GEOMETRICAL PRODUCT SPECIFICATIONS (GPS)

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APPLICATION OF GEOMETRICAL TOLERANCING TO STEP DIMENSIONS

PREFACE

The previously published articles about geometrical product specifications dealt with standards of the GPS concept required to describes geometrical features.

- Geometrical product specifications (GPS) – an incomplete survey
- Geometrical product specifications (GPS) – ISO 8015 basic GPS standard
- Geometrical product specifications (GPS) - ISO 14405-1, the general GPS standard for dimensional tolerancing of linear sizes
- Geometrical product specifications (GPS) – consequences on the tolerancing of features of size

ISO 14405-2 "Geometrical product specifications (GPS) - Dimensional tolerancing - Part 2: Dimensions other than linear sizes" was published in 2011. It applies to mere distances (linear features of size as mentioned in GPS – part 3 excluded) and radiuses. This article is about "step heights" in the context of the specifications provided by this standard.

Note: All numerical data are given in mm without indicating this unit of measurement in the following.

STEP DIMENSIONS IN TRADITIONAL DIMENSIONING

Step dimensions are distances between two opposite planes or edges whose planes / edges are parallel but displaced from one another. You cannot measure the two-point distance based on contact points on the geometric forms and a vertical alignment of one of the two planes / edges (Figure 1). The distances between waves offset from the front surfaces are usually typical step dimensions, too, except for parallel front surfaces restricting annular grooves.

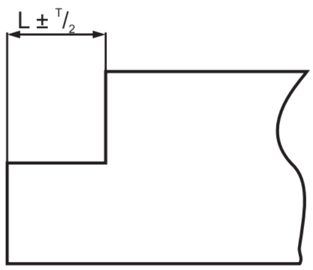

Figure 1

The options available to measure the component in Figure 1 are ambiguous, especially when you apply the two-point size defined on the feature of size as shown in Figure 2.

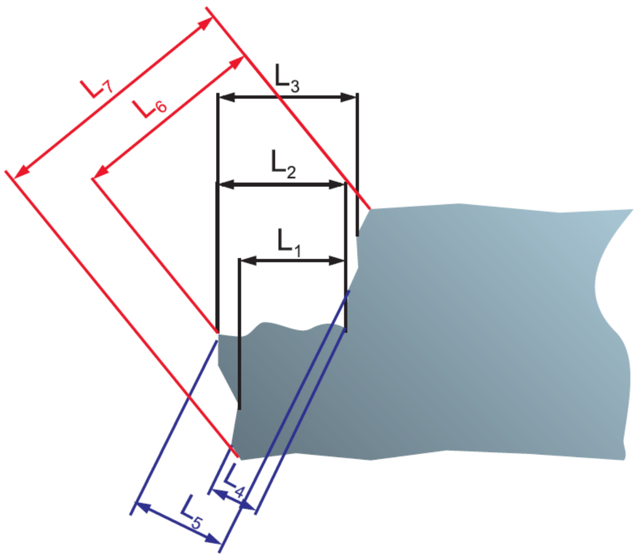

Figure 2

The ambiguity relating to component inspection is the main reason why ISO 14405-2 suggests replacing linear dimensioning of such step heights by geometrical tolerancing according to ISO 1101.

We want to illustrate this issue based on a simple example.

The plane surface as shown in Figure 3 is subject to traditional dimensioning. Even though you might assume that you can dimension this component in a different way to avoid step dimensions – which is absolutely correct – we just ignore this fact right now.

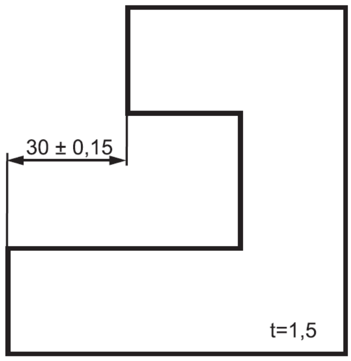

Figure 3

STEP DIMENSIONS TOLERANCED WITH POSITIONAL TOLERANCES AND DATUM

ISO 14405-2 offers the following two options to replace the linear size tolerated with deviations (Figure 3) by applying a theoretically exact dimension related to a positional tolerance and a datum (Figure 4).

1st tolerancing option based on ISO 14405-2 (left)

An edge is used as a datum and a tolerance for the other edge is given in relation to this datum. The distance is specified in the form of a theoretically exact dimension (TED).

2nd tolerancing option based on ISO 14405-2 (right)

An edge is used as a datum and a tolerance for the other edge is given in relation to this datum. The distance is specified in the form of a theoretically exact dimension (TED). Compared to the first option, we switched edges.

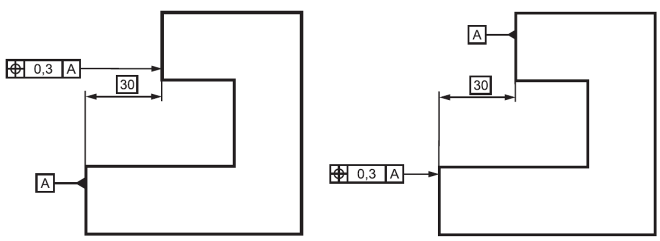

Figure 4

In order to evaluate the current geometric condition at the component, you have to eliminate the form deviations of the plane surface's edges representing datum A. ISO 5459 introduces the term of situation features in this context and specifies the respective minimum zone for lines or planes. The tolerated feature connected directly to tolerance frame (here: an edge) is now related to a positional tolerance zone with regard to the desired distance of 30. The tolerance zone of ± 0.15 is symmetrical to the nominal position at a distance of 30 from A. Based on this zone, you are able to identify form deviations, orientation deviations from A and deviations from linear dimensions.

From the perspective of industrial quality, there are two reasons why it is important to analyse whether a component meets these geometrical product specifications (analysis referred to as verification in GPS standards).

- **Quality assurance** requires information about whether or not the component meets the specification. This type of information has to be recorded.

- **Quality control** demands information about the characteristic causing a geometric error and, if necessary, about the direction the geometrical features have to face in order to correct the manufacturing process.

Unfortunately, the positional deviation has not been defined in any standard of the GPS system yet. There are three interpretations of positional deviations, however, based on the model of tolerance zones and applied in metrology. We provide you with an example of the 1st option in the following; it applies to the 2nd option in the same way.

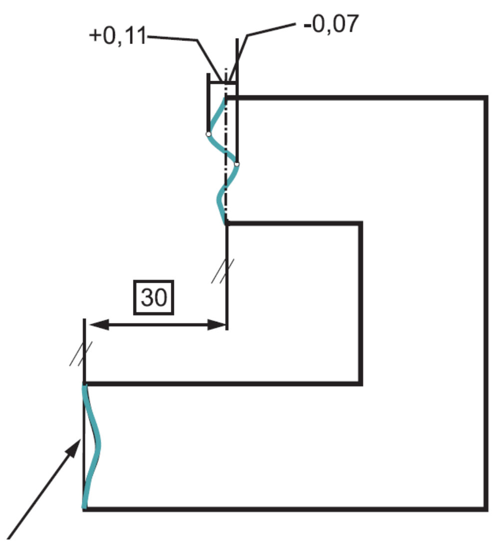

Figure 5 Form deviations of the datum were eliminated with the help of the applied lines (minimum zone).

A CMM measured the component in Figure 5. The positional deviation from the nominal position A of 30 is mainly caused by the form deviation in this example.

Positional deviation$_1$

The positional deviation$_1$ is the largest directional distance of the recorded feature from the nominal position. The direction usually refers to the boundary surface, i.e. from “out of the material” to “into the material”.

+	Direction of the nominal position indicating “out of the material”
-	Direction of the nominal position indicating “into the material”

The positional deviation$_1$ in this example is thus + 0.11.

Positional deviation$_1$ meets **quality assurance** demands:

$+ 0.11 \leq T_{pos}/2 = 0.15$ -> component o.k.

Positional deviation$_1$ meets **quality control** demands:

Peak with a height of 0.11 was located as a local form deviation.

Positional deviation$_2$

The positional deviation$_2$ is the largest distance (absolute value) of the recorded feature from the nominal position. The positional deviation$_2$ thus amounts to + 0.11.

Positional deviation$_2$ meets **quality assurance** demands:

$+ 0.11 \leq |T_{pos}|/2 = 0.15$ -> component o.k.

Positional deviation$_2$ cannot be applied to **quality control**.

Positional deviation$_3$

The positional deviation$_3$ is the area of the tolerance zone the geometrical feature “takes up” or “occupies” due to its deviation. It is twice the positional deviation$_3$, i.e. 2 x 0.11 = 0.22.

Positional deviation$_3$ meets **quality assurance** demands:

$2 \times 0.11 = 0.22 \leq T_{pos} = 0.30$ -> component o.k.

Positional deviation$_3$ cannot be applied to **quality control**.

If you do not measure a component by using a CMM but apply linear measurements – even though the drawing indicates otherwise – you have to consider the following aspects.

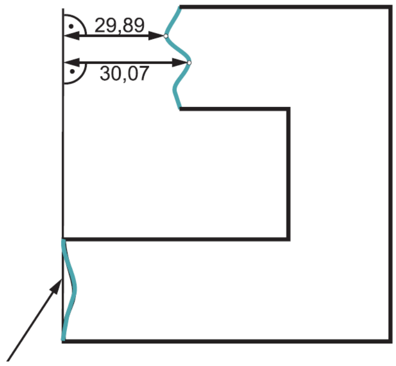

Figure 6 Form deviations were eliminated with the help of the applied lines (minimum zone).

Positional deviation$_1$

The positional deviation$_1$ is calculated from the minimum and maximum size of the determined distances. You no longer need the relation to the material boundary surface as described above. The traditional calculation formula for distances leads to the respective sign (direction).

Deviation = actual (size) – nominal (size)

This leads to the following calculation: 30.07 - 30 = + 0.07 and 29.89 – 30 = -0.11

Compared to the CMM measurement, you reverse the directions!

Positional deviation$_1$ meets **quality assurance** demands:

- 0.11 ≤ $T_{pos}/2$ = - 0.15 -> component o.k.

(The "negative tolerance" only helps to illustrate and assess the direction of the deviation. According to official definitions, tolerances are unsigned interval specifications.)

Positional deviation$_1$ meets **quality control** demands:

Deviation of - 0.11 is based on a linear measurement where L_{max} = 30.07 and L_{min} = 29.89

The same applies to positional deviation$_2$ and positional deviation$_3$.

Recommended applications for option 1 or 2

Options 1 and 2 shall be applied to tolerated distances having or needing a datum in terms of a functional or manufacturing basis. If required, you have to limit the form deviations for the datum by indicating a form tolerance. You might also need to add form and orientation tolerances to the positional tolerance of a geometrical feature, if a separation between these aspects is of advantage from a functional perspective or for reasons concerning the manufacturing process.

STEP DIMENSIONS TOLERANCED WITH POSITIONAL TOLERANCES BUT WITHOUT DATUM

ISO 14405-2 adds a third option to these two tolerancing approaches. In this case, a datum is not indicated. The geometrical features creating the distance both become subject to a positional tolerance but also need to modified by placing the label CZ in the tolerance frame indicating a common tolerance zone (CZ = common zone).

3rd tolerancing option

Not a single edge is used as a datum, the distance between both edges is toleranced by applying tl modifier CZ. The tolerance zone applie

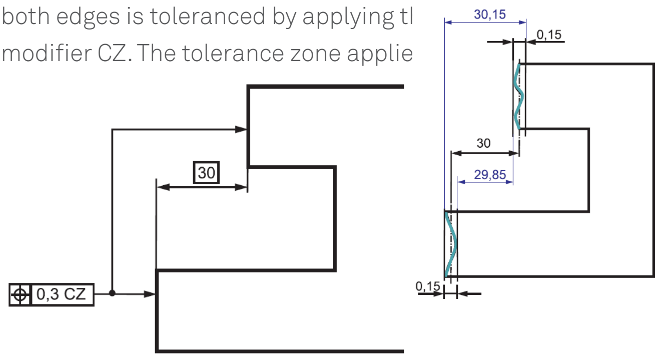

Figure 7

Apply the definition of the tolerance zone to the positional tolerance. By indicating CZ on the drawing, both features have the size of the tolerance zone in common. Only a tolerance range of $T_{pos}/2$ is available for each edge now. The zone itself is aligned with the geometrical features subject to deviations since there is not any datum defined.

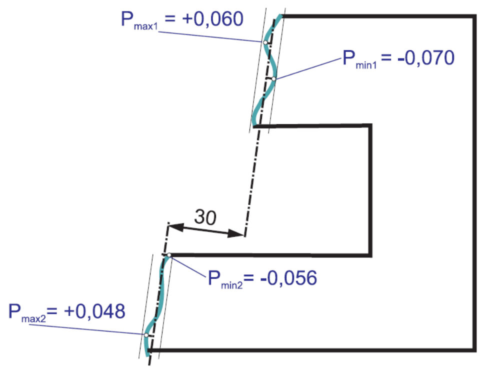

Figure 8

The aspect of how to position a pair of lines between both available lines a theoretically exact distance of 30 apart is still undefined or unsettled. Due to the common zone modifier and the application of positional tolerance zones, it obviously has to be a pair of parallel lines corresponding to the Gaussian median feature whose orientation is not restricted but with two equidistant but being the demanded distance apart. You may assess the local deviations in the directions of the nominal positions out of and into the material, as shown in Figure 8.

Positional deviation$_1$

The positional deviation$_1$ is the largest directional distance of the recorded feature from the nominal position. The direction usually refers to the boundary surface, i.e. from "out of the material" to "into the material".

Positional deviation$_1$ meets **quality assurance** demands:

$- 0.070 \leq T_{pos}/4 = - 0.075$ -> component o.k.

It is sufficient to evaluate the pair of lines as "a single entity". You only analyse the maximum deviation, the associated edge does not play a role. Please consider that the local tolerance takes up at most ¼ of the positional tolerance.

Positional deviation$_1$ meets **quality control** demands:

The positional deviation$_1$ is simply a form deviation from the line; it amounts to $P_{min1} = - 0.070$ for the 1st line.

The positional deviation$_1$ is simply a form deviation from the line; it amounts to $P_{min2} = - 0.056$ for the 2nd line.

When you add a graphic chart to the measurement results in order to illustrate the relations, the aspect of quality control improves even further.

Positional deviation$_2$

The positional deviation$_2$ is the largest distance (absolute value) of the recorded feature from the nominal position. The positional deviation$_2$ thus amounts to 0.07.

Positional deviation$_2$ meets **quality assurance** demands:

$0.070 \leq |T_{pos}|/4 = 0.075$ -> component o.k.

It is sufficient to evaluate the pair of lines as "a single entity". You only analyse the maximum deviation, the associated edge does not play a role.

Positional deviation$_2$ cannot be applied to **quality control**.

Positional deviation$_3$

The positional deviation$_3$ is the area of the tolerance zone the geometrical feature "takes up" or "occupies" due to its deviation. It is twice the positional deviation$_2$, i.e. 2 x 0.07 = 0.14.

Positional deviation$_3$ meets **quality assurance** demands:

$0.14 \leq |T_{pos}/2| = 0.15$ -> component o.k.

It is sufficient to evaluate the pair of lines as "a single entity". You only analyse the maximum deviation, the associated edge does not play a role.

Positional deviation$_3$ cannot be applied to **quality control**.

Recommended application for option 3

Option 3 is recommended when you are able translate classical linear dimensioning into positional tolerancing and none of the features observed serves as a datum.

ATTEMPT TO EVALUATE STEP DIMENSIONS TOLERANCED WITH POSITIONAL TOLERANCES

The reason why you switch from linear dimensioning to positional tolerancing is the fact that you want to avoid the ambiguity occurring in the verification phase. The information given above, however, clearly showed that this is quite complicated and you have to face some pitfalls when you interpret and evaluate such newly toleranced linear sizes.

Which advantages does the change of dimensioning concept offer?

- It becomes easier for the design engineer to clearly translate his functional requirements into a specification operator. There are only three options available that are based on drawings and the engineer can adapt them to the respective function. Any ambiguities concerning the interpretation of his requirements are then completely eliminated.

- The GPS system does not introduce a new code system but applies the well-known codes based on positional tolerancing according to ISO 1101. It is thus formally ensured that anyone already familiar with this topic is able to understand and comprehend the specification of positional tolerances for distances.

- Even the 2009 version of ASME Y 14.5, the American standard regarding geometry, specifies a similar approach. However, it switches from dimensioning to geometrical tolerancing by using form tolerances for lines (in case of edges) and form tolerances for surfaces (in case of surfaces). People familiar with GPS and / or ASME have about the same understanding of this topic.

We also want to talk about possible disadvantages.

- Design engineers might be annoyed when they have to quit a familiar dimensioning concept and do not see the benefits of the additional effort required to “re-dimension” all those features. It seems like it does not bring any advantages in improving the functionality or the production process. Especially “old stagers” with extensive design experience might have a high acceptance threshold.

- Drawings quickly become confusing since the number of tolerance frames and theoretically exact dimensions they contain rises. It takes more time to work through a drawing. The “customer” of the drawing might be dissatisfied and angry.

- The deviation to be specified, the allocation criteria for situation features when applying positional tolerances without datum and the preferred verification method have not been defined by a standard yet. Logging the determined deviations is by no means easier than in classical linear dimensioning (see examples above). In case of need, you have to create company guidelines including rules for interpreting such drawing indications as long as the GPS system does not provide any.

- Measurement tasks that seem to be easy require complicated measuring machines and measuring systems. The new drawing indications might lead to expensive inspections that do not even have to be more economical.

- Maybe the self-inspections made by the operators (at the supplier or in his own company) fall by the wayside when measurements seeming to be easy by all appearances suddenly are complicated to illustrate and record. Companies need to provide training and sometimes even some extra motivation - demands that have to be covered quickly.

GUIDANCE

Even though the author's list of disadvantages is longer than the list of advantages, the disadvantages do not outweigh the advantages. There is no reason to distance from this new tolerancing approach or even reject it completely. Product developers and design engineers shall establish rules defining whether and which step dimensions and distances are to be replaced by positional tolerances. This preferably applies to the specified coordinates given in a table. Plane surfaces eliminating form deviations of wavelike components shall always be dimensioned with positional tolerances whereas the remaining compounds "without functionality" are dimensioned with general tolerances.

Process technicians and technicians in measurement technology have to create evaluation rules based on the evaluation strategies proposed by the manufacturers of measuring instruments. This at least ensures the aspect of quality control which is going to satisfy all parties.

CONCLUSION

Last but not least, we want to quote ISO 14405-2. It says in chapter 7 "Illustrations of ambiguous ± tolerancing vs. unambiguous geometrical tolerancing" under 7.1 "General":

> Geometrical tolerances can be used to avoid the ambiguity of dimensions with ± tolerances.

Anyone who is able to can use geometrical tolerances but does not have to!

Interested in this topic?

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