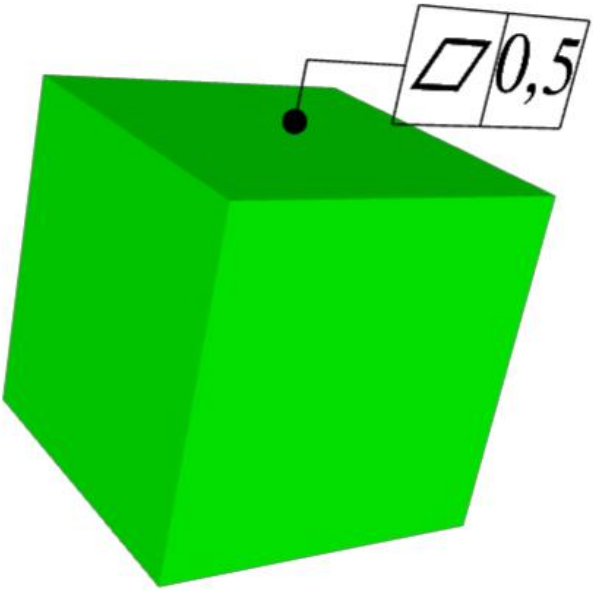
BOOKLET

Geometrical Product Specification



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gps-booklet-rev4

DISCLAIMER:

This booklet has been written taking into account ISO standards issued before january 2019. It should be pointed out that ISO 5459 and ISO 8015 for example are in the process of revision.
This document was written and checked carefully, however typos or even errors may remain. We strongly encourage the reader to raise those issues by sending an e-mail to the following address:

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FOR FURTHER READING:

The author has also written a book, in French, published by DUNOD in the DunodTech serie entitled:

Génie mécanique

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History

Since 1980 a large project has been launched to develop an ISO international standardization system whose objective is to provide documents that can be used to define without ambiguity the geometry of any product.

The standard system ISO 'GPS' ('Geometric Product Specification') is a set of hierarchical standards for the definition of the specification of the product geometry from its design up to its verification with metrology.

ISO GPS standards hierarchy	
level 1	fundamental standards
level 2	global standards
level 3	general standards
level 4	complementary standards

Rules defined in higher level apply to rules defined in lower level except if the specification explicitly overrides the rule.

some ISO standards of common use	
numver : issue	**title**
ISO 14405-1:2016	Geometrical product specifications (GPS) — Dimensional tolerancing — Part 1: Linear sizes
ISO 1101:2017	Geometrical product specifications (GPS) — Geometrical tolerancing — Tolerances of form, orientation, location and run-out
ISO 5458:2018	Geometrical product specifications (GPS) — Geometrical tolerancing — Pattern and combined geometrical specification
ISO 5459:2011	Geometrical product specifications (GPS) — Geometrical tolerancing — Datums and datum systems
ISO 2692:2014	Geometrical product specifications (GPS) — Geometrical tolerancing — Maximum material requirement (MMR), least material requirement (LMR) and reciprocity requirement (RPR)
ISO 10579:2010	Geometrical product specifications (GPS) — Dimensioning and tolerancing — Non-rigid parts

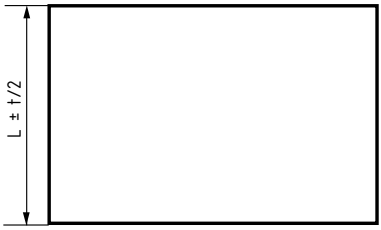
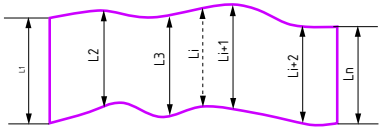
Principle	
Principle	**Statement (Cf ISO 8015:2011)**
invocation	If one of the standard of the GPS system is referenced then all standards from this system shall apply. It is not anymore mandatory to write 'ISO 8015 tolerancing' on the drawing.
definitive drawing	All the requirements shall be stated on th edrawing or on referenced documents. The requirements applicable at a specific phase of the manufacturing process shall be indicated except if the phase is the final one.
feature	Geometrical features are determined by natural boundaries that are generally edges, however an assembly of a cylinder with half-sphere with same diameter is considered as a natural boudary even if the surfaces are tangent at the boundary.
independence	Each specification shall be fulfiled independently of other specification. This rule can be overidden with some modifiers.
decimal	Non indicated decimals in values are zeros. The number 0,3 shall be interpreted as 0,30… and 3 as 3,0…
default specification operator	A specification is based on the default specification. The default specification is defined in ISO GPS standard. Default can be changed with modifiers or with drawing default.
rigid part	The part is assumed to be rigid.
duality	A specification is defined independently of any measurement process. The acceptability of a measurement process depends on the uncertainty associated with this process.
functionnal control	A geometrical specification is complete when all functions are controled by geometrical specifications. In real word a drawing can be incomplete if not all functions correspond to geometrical specifications.
general specification	General specifications apply to each feature without any individual specification. Only individual specifications apply if no general specification is indicated on the drawing.
responsability	The designer has the responsability of the adequacy of the specifications to the functions. The uncertainty associated to the measurement process is the responsability of the party in charge of the verification.
The reference temperature is 20°C. Indications between rounded brackets are not specifications.	

Linear dimension

ISO 14405-1 defines the default size as the distance between two opposite points. This definition applies only to features where opposite points can be defined e.g. cylinders or two opposite parallel planes. Those are example of feature of size. Shape deviations are not controlled by dimensional specification.

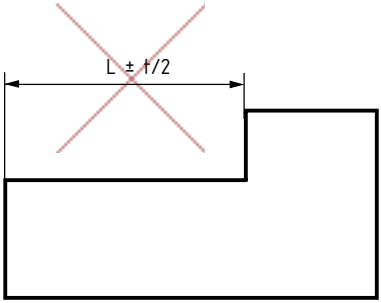
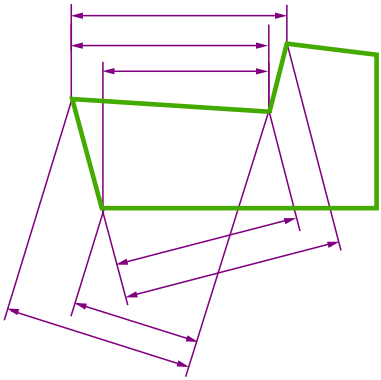
The feature of linear size are cylinder, sphere, torus (if the large diameeter of the directrix is fixed), circle, two parallel opposite planes, two parallel ooposite straight lines.

Dimension between two opposite points by default

Drawing	Real part
 specification	 meaning

A dimensional specification without opposite points is strongly discouraged. It is considered ambiguous according to ISO 14405-2.

Dimension on a part with non-opposite surfaces

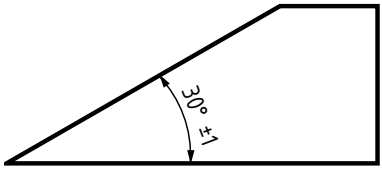
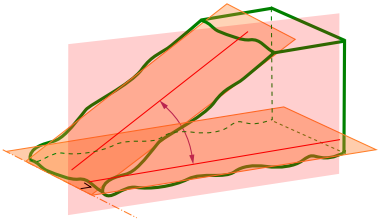
Drawing	Real part
 ambiguous specification	 meaning

Angular dimension

Angular dimensions values are angles as linear dimension values are lengthes.

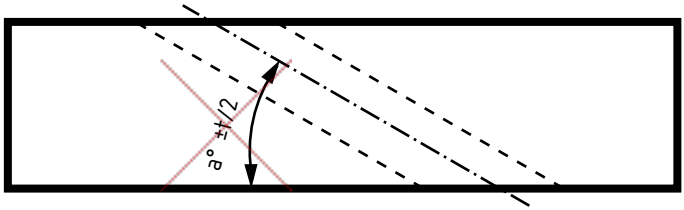
Angular dimensions as linear dimensions don't control shape. Angularity as a geometrical specification, shall be prefered when the function implies an orientation between two plane surfaces including a flatness requirement on each surface.

ISO 14405-3:2016 standard (Geometrical product specifications (GPS) — Dimensional tolerancing — Part 3: Angular sizes) defines angumar dimensions.

Angular dimension	
Drawing	**ISO 14405-3:2016**
	

The angle is is defined between two associated straight lines with minmax criterion in planes perpendicular to the intersection line between least squares planes without external contraints. (see ISO 14405-3:2016 annex A)

As for linear dimensions, angular specifications between axis lines are not allowed.

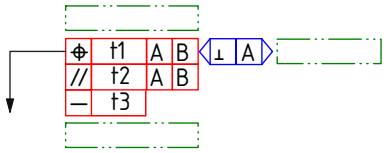
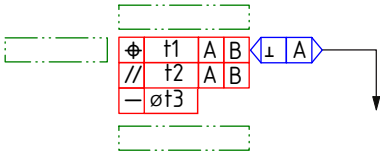
angle on an axis line (derived feature)
discouraged specification according to ISO 14405-2


An angularity specification should be used if the function implies a control of the shape of the plane features.

Description

The following objects have to be specified in order to define a geometrical specification:

Tolérance géométrique	
Object	**Description**
Toleranced feature:	It is the portion of part that is concerned by the geometrical specification considered. It is a real feature with deviations.
Associated datum:	It is a perfect feature build from a real feature of the part. No associated datum are needed in some spcifications such as shape specifications.
Tolerance zone:	A perfect volume or surface that should contain the toleranced feature. The tolerance zone can be constrained in orientation or location from datums or from other tolerance zones. Theoretically Exact Dimensions (dimension with framed value) are used to explicit the constraints.

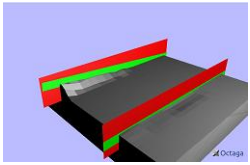
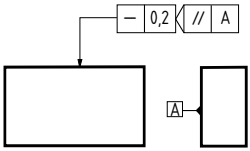
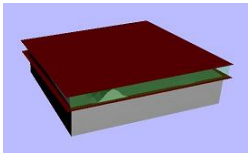
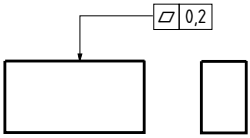
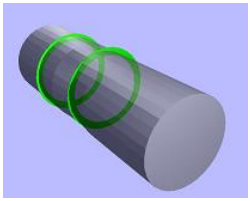
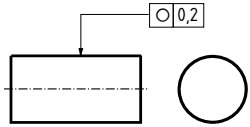
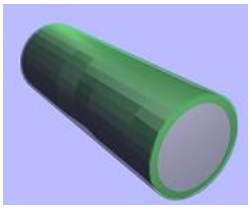
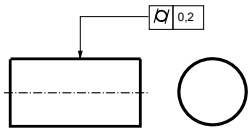
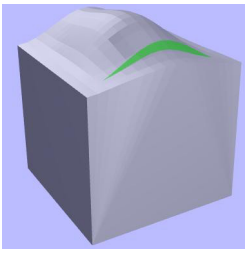
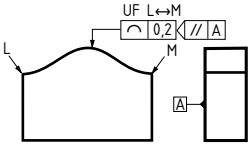
geometrical specification : tolerance indicator	
schema 1	**schema 2**
	

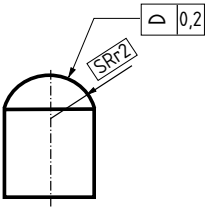
Description	
zone	**content**
red	tolerance indicator (symbol, tolerance value, datum)
blue	orientation plane indicator, intersection plane indicator, collection plane indicator, direction feature indicator
green	adjacent indication

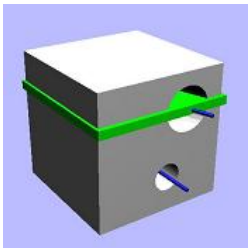
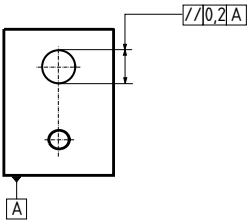
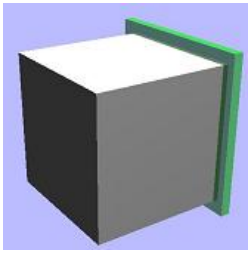
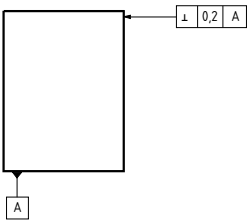
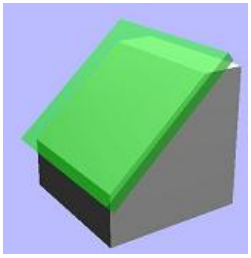
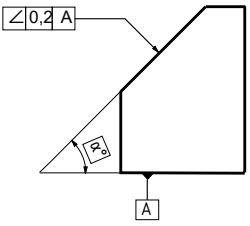
The tolerance zone for most specification is the space between two parallel opposite planes except if the symbole ø is used to indicate a cylindrical zone. Sø indicate a spherical zone. The tolerance zone for a profile of a line or a surface is build from a circle or a sphere whose centre moves on the nominal line or surface.

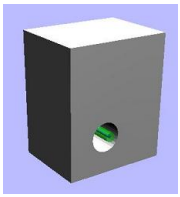
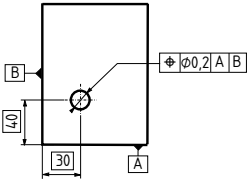
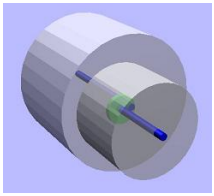
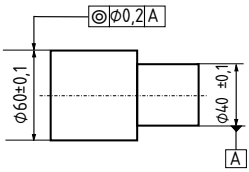
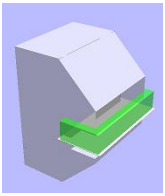
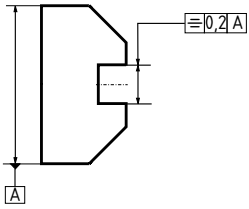
Geometrical tolerance symbols		
Geometrical specification family	**Geometrical specification**	**Symbol**
form tolerance	straightness	—
	flatness	▱
	circularity	○
	cylindricity	⌭
	profile of a line	⌒
	profile of a surface	⌓
orientation tolerance	parallelism	//
	perpendicularity	⊥
	angularity	∠
	profile of a line (*)	⌒
	profile of a surface (*)	⌓
location tolerance	position	⌖
	concentricity ou coaxiality	◎
	symmetry	⌯
	profile of a line (*)	⌒
	profile of a surface (*)	⌓
run-out tolerance	circular run-out	↗
	total run-out	⌰

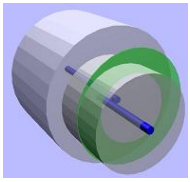
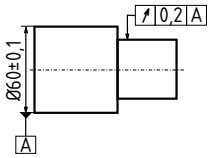
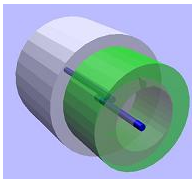
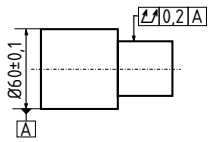
(*) Profile tolerance can be used as location tolerance or orientation tolerance if they have datums.

Form geometrical specification		
Tolerance zone	**Drawing**	**Meaning**
		All line from the real surface parallel to an intersection plane which is parallel to A shall be included inside 2 parallel straight lines spaced 0,2 mm apart.
		The real surface shall be included between two parallel planes spaced 0,2 mm apart
		The line in each cross section shall be included inside two coplanar circles with same centre spaced 0,2 mm apart
		The considered surface shall be included between 2 coaxial cylinders spaced 0,2 mm apart
		In each cross section parallel to intersection plane (A), the real line shall be included between 2 lines build as envelop of circles (ø0,2) whose centre are on the nominal line.

Form geometrical specification (continued)		
Tolerance zone	**Specification**	**Meaning**
		The considered surface shall be included between 2 surfaces build as the envelopes of spheres with diameter 0,2 mm whose centre lies on a surface with the nominal shape.

Orientation geometrical specification		
Tolerance zone	**Specification**	**Meaning**
		The toleranced feature shall be included between two parallel planes spaced 0,2 mm apart parallel to the plane associated to surface A.
		The toleranced surface shall be included between two parallel planes 0,2 mm apart perpendicular to the datum A.
		The inclined surface shall be included between two parallel planes 0,2 mm apart with an angle of α° from the datum A.

Location geometrical tolerance		
Tolerance zone	**Specification**	**Meaning**
		The real axis of the hole shall be included in a cylinder with diameter 0,2 mm whose axis lies in perfect location.
		The real axis of the cylinder linked to the specification shall be included in a cylinder with diameter 0,2 mm coaxial to the datum which is a straight line.
		The real median plane of the slot shall be included between two parallel planes 0,2 mm apart lying in symmetrical position from the median plane of the datum.

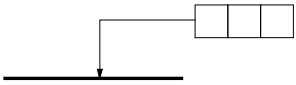
Run-out geometrical specification		
Tolerance zone	**Specification**	**Meaning**
		The radial displacement shall not be greater than 0,2 mm in each cross section when the part is rotated around the datum axis.
		The radial displacement shall not be greater than 0,2 mm on each line of the surface when the part is rotated and translated along the datum axis.

Toleranced feature

Geometrical specifications are defined in the standard ISO 1101.

The toleranced feature is a portion of the real part where the specification applies.

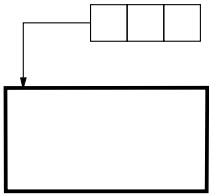
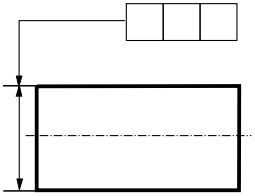
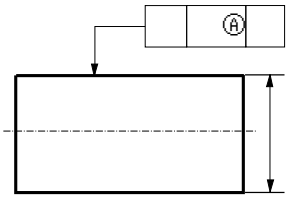
The specification applies to the full extent of the feature unless otherwise indicated.



tolerance feature designation

The reference line can be attached to one the the two ends of the frame.

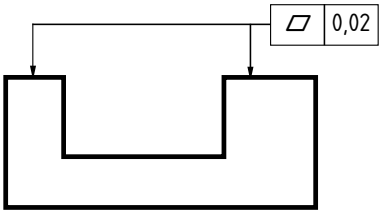
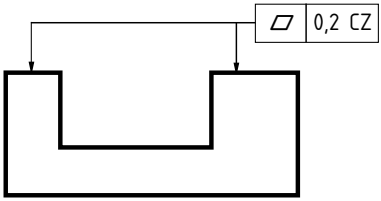
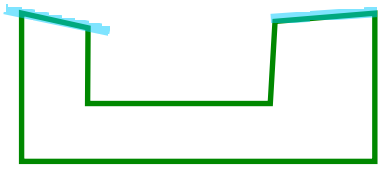
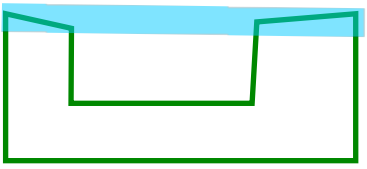
The designation of several features is achieved by adding 'n x' on top of the frame.

Feature designation	
Surface	
Median feature (e.g. axis)	
Median feature (e.g. axis)	

Tolerance zone

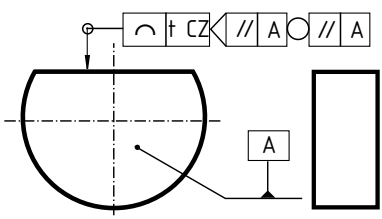
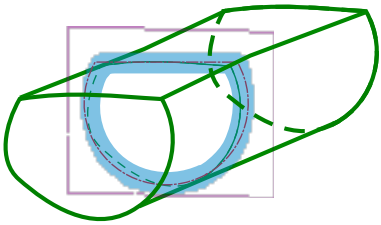
The tolerance zone is the volume or surface inside which the toleranced feature should be included in order to fulfil the specification.

Shape of tolerance zone	
Tolerance zone is:	a disk
	the space between two concentric circles
	the space between two equidistant lines
	the space between two parallel straight lines
	the volume of a cylinder
	the space between two coaxial cylinders
	the space between two surfaces apart from the distance of the value of the tolerance
	the space between two parallel planes
	the volume of a sphere

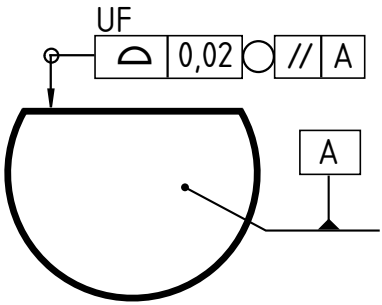
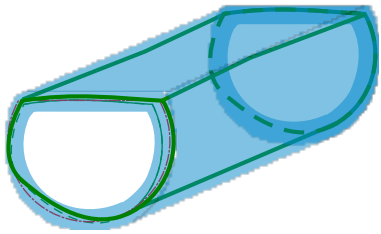
Independent zones or combined zones	
Independent zones	**Combined zones**
	
	

When CZ is used, tolerance zones have location and orientation constrains each other defined with explicit and implicit theoretical exact dimensions.

It is possible to designate a toleranced feature as a line all around of the part. The tolerance is shown here only in one particular section however all sections are to be considered.

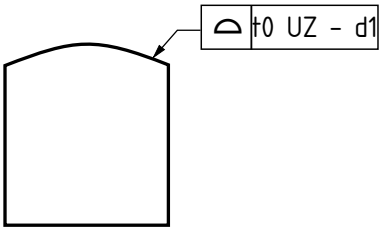
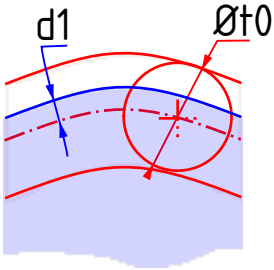
Toleranced lines all around the part	
Drawing	**Tolerance zone**
 **all around line**	 **all around surface**

It is possible to indicate a surface all around the part.

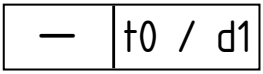
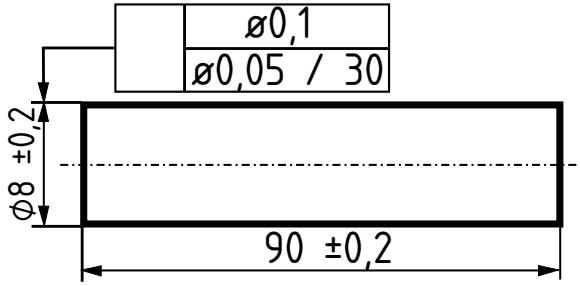
Toleranced surface all around the part.	
Drawing	**Tolerance zone**
	

It is possible to use the symbol 'between' (↔) to specify only a restricted zone.

UF ('United Feature') symbol allows to specify of a unified feature compared to independent single features which is the default (see ISO 8015:2011)

Offset tolerance zone	
Drawing	**Meaning**
	

Minus sign corresponds to an offset toward material. The blue line is the nominal profile. Le material side is coloured in light blue. The red lines are the boundaries of the tolerance zone.

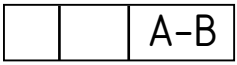
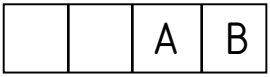
Floating tolerance zone
indication

Example


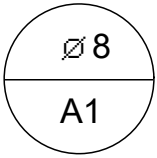
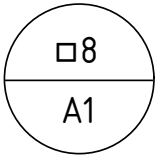
In the above example, the first specification applies on the overall length of the part. The second one applies on a restricted portion of length thirty millimetres which is floating all along the part.

Specification of datums

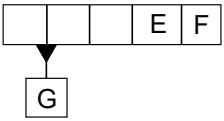
Datums are described in ISO 5459 standard.

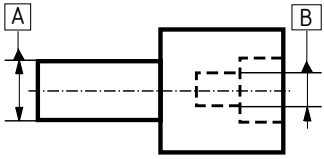
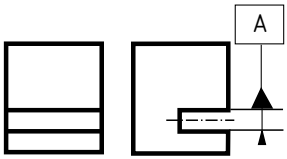
Definitions	
Terms	**Definitions**
Datum feature:	Real features on the real part.
Specified datum:	Situation features build on the associated feature. The associated features are perfect features build on real feature with an association criterion. Situation features are used to assign an orientation or a location to tolerance zone

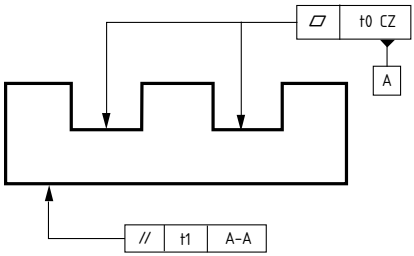
Datum types	
Specification	**Type of datum**
	simple datum
	common datum
	datum system

Datum target	
On a disk	**On a square**
	

Equivalent writing	
Use of an full triangle	**Use of an empty triangle**
	

Datum indication	
Drawing	**Meaning**
	The specified datum and the associated datum are perfect planes build on the real surface of the part. It is the 'minmax' plane external to material according to ISO 5459:2011.
	It is possible to use the geometrical tolerance frame to indicate a datum. The toleranced feature is indicated also as a datum feature.

Indication of a median plane	
Drawing	**Comment**
	Indication of a datum axis
	Indication of a median plane datum

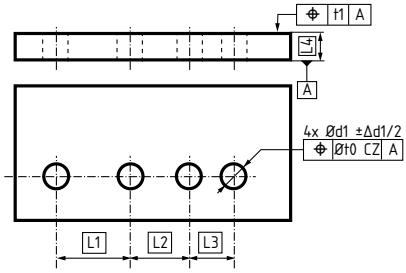
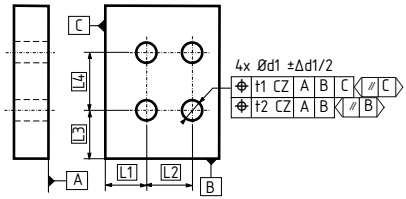
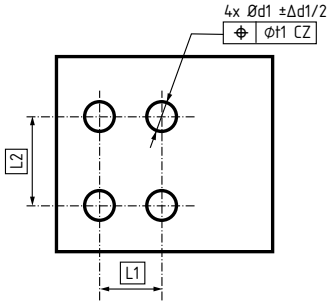
Common datum example


Position

ISO 5458:2018 standard defines the rules for position specifications for cylinders (pin or hole) and parallel opposite planes (slot or tab). This issue of the standard makes the use of SZ (Separate Zone) symbol or CZ (combined zone) mandatory to avoid ambiguity.

Following examples illustrate the use of SZ and CZ symbols and also the use of orientation planes for tolerance zones defined as the space between parallel planes.

Exemples

Dessin	Commentaire
	The tolerance zone of holes is made of four cylinders aligned perpendicular to the datum A and constrained with theoretical exact dimensions (TED). The tolerance zone for the plane is the space between two planes centered on the TED issued from A.
	The tolerance zones are aligned on the model of theoretical exact dimensions and oriented with orientation planes. The CZ symbol is used to build a group.
	The tolerance zones are cylinders. The set of holes is not located from the edge of the part. The tolerance zones are located with the theoretical dimension system (TED). The CZ symbol is used to build a group.

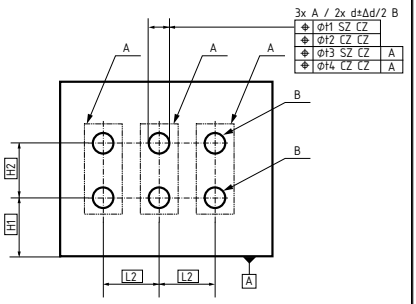
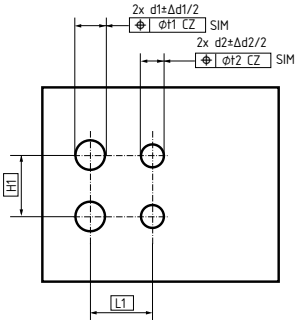
Groups

ISO 5458:2018 standard allows to define groups with several levels for cylinders (pin or hole) and for parallel planes (slot or tab). SZ symbol (separate zones), CZ (combined zones) and CZR (combined zones for rotation) allows to specify contraints inside a group and between groups.

ISO 5458:2018 standard allows to define several levels of groups and the repetition of a pattern made of several holes for example.

ISO 5458:2018 standard allows also to define groups of different features by using the symbol SIM for 'simultaneous'.

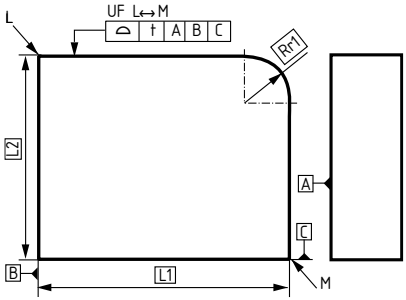
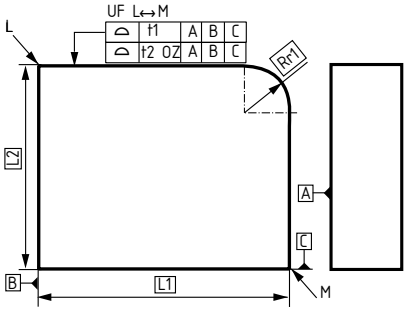
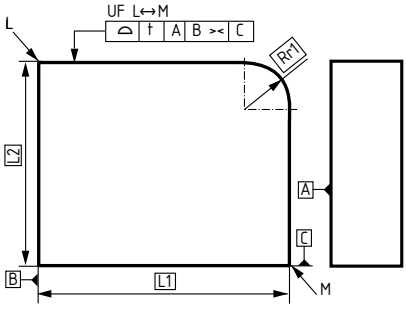
Examples

Drawing	Comment
	The specifications apply to three groups (A) each made of two holes (B). The first symbol SZ or CZ in the tolerance indicator is about the constraints of the A groups between each other. The second symbol is about the constraints of B holes inside the A groups. The tolerance value t2 shall be greater than t1. The tolerance value t4 shall be greater than t3.
	The two specifications define groups of two holes thanks to CZ symbol. These holes are contrained together with the modifier SIM that links the two position specifications for holes with different diameter.

Surface profile

ISO 1660:2017 stadard illustrate the use of profile specifications. UF and CZ symbol are used to constrain the single features or tolerance zones. Rules are defined in ISO 1101:2017 standard.

Examples

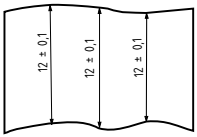
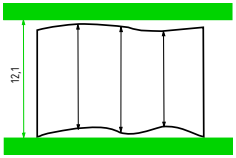
Drawing	Comment
	The tolerance zone is build with a sphere with a diameter equal to the tolerance value and which centre moves on the nominal surface. UF ('United Feature') symbol permits to unify single features in one feature.
	OZ ('Offset Zone') symbol make the dimension used for the definition of the theoretical exact surface ('TEF') variable. See rule F in ISO 1101:2017. OZ symbol allows to make the tolerance zone 'expandable'. The value of the tolerance is not changed.
	>< ('orientation only') symbol allows to applys only orientation constraints to the tolerance zone for the datum B.

Envelope

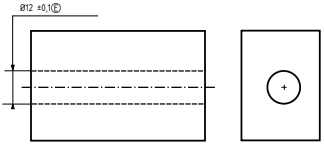
The envelope requirement is specified with the symbol Ⓔ after a linear dimension tolerance value. This specification is used for a function of assembly for cylindrical or prismatic parts.

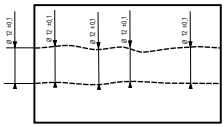
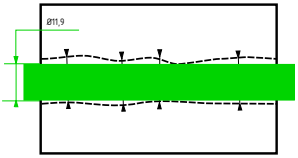
Envelope requirement	
specification	**requirement**
toleranced size	The tolerance at least material shall be fulfiled for every opposite points (local dimension)
envelope	the surface of the real part shall be included in a cylindrical shape at maximum material size

Specification with envelope on a prismatic part

Size verification	Envelope verification
	

Specification with envelope on a hole

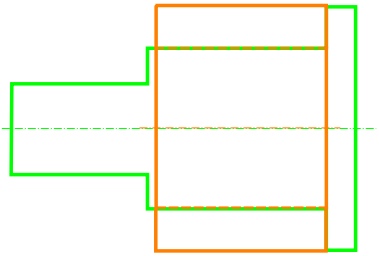


Size verification	Envelope verification
	

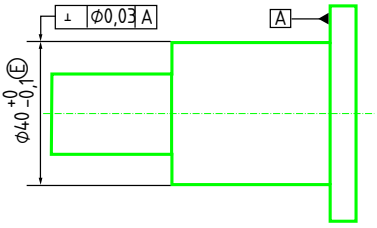
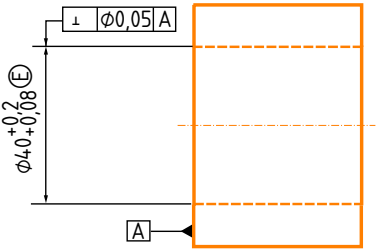
Maximum material

Maximum material requirement allows to increase the geometrical tolerance when the size is not at the maximum material to fulfil a requirement of assembly of parts. See ISO 2692:2021.

Example of an assembly of a pin and a hole

Drawing	Comment
	The funtionnal requirement is to have a minimal clearance of 0 and contacting planes between the two parts. So: $j \geq 0$ j : clearance between the cylindrical feature and the hole

Specification

Pin	Hole
	

$$j = (D_m - \perp\text{hole}_M) - (d_M + \perp\text{pin}_M)$$

j_m : minimum clearance
D_m : minimum diameter of the hole
$\perp\text{hole}_M$: maximum deviation for the perpendicularity of the hole
d_M : maximum diameter of the pin
$\perp\text{pin}_M$: maximum perpendicularity deviation for the pin

The relation is fulfiled with the selected values:

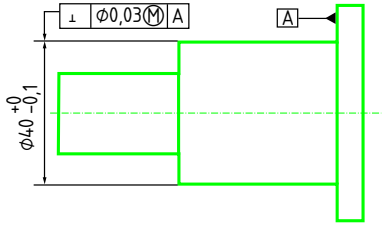
Worst case checking

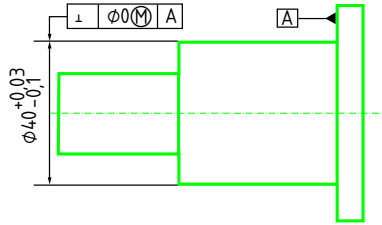
Condition	Comment
$j = (40{,}08 - 0{,}05) - (40 + 0{,}03) = 0$	Worst case clearance is in accordance with functional requirement.

Example of a manufactured pin		
Pin	**Criterion**	**Conclusion**
$d = 39,90$ mm $\perp$pin $= 0,1$ mm	The size is inside the tolerance however the perpendicularity deviation is too large.	The part geometry checker shall declare the part as non conformant to the specification however he can sometimes ask for a derogation to check whether tehe part could be used as is.

Functional requirement checking	
Hypothèse	**Vérification**
The manufactured part will fit inside the worst possible hole.	$j = (40,08 - 0,05) - (39,9 + 0,10) = 0,03 \geq 0$ The manufactured pin is acceptable because the functional requirement is fulfiled however the part is non-conformant. A derogation can be issued without risk.

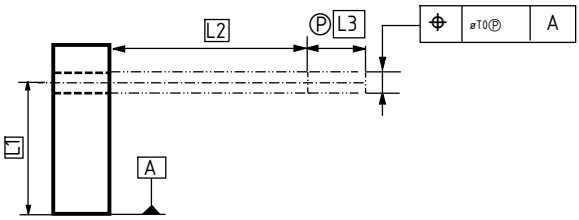
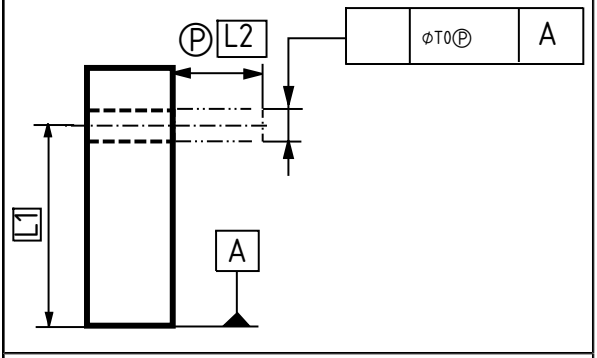
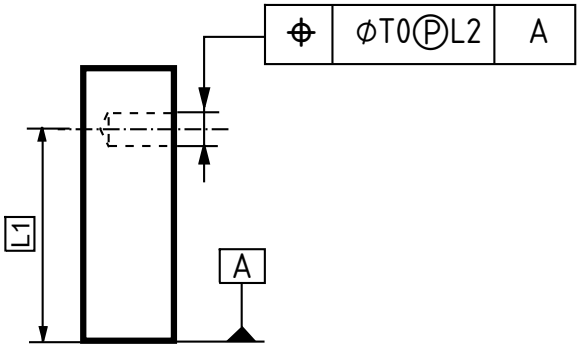
This situation comes from the fact that the allowable perpendicularity deviation depends on th actual size value of the part. Adding a maximum material modifier allows to better manage this situation.

Specification with maximum material modig=fier	
Drawing	**Meaning**
	The verification is in two steps: verification of the size and then the verification of maximum material virtual condition as per the following equation: $d + \perp\text{pin} < \delta = 40,03$ mm δ : maximum material virtual diameter (perfect cylinder)

Specification with 0 at maximum material	
Drawing	**Comment**
	The dimensional specification at maximum material has been changed in order to accept also parts with large diameter and small perpendicularity deviation.

Projected zone tolerance

Projected zone tolerance allows to specify a virtual zone indicated with a two dotted line which is outsie the part. The tolerance value indicated with a modifier Ⓟ applies in thos zone.

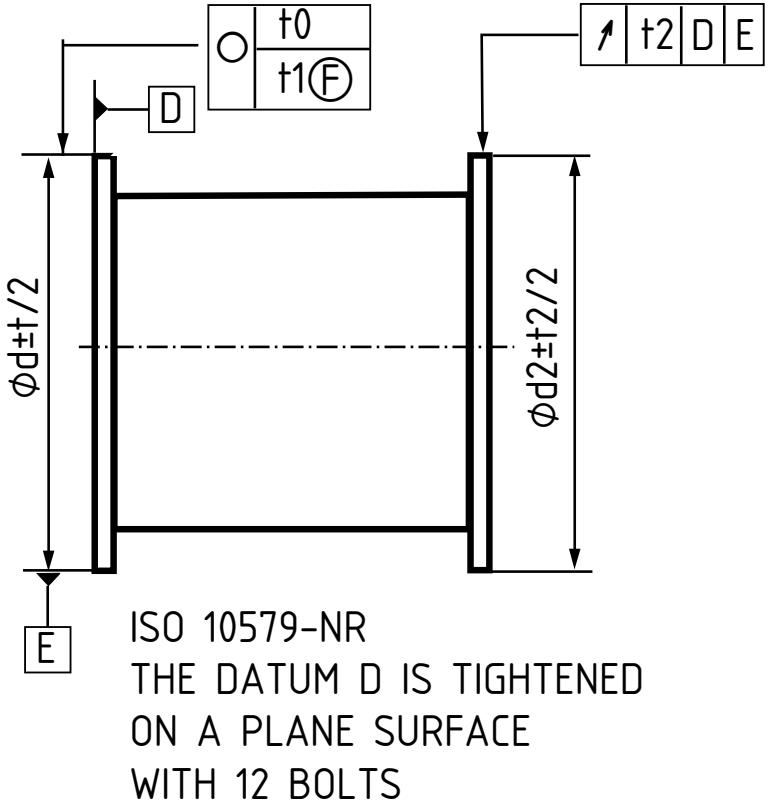
Writing	
Drawing	**Comment**
	Projected tolerance zone outside the part
	Projected tolerance zone right outside the part
	

Non rigid parts

ISO 10579 standard allows to specify a free state of the part with the modifier Ⓕ and a constrained state which shall described on the drawing or in a referenced document.

Example of a specification of a non rigid part

Drawing



Meaning

example of the specification of a non rigid part: the specifications with modifiers are to be considered at the free state of the part. Other specifications are to be considered in the constrained state which is described in the note.

NOTES:

trainings

structural analysis	tolerancing	metallic materials
strength analysis	ISO GPS tolerancing	metallic material selection
finite element method	ASME GD&T	stainless steels
fatigue analysis	mechanical drawing interpretation	corrosion - surface finishing
design method	**industry**	**fast track**
mechanical device	pressure vessel	strength analysis
structural analysis, tolerancing, material selection	piping, structure	metallic material

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