Geometrical Product Specifications (GPS) – ISO 14405-1, the General GPS Standard for Dimensional Tolerancing of Linear Sizes

Preface

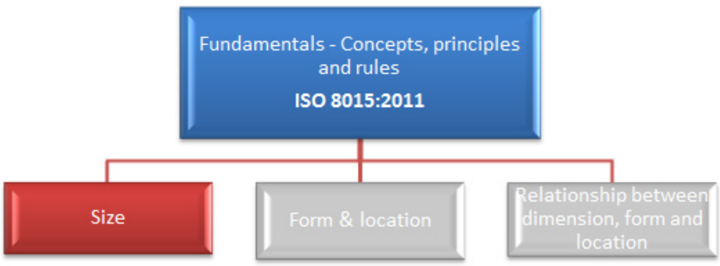
The first two articles of this series offered an overview of fundamental standards of the GPS concept required to describe geometrical characteristics. These two articles are:

- Geometrical Product Specifications (GPS) – an incomplete survey
- Geometrical Product Specifications (GPS) – ISO 8015 basic GPS standard

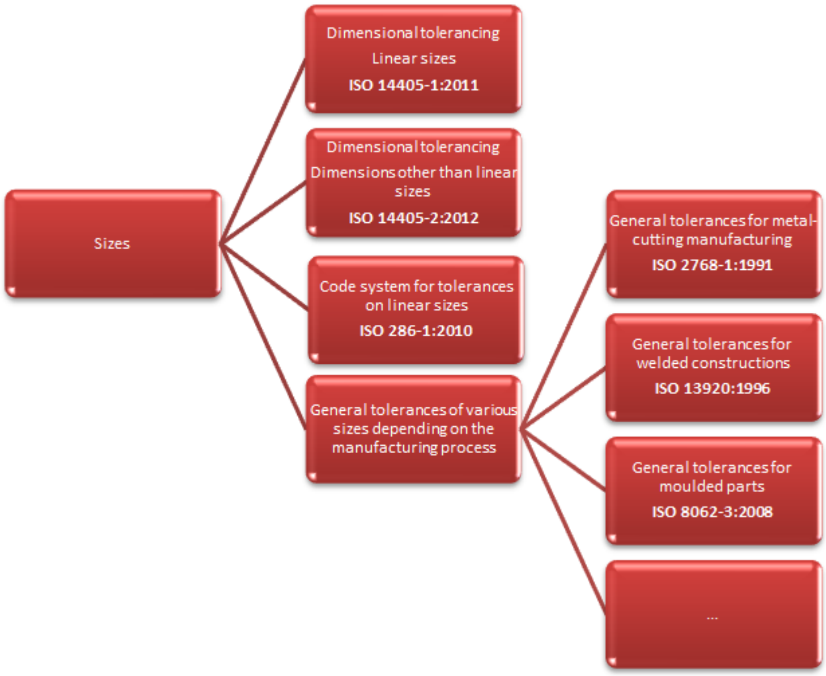
This article presents the general standard ISO 14405-1 describing and defining tolerances of linear sizes. We do not intend to discuss every single aspect of this standard but try to focus on the contents the author considers relevant for the purpose of defining specifications, especially of creating drawings and interpreting them.

The status of ISO 14405-1 in the GPS concept

ISO 14405-1 is right below the ISO 8015 basic standard in the GPS hierarchy and represents the main standard for geometric dimensioning and tolerancing. It establishes the default specification operator – thus the default drawing indication – for linear size and provides options to modify this default specification operator.



As the following chart shows, the given definitions of sizes specified in this standard apply to all the other standards relating to this topic.

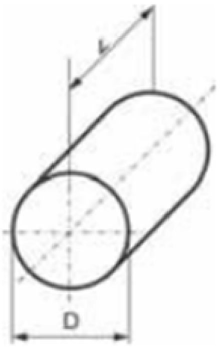


Linear sizes as a (linear) feature of size

Although the title of ISO 14405-1 refers to linear sizes, the standard itself (its contents) talks about features of size. This wording reflects the terminology of geometric tolerancing of form and location. This specialist field introduced geometrical features a long time ago.

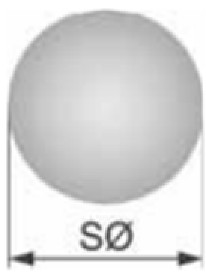
Features of size are always based on a geometric form.

Cylinder



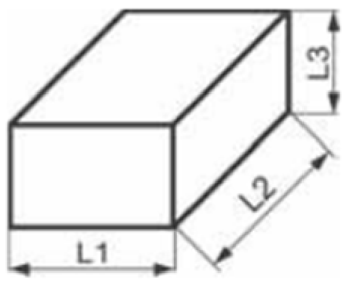
Diameter size D
Linear size (distance between two parallel faces) L

Ball



Diameter size SØ

Cuboid



Three linear sizes (distance between two opposite planes) L1, L2 and L3
The cuboid becomes a cube when all six faces are square. In this special case, the features of size are two pairs of parallel lines, e.g. L1 and L3.

The size of a feature of size describes its dimension as the minimum distance between opposite points of the zero-deviation, theoretical geometric form. Features of size thus do not include distances between parallel but not exactly opposite lines or planes (“step heights”), distances between two axes or midplanes or between an axis / midplane and a surface and arc lengths. These are the kind of dimensions ISO 14405-2 deals with. The ISO standard is called “Dimensional tolerancing – Dimensions other than linear sizes” but actually it could be referred to as “Other dimensions than features of size".

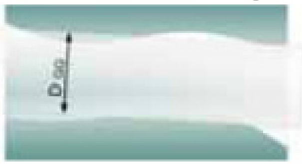
This article deals with different features of size, namely cylinder, ball and a pair of opposite planes. We have already defined size characteristics for these features; however, we distinguish between global and local sizes determined on a real geometric part that may be subject to deviations.

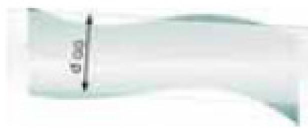
Global size

A global size is a size characteristic having by definition a unique result of evaluation along and around the tolerance feature of size (cylinder, ball). These characteristics are created in measurements by eliminating the sizes of form and location deviation affecting the characteristic.

(GG) Least squares size

Size of the geometrical feature associated to the extracted geometrical feature(s) with the least squares fitting credited to Gauss.

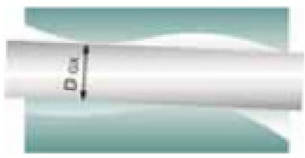




Application in metrology:
Three-dimensional measurement process including a numerical calculation of this feature of size.

(GX) Maximum inscribed size

Size of the geometrical feature associated to the extracted geometrical feature(s) with the maximum intrinsic characteristic criterion.
Applied to internal geometrical features, this size was referred to as a mating size for holes and grooves in previous standards.



Application in metrology:
Three-dimensional measurement process including a numerical calculation of this feature of size or mechanical measure of a permissible limit for the respective size characteristic (limit gauge as a mandrel).

(GN) Minimum inscribed size

Size of the geometrical feature associated to the extracted geometrical feature(s) with the minimum intrinsic characteristic criterion.
Applied to external geometrical features, this size was referred to as a mating size for shafts and springs in previous standards.

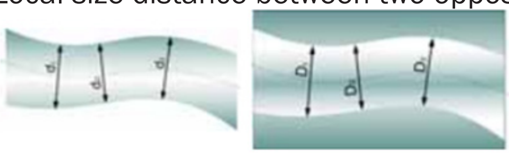
Application in metrology:
Three-dimensional measurement process including a numerical calculation of this feature of size or mechanical measure of a permissible limit for the respective size characteristic (limit gauge as a sleeve).

The specification modifiers in the frame can be assigned to the dimensions indicated on the technical drawing. By using these specification modifiers, you change or modify the default specification operators.

Local size

A local size is a size characteristic having by definition a non-unique result of evaluation along and / or around the feature of size. These characteristics are created in measurements when sizes of form and location deviation affecting the characteristic are not eliminated. As we all know, the result is that the local sizes vary over the linear expansion of the feature of size. ISO 14405-1 reasonably defines two-point sizes as a local size.

LP **Two-point size**
Local size distance between two opposite points taken on the feature of size.



Application in metrology:
Any typical mechanical, pneumatic or optical procedures for two-point measurements.

The two-point size is the GPS default specification operator for features of size, i.e. indicated dimensions without specification modifiers are always local two-point sizes. The specification modifier LP thus only has to be applied when you depart from this standard and you want to denote the limit of a tolerance interval as a two-point size.

In order to be able to evaluate a feature of size globally even based on the method of a two-point measurement, the standard also defines indirect global sizes. According to the ISO standard, indirect global sizes are calculated sizes or statistics calculated from a set of two-point size values of a feature of size, also referred to as rank-order size. Calculated sizes are diameters calculated from the area, circumference and volume of a circle. The standard also provides the specification modifiers to be applied.

Rank-order sizes are defined mathematically from a homogeneous set of local size values obtained along and/or around a feature of size. These sizes just need the relatively simple method of a two-point measurement to evaluate a feature of size globally.

The standard introduces:
SX Maximum size
SN Minimum size
SA Average size (arithmetic mean)
SM Median size (middle number in a sorted list of sample values)
SD Mid-range size (mean of the maximum and the minimum value of a sample)
SR Range of sizes (difference between the maximum and minimum value of a sample)

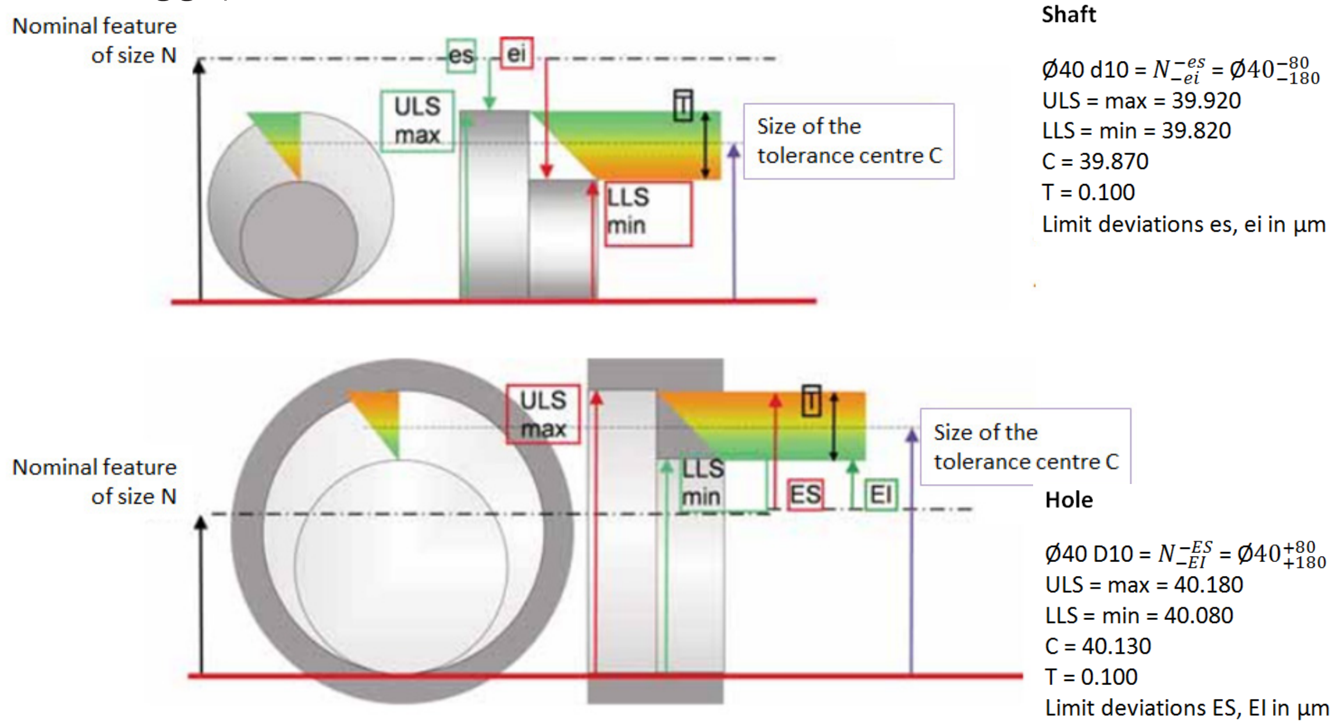
These definitions of the ISO standard, by the way, provide an additional field of application for Q-DAS products, such as qs-STAT: the evaluation of measurement series determined from a feature of size and provision of rank-order sizes demanded by the respective specification.

Dimensions indicated on product specifications

Previously common indications of dimensions and dimensional tolerances of features of size have not changed as the following overview shows. As is customary, the following numerical examples all refer to mm as a measurement unit.

	GPS drawing indications for features of size	Examples		
1	Nominal feature of size ± limit deviation N ± es/ei for external sizes N ± ES/EI for internal sizes	$100_{-0.3}$	$\varnothing 20^{+0.1}_{-0.2}$	20 ± 0.2
2	Nominal feature of size based on ISO tolerance codes in accordance with ISO 286-1 (specification of a tolerance class indirectly defining the limit deviations ES, EI, es and ei)	50 H9	Ø 62 k6	165 js10
3	Value of the upper limit of size (max or ULS) Value of the lower limit of size (min or LLS)	85.2 max 84.8 min	29.000 28.929	120.2 119.8
4	Nominal feature of size without brackets and without rectangular frame but referring to general tolerances placed in a title block	At the size characteristic: 10 In the title block: ISO 2768 - m		

How the nominal feature of size, limit deviations and tolerance intervals are related is well known. The following graphic illustrates these facts.



In order to display nominal features of size and limit deviations, we refer to well-known relationships.

The tolerance (or actually the tolerance interval) is defined as

$$T = ULS - LLS = max - min = ES - EI = es - ei$$

which always leads to a positive value.

Besides these well-known relationships, you have to specify the criteria required to inspect the quality of a feature of size. It is important to indicate in product specifications / on the drawing whether you extract local, global or indirect global sizes of a feature of size.

A ISO default specification operator for size

(for cylinders, balls, parallel planes or lines)

The GPS specification operator of sizes is the two-point size.

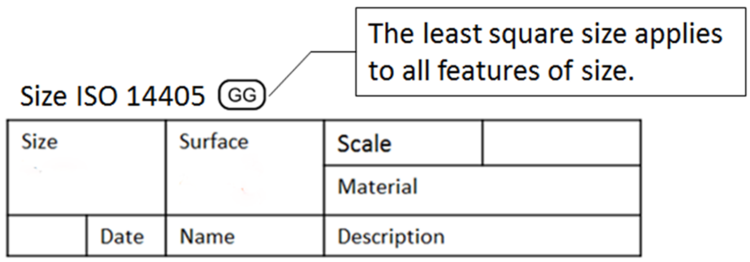
The ISO GPS system has to be invoked by quoting a general standard (see ISO 8015, principle 1 as mentioned in "Geometrical Product Specifications (GPS) – ISO 8015 basic GPS standard").

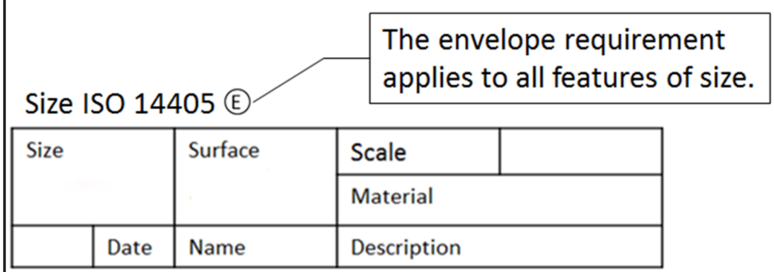
This definition also applies to sizes associated to a tolerance class of the ISO GPS system for limits and fits in accordance with ISO 286. Even in the latest version of this standard (2010), the two-point size is the default association criterion.

If the title block refers to the ISO standard for general tolerance, the default specification operator, i.e. the two-point size, also applies to these sizes.

Z Drawing-specific specification operator for size

A drawing-specific GPS specification operator for indicated dimensions has to be specified in or near the title block by referring to ISO 14405 together with the specification modifier applying to this drawing.





If the title block refers to the ISO standard for general tolerances, the default specification operator, i.e. the two-point size, also applies to these sizes.

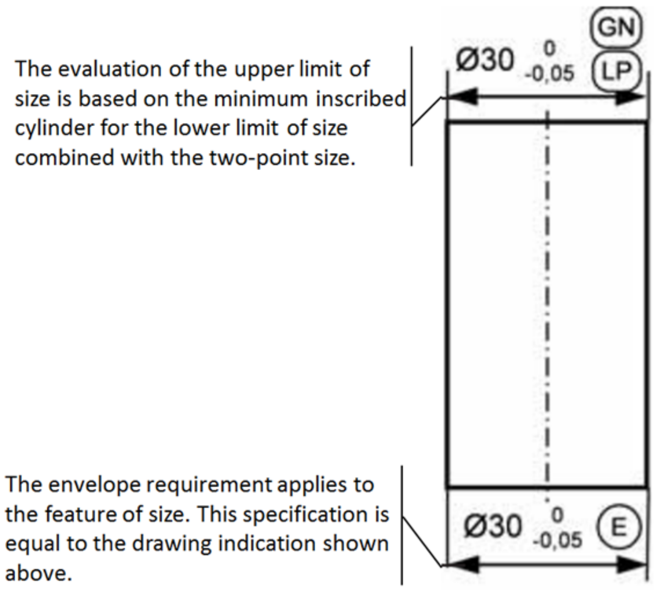
1st example Applying the envelope requirement

The envelope requirement ensures the interchangeability of the mating features of size shaft – hole or tongue – groove while keeping a minimum clearance. Both limits of the tolerance interval are thus…

• the minimum inscribed size to be compared to the upper limit of size (ULS), which refers to the GN specification modifier • the two-point size LP to be compared to the lower limit of size (LLS) in case of SHAFTS.	• the maximum inscribed size to be compared to the lower limit of size (LLS), which refers to the GX specification modifier • the two-point size LP to be compared to the upper limit of size (ULS) in case of HOLES.

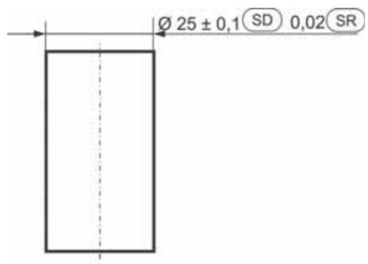
As an alternative, you may once again put modifier Ⓔ (envelope) right next to the indicated dimension.

The drawing indications look as follows:



2nd example Applying rank-order sizes

2.1 Centre of an interval associated with the range of two-point sizes



The interval centre of the range
SD = ½ (MAX(n) + MIN(n))
must not exceed the tolerance interval reaching from 24.9 to 25.1.
The range SR = MAX(n) – MIN(n) must not exceed 0.02.

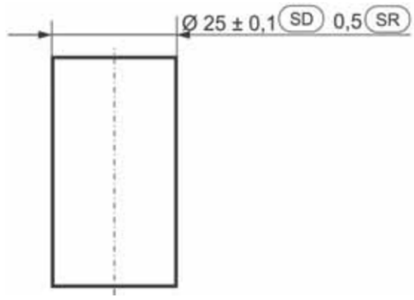
Meaning:

The interval centre of the range might vary around a value of 0.2 mm depending on the respective part; however, the sizes of a component only vary in a range of 0.02 mm. The range SR thus kind of replaces the geometrical tolerance of a cylinder.

What you cannot find out by applying SR is the effect of triangular forms in the circular cross section and of axial curvatures in the axial section of the cylinder.

While planning an inspection, you have to define how many measurements n you want to take at which position of the component.

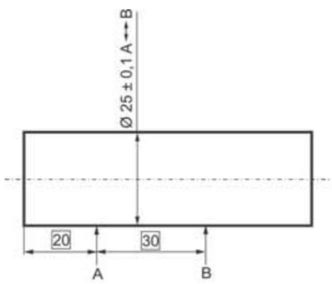
2.2 ***Centre of an interval associated with the range of two-point sizes***



The interval centre of the range
SD = ½ (MAX(n) + MIN(n))
must not exceed the tolerance interval reaching from 24.9 to 25.1.
The range SR = MAX(n) – MIN(n) must not exceed 0.5.

<u>Meaning:</u>
The interval centre of the range might vary around a value of 0.5 mm depending on the respective part; however, the sizes of a component only vary in a range of 0.5 mm. The range SR thus kind of replaces the geometrical tolerance of a cylinder.
What you cannot find out by applying SR is the effect of triangular forms in the circular cross section and of axial curvatures in the axial section of the cylinder.
While planning an inspection, you have to define how many measurements n you want to take at which position of the component.

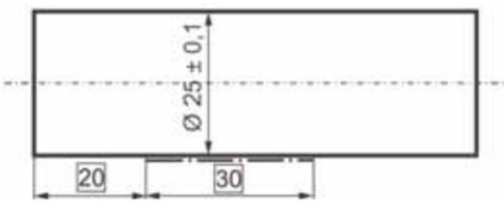
3rd example ***Feature of size requirements; restricted to a portion of the extracted feature***



The size is a two-point size and must not exceed the tolerance interval of 25 ± 0.1 in the interval from A to B where A = 20 mm.

4th example ***Feature of size requirements; restricted to a portion of the extracted feature***

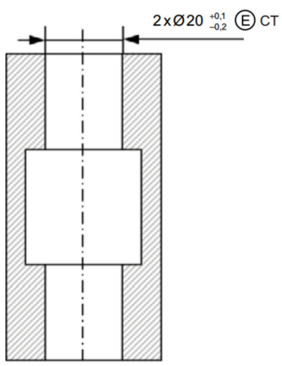
(The statement is identical to the 3rd example.)



The size is a two-point size and must not exceed the tolerance interval of 25 ± 0.1 in an interval of 30mm starting at 20mm from the front side. The field of application is indicated by a long dashed and dotted line.

You may now even apply limits of size to more than a single feature of size by using a specification modifier. This modifier is referred to as common tolerance and is indicated by CT without a frame.

5th example



The envelope requirement applies to the common cylindrical feature of size, i.e. the maximum inscribed size of the cylinder must be a mating size for both cylinders with Ø20. When both cylinders are close to the minimum circumscribed size Ø19.8, they need to be coaxial. A two-point measurement has to ensure that the two-point size of each cylinder does not exceed the maximum inscribed size of 20.1.

Eventually, this ISO GPS standard contains other interesting specification modifiers, such as the free state condition Ⓕ or the indication of valid individual sizes in special (SCS) or any (ACS) cross sections of a cylinder or two parallel opposite planes. Describing these modifiers, however, goes beyond the scope of this article, so we recommend you to read the original standard for further information.

What are the benefits of this type of tolerancing?

As described before, this standard provides plenty of options for functional, contrivable and testable dimensioning and tolerancing without leaving the principles of traditional dimensioning completely behind.

The advantages are obvious.

- There are two ways to indicate the envelope requirement. The first edition of ISO 8015 already introduced Ⓔ in 1986; you may still continue to use this modifier. However, even the second version (see 1st example) can be beneficial since each of both limits of size of the tolerance interval show the corresponding specification modifier and thus makes it easy to move on to a dimensional inspection including limit gauges or to conduct an alternative measurement procedure more quickly. The transfer from a specification operator to a verification operator incurs a lower risk (see ISO 8015, principle 10: duality principle as described in GPS - part 2).
- Two-point sizes can be associated with rank-order sizes. By separately tolerancing an average or a centre of an interval and a range, the limit of the form deviation based on a form tolerance often demanded by the envelope requirement becomes unnecessary. You do not need the extra inspection effort including more complex measurement technology.
- 3-D measuring machines scanning parts mechanically to measure them or shaft measuring system with optical scanners make it more difficult to determine two-point sizes. The evaluation of the global size based on the least squares fitting (Gauss) leads to stable and easily reproducible results. Together with a form tolerance also referring to the Gaussian element to be evaluated, this approach provides a real alternative to the envelope requirement, particularly in case of non-mating sizes. It makes a direct global evaluation of the feature of size possible.

Design engineers, process engineers and measurement engineers should meet to discuss the new options of tolerancing sizes with respect to the respective mode of operation, production and inspection. It is important to test the application in practice.

The only disadvantage is the amount of symbols and specification modifiers this standard involves. Readers who are not familiar with this standard will hardly be able to find out the meaning of these symbols in a drawing. This fact might cause problems of acceptance at first; hopefully it will not turn out to be an impenetrable barrier.

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