NOTE 2 For flat surfaces and straight lines, it is often possible to use, for example, parallelism instead of position to achieve the same effect as OZ.

8.2.2.1.4.2 Unspecified angular tolerance zone offset specification element

The VA modifier shall be indicated in the zone, feature and characteristic section of the tolerance indicator when the tolerance zone is defined from a TEF, which is an angular feature of size, having its size considered variable (unspecified), see Figure 24. See also example in ISO 3040.

The nominal angular size of the TEF may not be defined by a TED for cones, e.g. in the case where there is only a ± tolerance indicated for the angular size. In this case, the VA specification element shall always be indicated for line profile specifications and surface profile specifications to make it explicit that the angular size of the TEF is not fixed.

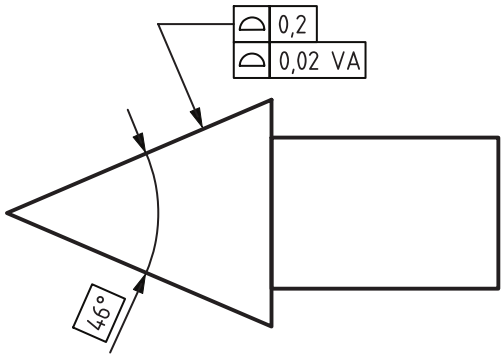


Figure 24 — Variable angle, VA, modifier

NOTE Because there are no bounds on the angular offset, a specification with the VA modifier is usually combined with another specification (angular dimensional specification or geometrical specification without VA modifier), see example in Figure 24.

8.2.2.1.4.3 Orientation only specification element

The orientation only symbol >< shall be indicated in the zone, feature and characteristic section of the tolerance indicator when the tolerance zone translation is unconstrained, i.e. only rotational degrees of freedom for the tolerance zone are constrained in a specification that would otherwise have its translational degrees of freedom constrained by datums. See also ISO 5459.

NOTE 1 For flat surfaces and straight lines, it is often possible to use, for example, parallelism instead of position to achieve the same effect as orientation only.

NOTE 2 Orientation only allows the tolerance zone to translate untransformed, whereas the tolerance zone is transformed when using OZ (inside radii becomes smaller and outside radii becomes bigger). This difference is significant for non-straight and non-flat surfaces and for features of size. In Figure 23, if orientation only had been used instead of OZ, key 3 would not have been transformed, but would have had the same shape as key 1. For single flat surfaces and single straight lines, the effect of OZ and orientation only is the same.

8.2.2.2 Toleranced feature specification element

8.2.2.2.1 Filter specification elements

All the terms related to filtration are defined in ISO 16610-1:2015. The specific filters are defined in the other parts of ISO 16610.

Currently, there is no default filtering defined in the GPS standards. Consequently, the filtering is undefined if it is not explicitly given using these specification elements or other means, see also C.3. This adds an ambiguity of specification, see ISO 17450-2.

NOTE See A.3.7 for former filtering practice.

The filter specification is an optional specification element. The specified filtering of the toleranced feature shall be indicated by a combination of two specification elements. One indicates the type of filter specified, the other indicates the nesting index or indices for the filter.

The symbols for the standardized filters are given in Table C.1. For details on the effect of filters and examples of filter indications, see Annex E.

The nesting indices and their meaning for each filter type are given in Table C.2. For a long-wave pass filter the index shall be followed by a "-". For a short-wave pass filter the index shall be preceded by a "-" . For a band pass filter using the same filter type for both sides, the long-wave pass filter index shall be given first and the short-wave pass filter index shall be given second. The indices shall be separated by a "-" .

For Fourier filters only, indicated by the specification element F (Fourier), a single value shall be indicated when the specification applies to a single harmonic (wavelength or UPR number). If the specification applies to a filtered feature containing a range of harmonics, the indication shall follow the rules given above.

For band pass filters using different filter types, the long-wave pass filter shall be indicated before the short-wave pass filter.

In the specification operator for band pass filters, the long-wave pass filter shall be applied before the short-wave pass filter.

Short-wave pass filters and band pass filters shall only be used for form specifications, i.e. specifications that do not reference datums, because they remove the location and orientation attributes from the toleranced feature.

For open features, e.g. straight lines, planes and cylinders in the axial direction, the nesting index shall be indicated in mm. For closed features, e.g. cylinders in the circumferential direction, tori and spheres, the nesting index shall be indicated in UPR (undulations per revolution). The units shall not be indicated.

If two different filters shall be used in the two directions for a feature that is open in both directions, e.g. a plane, an intersection plane indicator shall be used to indicate the direction in which the first indicated filter shall be applied. "×" shall be used to separate the two filter indications. The second indicated filter shall be applied in the direction perpendicular to the first filter direction.

For a feature that is open in one direction and closed in the other direction, e.g. a cylinder, the filter for the open direction shall be indicated before the filter for the closed direction. "×" shall be used to separate the two filter indications.

If both filters are of the same type, regardless of whether the two directions are both open (e.g. a plane), both closed (e.g. a sphere) or one of each (e.g. a cylinder), the filter type shall be indicated only once.

When the toleranced feature is a derived feature or an associated feature, the filtration shall be applied on the integral feature before the derivation or association operation.

See E.2 for examples of specifications using filters.

8.2.2.2.2 Associated toleranced feature specification element

By default, the specification applies to the indicated extracted integral or derived feature itself. The associated toleranced feature specification element is an optional specification element. It shall be used to indicate that the specification does not apply to the indicated feature itself, but to a feature associated with it. If a filter is indicated, the association shall be to the filtered feature.

The associated toleranced feature specification element shall only be used for specifications that reference datums, i.e. orientation and location specifications.

If the associated toleranced feature specification element is used together with a filter specification element, the association shall be to the filtered feature as the non-ideal feature.

When the toleranced feature is a derived feature, the associated feature shall be the indirectly associated feature, see ISO 22432.

The extent of the associated toleranced feature shall be equal to the extent of the feature to which it is associated.

The associated toleranced feature specification element shall not be used together with a reference feature association specification element, see 8.2.2.3.1, a parameter specification element, see 8.2.2.3.2, or a material condition specification element, see ISO 2692.

The following associated toleranced feature specification elements are available.

Ⓒ shall be used to indicate that the toleranced feature is the associated minimax (Chebyshev) feature without material constraint. This specification element can be used for features that are nominally straight lines, planes, circles, cylinders, cones and tori.

Figure 25 shows an example of a position specification that applies to the associated minimax (Chebyshev) feature. See also Figure 26.

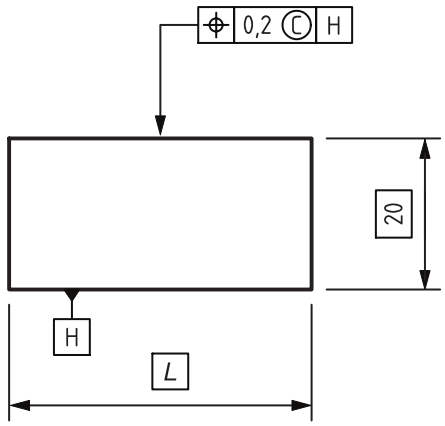
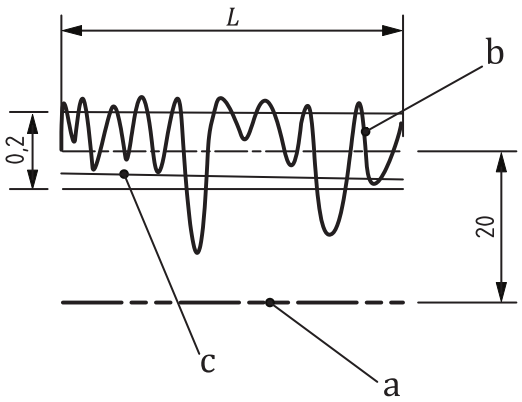


Figure 25 — Minimax (Chebyshev) associated toleranced feature — Drawing indication



Key

a datum H

b real feature or filtered feature

c minimax (Chebyshev) feature (toleranced feature)

NOTE The toleranced feature is a surface, but for ease of illustration it is shown as a line.

Figure 26 — Minimax (Chebyshev) associated toleranced feature — Interpretation

Ⓖ shall be used to indicate that the toleranced feature is the associated least squares (Gaussian) feature without material constraint. This specification element can be used for features that are nominally straight lines, planes, circles and cylinders, cones and tori.

Figure 27 shows an example of a position specification that applies to the associated least squares (Gaussian) feature. See also Figure 28.

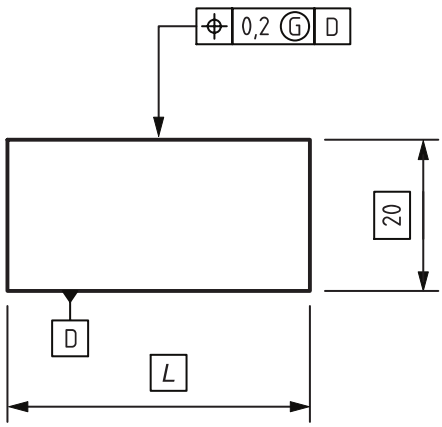
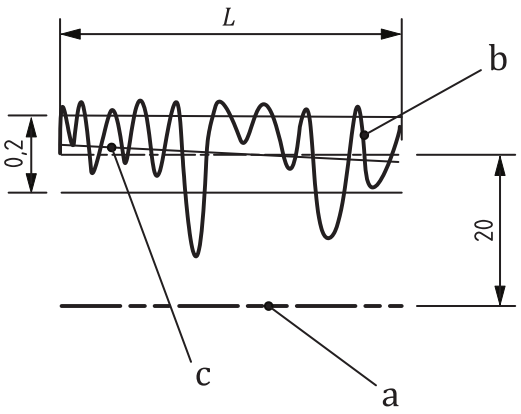


Figure 27 — Least squares (Gaussian) associated toleranced feature — Drawing indication



Key

a datum D

b real feature or filtered feature

c least squares (Gaussian) associated feature (toleranced feature)

NOTE The toleranced feature is a surface, but for ease of illustration it is shown as a line.

Figure 28 — Least squares (Gaussian) associated toleranced feature — Interpretation

Ⓝ shall be used to indicate that the toleranced feature is the associated minimum circumscribed feature or its derived feature. The minimum circumscribed feature association minimizes the size of the associated feature with the constraint that the associated feature circumscribes the non-ideal feature. This specification element can only be used for features of linear size.

Figure 29 shows an example of a position specification that applies to the associated minimum circumscribed feature. See also Figure 30.

NOTE Although the Ⓝ specification element is usually used for external features, e.g. shafts as in Figure 29, it can also be used for internal features, e.g. holes.

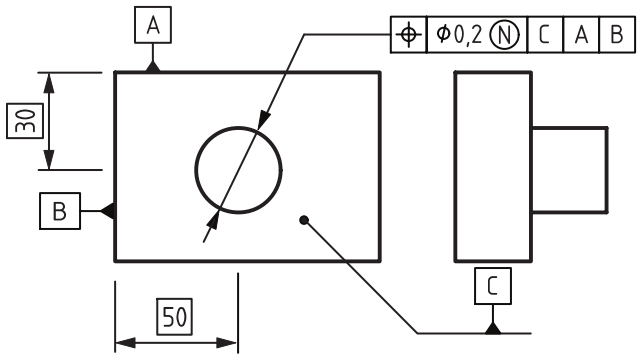
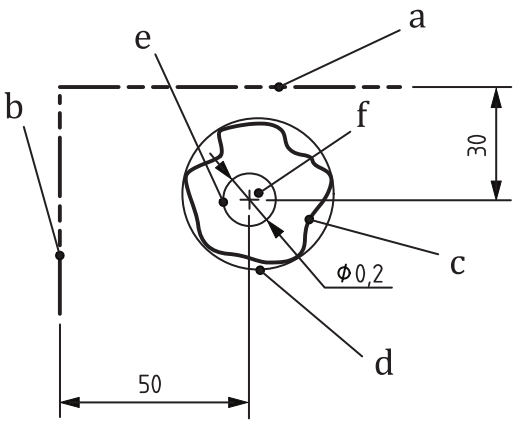


Figure 29 — Minimum circumscribed associated toleranced feature — Drawing indication



Key

a datum A
b datum B
c real feature or filtered feature
d minimum circumscribed feature
e tolerance zone
f toleranced feature (centreline for d)

NOTE The toleranced feature is a straight line (the centre line of the associated feature), but for ease of illustration it is shown as a point.

Figure 30 — Minimum circumscribed associated toleranced feature — Interpretation

Ⓣ shall be used to indicate that the toleranced feature is the associated tangent feature based on the L_2 norm with the constraint that the tangent feature is outside the material of the non-ideal feature. This specification element can only be used for nominally straight lines and plane features. The toleranced feature is the tangent straight line or plane, as applicable, of the indicated feature.

NOTE The L_2 norm with the constraint that the tangent feature is outside the material is the association criterion for datums, see ISO 5459.

Figure 31 shows an example of a parallelism specification that applies to the associated tangent feature. See also Figure 32.

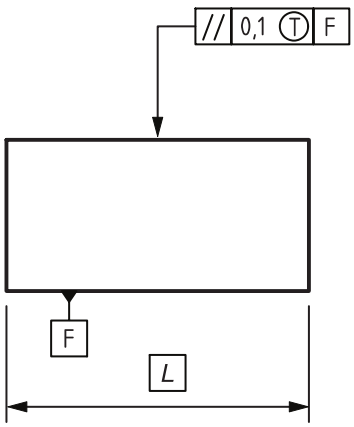
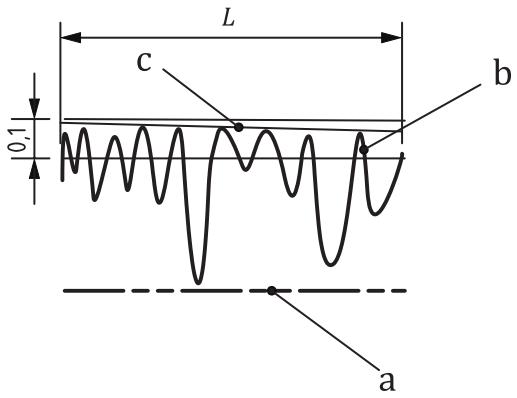


Figure 31 — Tangent associated toleranced feature — Drawing indication



Key

a datum F

b real feature or filtered feature

c tangent feature (toleranced feature)

NOTE The toleranced feature is a surface, but for ease of illustration it is shown as a line.

Figure 32 — Tangent associated toleranced feature — Interpretation

Ⓧ shall be used to indicate that the toleranced feature is the associated maximum inscribed feature or its derived feature. The maximum inscribed feature association maximizes the size of the associated feature with the constraint that the associated feature is inscribed within the non-ideal feature. This specification element can only be used for features of linear size.

NOTE Although the Ⓧ specification element is usually used for internal features, e.g. holes as in Figure 33, it can also be used for external features, e.g. shafts.

Figure 33 shows an example of a position specification that applies to the associated maximum inscribed feature. See also Figure 34.

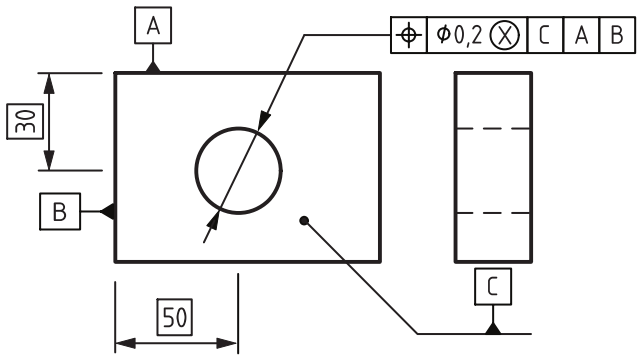
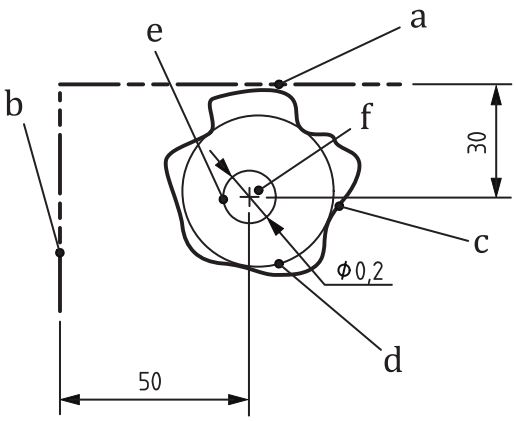


Figure 33 — Maximum inscribed associated toleranced feature — Drawing indication



Key

a datum A
b datum B
c real feature or filtered feature
d maximum inscribed feature
e tolerance zone
f toleranced feature (centreline for d)

NOTE The toleranced feature is a straight line (the centre line of the associated feature), but for ease of illustration it is shown as a point.

Figure 34 — Maximum inscribed associated toleranced feature — Interpretation

A summary of which associated toleranced features can be applied to which types of features is shown in Table 5.

Table 5 — Summary of applicable associated toleranced features by type of feature

Type of feature	Ⓒ	Ⓖ	Ⓝ	Ⓣ	Ⓧ
Straight line	Yes	Yes		Yes	
Plane	Yes	Yes		Yes	
Circle	Yes	Yes	Yes		Yes
Cylinder	Yes	Yes	Yes		Yes
Cone	Yes	Yes			
Torus	Yes	Yes			
Feature of size: 2 parallel planes	Yes	Yes	Yes	Yes	Yes

The associated toleranced feature specification element can be combined with filter specification elements. Figure 35 shows an example where the Ⓣ specification element is combined with the H0 convex hull specification element, indicating that it is the L_2 norm tangent of the convex hull that is the toleranced feature. This toleranced feature is defined the same way a datum based on a plane datum feature is defined, see ISO 5459, thus allowing a specification to control the orientation and location of a datum. See Figure 36.

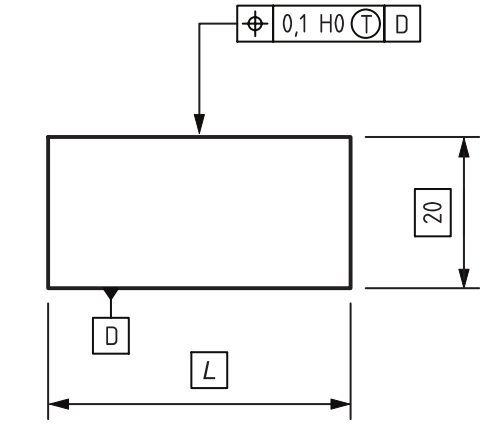
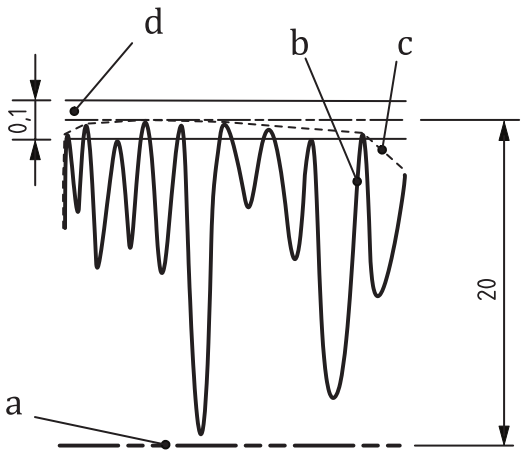


Figure 35 — Tangent toleranced feature associated to the convex hull filtered feature — Drawing indication



Key

a datum D
b real feature
c convex hull filtered feature
d tangent feature to the convex hull filtered feature (toleranced feature)

NOTE The toleranced feature is a surface, but for ease of illustration it is shown as a line.

Figure 36 — Tangent toleranced feature associated to the convex hull filtered feature — Interpretation

8.2.2.2.3 Derived toleranced feature specification element

By default, the specification applies to the indicated feature itself, except as given in Clause 6. The derived toleranced feature specification element is an optional specification element. It is used to indicate that the specification does not apply to the integral feature itself, but to a feature derived from it.

The following derived toleranced feature specification elements are available.

— Ⓐ is used to indicate that the toleranced feature is the derived feature. Therefore, this specification element can only be used for features of size. Because the indication would be ambiguous, if the feature of size is made up of two features, e.g. two parallel planes, this specification can only be used for revolutes. The derived feature is the median line, if the indicated feature is a cylinder, or the median point, if the indicated feature is a circle or a sphere.

— Ⓟ is used to indicate that the tolerance zone applies to an extended feature (projected toleranced feature), see Clause 12.

Figure 37 shows an example of a straightness specification that applies to the derived feature, i.e. the median line of the cylinder.

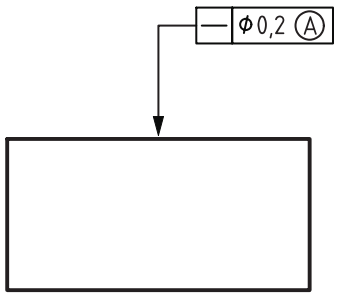


Figure 37 — Specification applying to the median feature

8.2.2.3 Characteristic specification elements

8.2.2.3.1 Reference feature association specification element

By default, the reference feature association is the minimax (Chebyshev) association without constraints. The reference feature association specification element is an optional specification element. It can be used for form specifications, i.e. specifications that do not reference datums, and other specifications that have at least one unconstrained non-redundant degree of freedom.

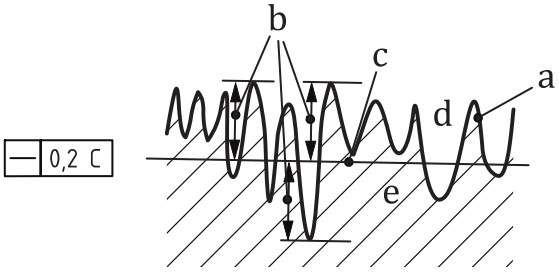
The following specification elements are available.

— C shall be used to indicate the minimax (Chebyshev) association. It minimizes the distance from the furthest point on the toleranced feature to the reference feature, see Figure 38 a).

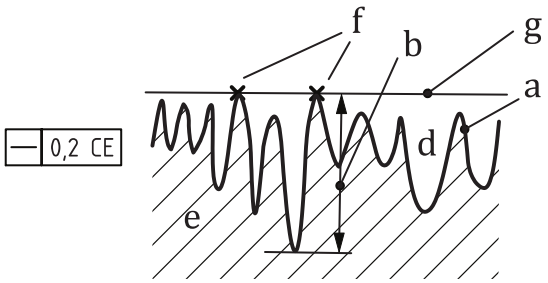
— CE shall be used to indicate the minimax (Chebyshev) association with the constraint external to the material. It minimizes the distance from the furthest point on the toleranced feature to the reference feature while maintaining the reference feature external to the material, see Figure 38 b).

— CI shall be used to indicate the minimax (Chebyshev) association with the constraint internal to the material. It minimizes the distance from the furthest point on the toleranced feature to the reference feature while maintaining the reference feature internal to the material, see Figure 38 c).

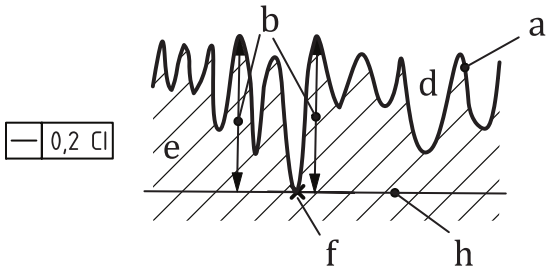
NOTE 1 The minimax (Chebyshev) association without constraint, the minimax (Chebyshev) association with the constraint external to the material and the minimax (Chebyshev) association with the constraint internal to the material (keys c, g and h in Figure 38) are all by definition parallel.



a) Minimax (Chebyshev) association without additional constraints



b) Minimax (Chebyshev) association with the constraint external to the material



c) Minimax (Chebyshev) association with the constraint internal to the material

a Toleranced feature.

b Minimized maximum distances.

c Minimax (Chebyshev) associated straight line without additional constraints – the reference feature with modifier C.

d Outside the material.

e Inside the material.

f Point of contact between the associated feature and the toleranced feature.

g Minimax (Chebyshev) associated straight line with the constraint external to the material – the reference feature with modifier CE.

h Minimax (Chebyshev) associated straight line with the constraint internal to the material – the reference feature with modifier CI.

NOTE The tolerance indicators shown in this figure do not show a parameter specification element, see 8.2.2.3.2, so the characteristic specified is the total range of deviations, which is the default parameter.

Figure 38 — Minimax (Chebyshev) associations

— G shall be used to indicate the least squares (Gaussian) association. It minimizes the square of the local deviations of the toleranced feature to the reference feature.

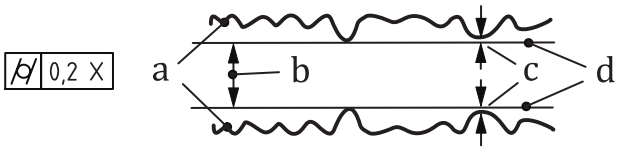
— GE shall be used to indicate the least squares (Gaussian) association with the constraint external to the material. It minimizes the square of the local deviations of the toleranced feature to the reference feature while maintaining the reference feature external to the material.

— GI shall be used to indicate the least squares (Gaussian) association with the constraint internal to the material. It minimizes the square of the local deviations of the toleranced feature to the reference feature while maintaining the reference feature internal to the material.

NOTE 2 The least squares (Gaussian) associations are similar to the minimax (Chebyshev) associations shown in Figure 38, except what is minimized is not the maximum distance to the associated feature but the square root of the sum of the squares of the local deviations between the toleranced feature and the reference feature.

NOTE 3 The least squares (Gaussian) association without constraint, the least squares (Gaussian) association with the constraint external to the material and the least squares (Gaussian) association with the constraint internal to the material (equivalent to keys c, g and h in Figure 38) are not parallel by definition.

— X shall be used to indicate the maximum inscribed association. It is only available for toleranced features of linear size. It maximizes the size of the reference feature while maintaining it entirely inside the toleranced feature. See Figure 39.



a Toleranced feature of size.

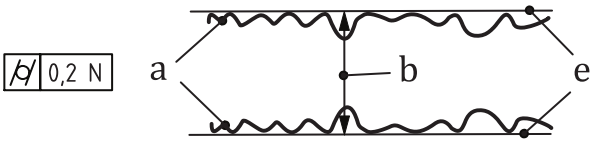
b Size of the associated feature (maximized).

c Equalized distance, in case of unstable association.

d Maximum inscribed associated feature of size.

Figure 39 — Maximum inscribed association

— N shall be used to indicate the minimum circumscribed association. It is only available for toleranced features of linear size. It minimizes the size of the reference feature while maintaining it entirely outside the toleranced feature. See Figure 40.



a Toleranced feature of size.

b Size of the associated feature (minimized).

e Minimum circumscribed associated feature of size.

Figure 40 — Minimum circumscribed association

Figure 41 shows an example of a straightness specification that applies relative to the least squares (Gaussian) reference feature. The intersection plane indicator indicates that the direction of the toleranced lines is parallel to datum C.

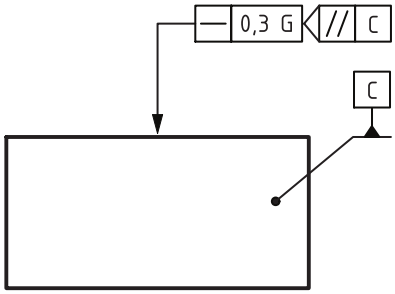


Figure 41 — Specification using the least squares (Gaussian) reference feature specification element

Figure 42 shows an example of a roundness specification that applies relative to the minimum circumscribed reference feature after the application of a Gaussian long-wave pass filter with a cutoff value of 50 UPR. The filter type specification element shall always be followed by the nesting index value and the reference feature specification element consists of letters only. When they both apply in the same specification, the filter type specification element shall always precede the reference feature specification element.

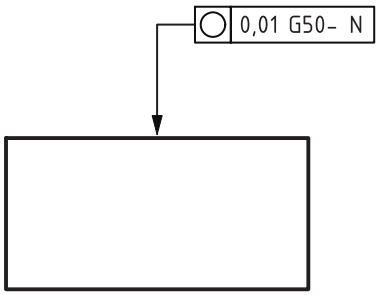


Figure 42 — Specification using a filter specification element and the minimum circumscribed reference feature specification element

8.2.2.3.2 Parameter specification element

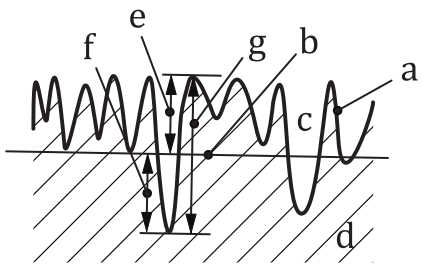
The default parameter that applies when no specification element is indicated is the total range of deviations, i.e. the distance from the lowest valley on the toleranced feature to the reference feature plus the distance from the highest peak of the toleranced feature to the reference feature. The parameter specification element is an optional specification element. It can be used for form specifications, i.e. specifications that do not reference datums, and other specifications that have at least one unconstrained non-redundant degree of freedom.

The following parameter specification elements are available.

— T may be used to indicate the total range of deviations, i.e. the default parameter, see Figure 43.

— P shall be used to indicate the peak height, i.e. the distance from the highest peak of the toleranced feature to the reference feature. The peak height is only defined relative to the minimax (Chebyshev) association and the least squares (Gaussian) association, i.e. the association specification elements C and G, see Figure 43.

— V shall be used to indicate the valley depth, i.e. the distance from the lowest valley of the toleranced feature to the reference feature. The valley depth is only defined relative to the minimax (Chebyshev) association and the least squares (Gaussian) association, i.e. the association specification elements C and G, see Figure 43.



a Toleranced feature.

b Minimax (Chebyshev) or least squares (Gaussian) associated straight line without additional constraints (reference feature).

c Outside the material.

d Inside the material.

e Peak height (P) parameter.

f Valley depth (V) parameter.

g Total range (T) parameter, T = P + V.

Figure 43 — Parameters

— Q shall be used to indicate the square root of the sum of the squares of the residuals or standard deviation of the toleranced feature relative to the reference feature.

$$Q = \sqrt{\frac{1}{l}\int_0^l Z^2(x)dx} \text{ for linear features,}$$

or

$$Q = \sqrt{\frac{1}{a}\int_0^a Z^2(x)dx} \text{ for areal features}$$

where

Q is the Q parameter;

l is the length of the toleranced feature;

a is the area of the toleranced feature;

$Z(x)$ is the local deviation function for the toleranced feature;

x is the position along the toleranced feature.

NOTE 1 The origin of $Z(x)$ is the reference feature, either the default reference feature [minimax (Chebyshev) without constraint] or the reference feature specified according to 8.2.2.3.1.

NOTE 2 The T specification element is the only one that conforms to the concept of a tolerance zone.

Figure 44 shows an example of a roundness specification that applies to the valley depth relative to the least squares (Gaussian) reference circle.

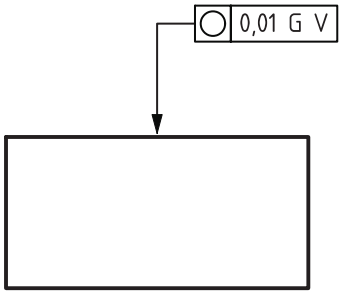


Figure 44 — Specification using the least squares (Gaussian) reference feature specification element and the valley depth characteristic specification element

Figure 45 shows an example of a cylindricity specification that applies to the peak height relative to the minimax (Chebyshev) reference cylinder after the application of a spline long-wave pass filter with cutoff values of 0,25 mm in the axial direction and 150 UPR in the circumferential direction.

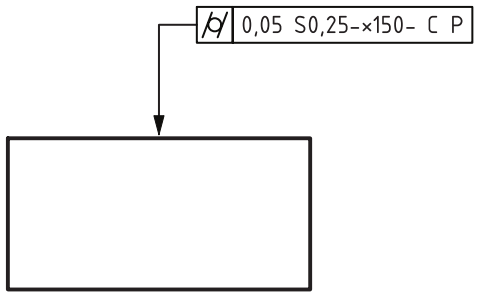


Figure 45 — Specification of a filter specification element, a reference feature specification element and a characteristic specification element

8.2.2.4 Material condition specification element

The material requirement specification elements, Ⓜ, Ⓛ and Ⓡ, are optional specification elements, see ISO 2692.

8.2.2.5 State specification element

The state specification element, Ⓕ, is an optional specification element, see ISO 10579.

8.2.3 Datum section

For datums and indications in the datum section, see ISO 5459.

8.3 Plane and feature indicators

Intersection plane indicators (Clause 13), orientation plane indicators (Clause 14), direction feature indicators (Clause 15) and collection plane indicators (Clause 16) can be indicated to the right of the tolerance indicator. If several of these are indicated, the intersection plane indicator shall be indicated nearest the tolerance indicator, followed by the orientation plane indicator or direction feature indicator (these two shall not be indicated together), and finally the collection plane indicator. There shall be no space between the tolerance indicator and the plane and feature indicator(s). When any of these indicators are indicated, the reference line can either be attached to the left hand end of the tolerance indicator or the right hand end of the last of the optional indicators.