerances of the internal cone (AT_i) and external cone (AT_e).

$$AT_P = AT_i + AT_e$$

A.4 Effect of cone angle tolerance

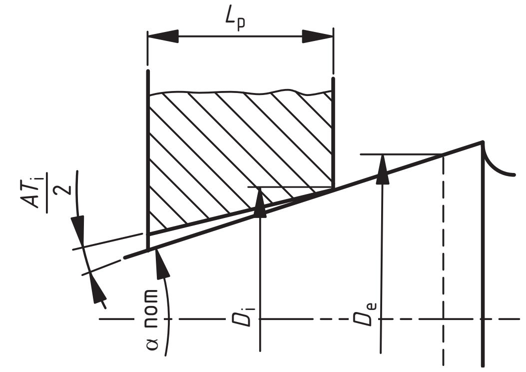
The cone angle tolerance for the internal cone (AT_i) and for the external cone (AT_e) affect the uniformity of the clearance or interference respectively and also the degree of contact at the conical surfaces and the alignment of the assembled conical workpieces over the length of the conical surfaces.

Furthermore, the cone angle tolerances determine, dependent upon the relationship with the basic cone angle, whether the first contact between the surfaces of the conical workpieces to be assembled is at the large or small cone diameter, or on the whole conical surfaces.

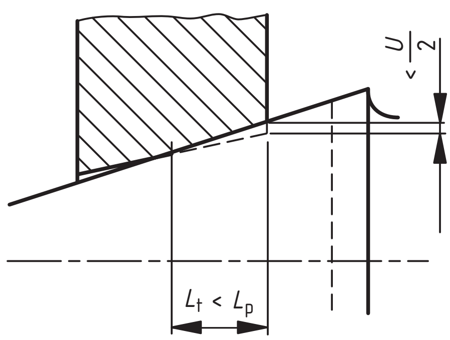
For interference cone fits, the cone angle tolerances should decrease corresponding to the designed interferences in order to obtain as great a contact length as possible between the conical surfaces. The relation between the contact length (L_t) with respect to the fit length (L_p) is zero at the moment of the first contact [see Figure A.1a)]. This increases after pressing together the workpieces through intermediate values smaller than 1 [see Figure A.1b)], until after further pressing, the relationship at the full contact length reaches the value 1 [see Figure A.1c)].

If the external cone is pressed in further, full contact is maintained but there is interference at position X [see Figure A.1d)] which results in an effective L'_t value, which is larger than 1.

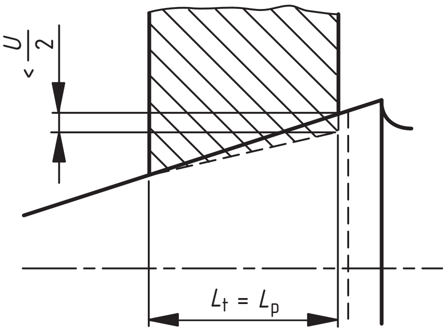
Figure A.1 **Contact lengths (L_t) of the fit surfaces (the external cone is assumed to be perfectly rigid)**



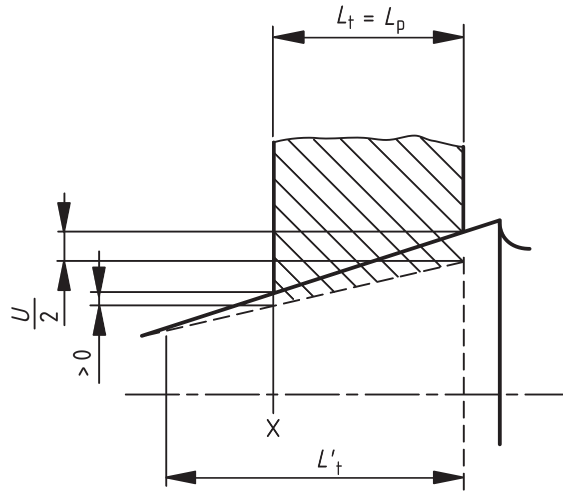
a) First contact: Contact length $L_t = 0$



b) Part contact: Contact length $L_t < L_p$ (L_p = fit length)



c) Full contact: Contact length $L_t = L_p$



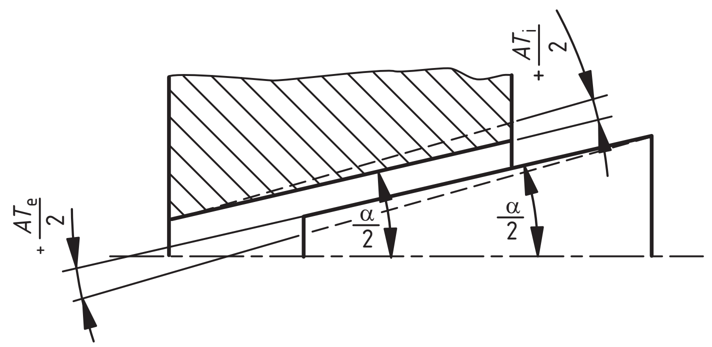
d) Full contact: Contact length $L_t = L_p$ but $L'_t > L_p$

A.4.1 Effect of cone angle tolerances having the same value and the same sign symbol for internal cone and external cone

The first contact between the conical workpieces to be assembled depends on the actual cone angles and occurs either at the small cone diameter or the large cone diameter (see Figure A.1 and Figure A.2).

If the basic cone angle (α) of the internal cone and of the external cone is indicated on the drawing with the same sign symbol (+ or –, see Figure A.2; $\pm$, see Figure A.3) and with the same amount for the angle tolerance (AT), then the maximum variation of cone angle fit (AT_p), i.e. the possible variation of the angle of fit between the internal cone and the external cone, is 2 AT.

Figure A.2 **Position of the cone angle tolerance (*AT*) on one side with regard to basic cone angle (*α*) with the same sign for AT_e and AT_i**



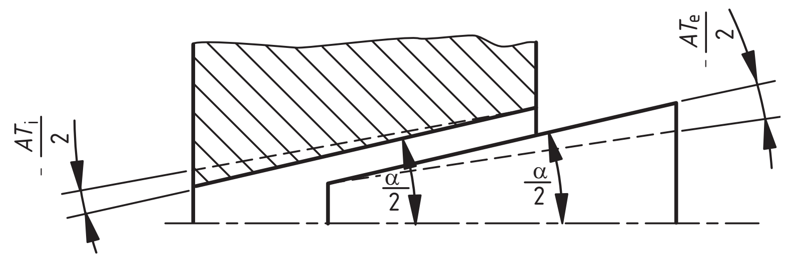
a)

From the indication on drawing a):

external cone $\alpha + AT_e$

internal cone $\alpha - AT_i$

result in first contact at the small or the large cone diameter or the whole conical surface depending on the actual cone angle.



b)

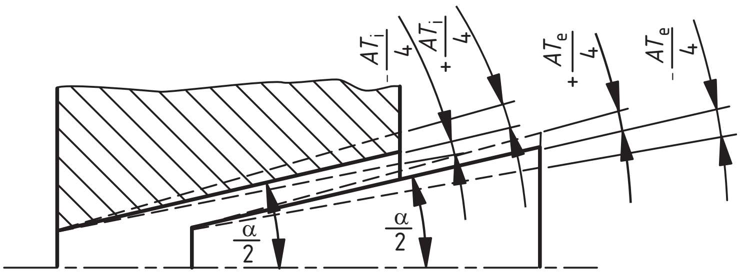
From the indication on drawing b):

external cone $\alpha - AT_e$

internal cone $\alpha - AT_i$

result in first contact at the small or the large cone diameter or the whole conical surface depending on the actual cone angle.

Figure A.3 **Position of the cone angle tolerance (*AT*) on both sides with regard to the basic cone angle (*α*)**

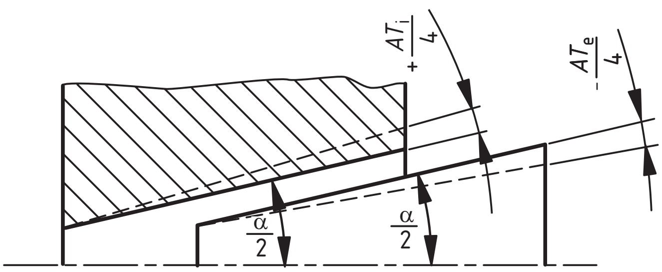


a)

From the indication on drawing a):

external cone $\alpha \pm \frac{AT_e}{2}$

internal cone $\alpha \pm \frac{AT_i}{2}$



b)

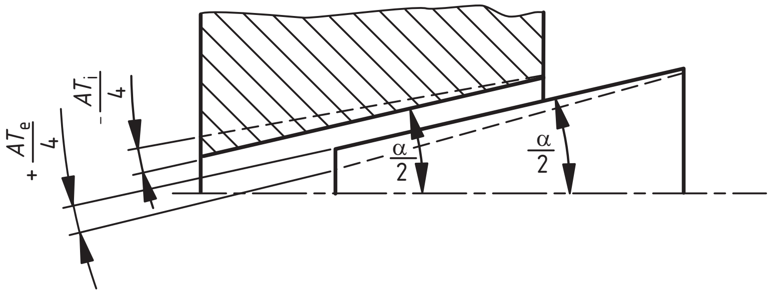
It follows:

b) First limiting case:

external cone $-\frac{AT_e}{2}$

internal cone $+\frac{AT_i}{2}$

results in first contact at the small cone diameter or the whole conical surface, depending on the actual cone angle.



c)

c) Second limiting case:

external cone $+\frac{AT_e}{2}$

internal cone $-\frac{AT_i}{2}$

results in first contact at the large cone diameter or the whole conical surface, depending on the actual cone angle.

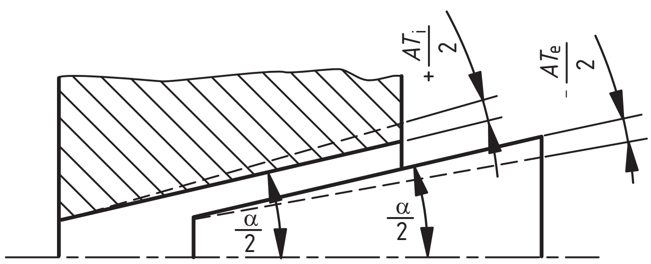
A.4.2 Effect of cone angle tolerances having the same value and opposite sign for internal and external cone

In this case, the maximum variation of cone angle fit (AT_p), i.e. the possible variation of angle of the fit between the internal cone and the external cone, is likewise 2*AT*.

The tolerance indications $+AT_i$ for cone angle α of the internal cone and $-AT_e$ for the cone angle α of the external cone result in a first contact at the small cone diameter or on the whole conical surface [see Figure A.4a)].

The tolerance indications $-AT_i$ for the cone angle α of the internal cone and $+AT_e$ for the cone angle α of the external cone result in a first contact at the large cone diameter or on the whole conical surface [see Figure A.4b)].

Figure A.4 **Position of the cone angle tolerance (*AT*) on one side with regard to the basic cone angle (*α*) with opposite sign for AT_e and AT_i**



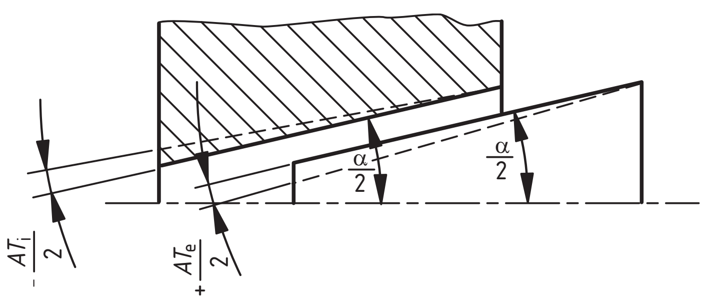
a)

From the indication on drawing a):

external cone $\alpha - AT_e$

internal cone $\alpha + AT_i$

result in first contact at the small cone diameter or the whole conical surface depending on the actual cone angle.



b)

From the indication on drawing b):

external cone $\alpha + AT_e$

internal cone $\alpha - AT_i$

result in first contact at the large cone diameter or the whole conical surface depending on the actual cone angle.

Annex B (informative) Maximum cone angle deviations resulting from the cone diameter tolerances (T_D) for 100 mm cone length

Table B.1 shows the maximum cone angle deviations resulting from the cone diameter tolerances (T_D) for 100 mm cone length.

For lengths other than 100 mm, the values given in the table should be multiplied by 100/*L*, where *L* is the cone length in millimetres.

Table B.1 **Maximum cone angle deviation**

Grades	**Ranges of cone diameters** mm						
	Up to 3	Over 3 to 6	Over 6 to 10	Over 10 to 18	Over 18 to 30	Over 30 to 50	Over 50 to 80
	$\Delta\alpha$, μrad						
IT01	3	4	4	5	6	6	8
IT0	5	6	6	8	10	10	12
IT1	8	10	10	12	15	15	20
IT2	12	15	15	20	25	25	30
IT3	20	25	25	30	40	40	50
IT4	30	40	40	50	60	70	80
IT5	40	50	60	80	90	110	130
IT6	60	80	90	110	130	160	190
IT7	100	120	150	180	210	250	300
IT8	140	180	220	270	330	390	460
IT9	250	300	360	430	520	620	740
IT10	400	480	580	700	840	1 000	1 200
IT11	600	750	900	1 100	1 300	1 600	1 900
IT12	1 000	1 200	1 500	1 800	2 100	2 500	3 000
IT13	1 400	1 800	2 200	2 700	3 300	3 900	4 600
IT14	2 500	3 000	3 600	4 300	5 200	6 200	7 400
IT15	4 000	4 800	5 800	7 000	8 400	10 000	12 000
IT16	6 000	7 500	9 000	11 000	13 000	16 000	19 000

Table B.1 **Maximum cone angle deviation** *(continued)*

Grades	Ranges of cone diameters mm					
	Over 80 to 120	Over 120 to 180	Over 180 to 250	Over 250 to 315	Over 315 to 400	Over 400 to 500
	$\Delta\alpha$, μrad					
IT01	10	12	20	25	30	40
IT0	15	20	30	40	50	60
IT1	25	35	45	60	70	80
IT2	40	50	70	80	90	100
IT3	60	80	100	120	130	150
IT4	100	120	140	160	180	200
IT5	150	180	200	230	250	270
IT6	220	250	290	320	360	400
IT7	350	400	460	520	570	630
IT8	540	630	720	810	890	970
IT9	870	1 000	1 150	1 300	1 400	1 550
IT10	1 400	1 600	1 850	2 100	2 300	2 500
IT11	2 200	2 500	2 900	3 200	3 600	4 000
IT12	3 500	4 000	4 600	5 200	5 700	6 300
IT13	5 400	6 300	7 200	8 100	8 900	9 700
IT14	8 700	10 000	11 500	13 000	14 000	15 500
IT15	14 000	16 000	18 500	21 000	23 000	25 000
IT16	22 000	25 000	29 000	32 000	36 000	40 000

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3) Referred to in the Foreword only.

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