CURRENT CONCEPT OF GEOMETRICAL ACCURACY

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Abstract

Within the solving VEGA 1/0615/12 research project "Influence of 5-axis grinding parameters on the shank cutter´s geometric accuracy", the research team will measure and evaluate geometrical accuracy of the produced parts. They will use the contemporary measurement technology (for example the optical 3D scanners). During the past few years, significant changes have occurred in the field of geometrical accuracy. The objective of this contribution is to analyse the current standards in the field of geometric tolerance. It is necessary to bring an overview of the basic concepts and definitions in the field. It will prevent the use of outdated and invalidated terms and definitions in the field. The knowledge presented in the contribution will provide the new perspective of the measurement that will be evaluated according to the current standards.

Key words

geometric tolerance, form, orientation, location, run-out

INTRODUCTION

In the production process of components, it is necessary to observe the tolerance specified by technical documentation. The system of tolerances fits ISO which is defined by the STN EN ISO 286-1:2010 standard, which is often used for prescription of the dimensional tolerance. According to the standard, accuracy of dimensions is prescribed by a letter and a number (e.g. H7, j6 ...):

- The letter defines the position of the tolerance zone related to the zero line, which is a function of the nominal dimension. Capital letters (A ..., ZC) are used for holes (or inside dimensions) and small letters of the alphabet (a ..., zc) are used for shafts (or external dimensions).
- The number defines the standard tolerance grade, which is abbreviated IT (e.g. IT7, IT9 ...). ISO system provides 20 tolerance grades. Grades IT1 to IT18 are for general applications. Grades IT0 and IT01 are not for general use.

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In the drawing or other technical documentation, parts are displayed in the ideal, geometrically well-defined forms, with defined relative positions. Such ideal components cannot be produced. As the result of the effects of various influences in the production process are real parts, which have at different points of surface different values of deviation from the ideal form. To this is added the deviation from the nominal position.

The aim of this paper is to analyse the geometric accuracy of components in today's terms - within the context of the currently valid standards. This is one of the starting points for solving the VEGA 1/0615/12 research project "Influence of 5-axis grinding parameters on the shank cutter´s geometric accuracy". The motivation was the frequent use of outdated and invalid terms and definitions in the field. The acquired knowledge will bring a new insight into the measurement.

GEOMETRIC TOLERANCE

Material objects cannot achieve perfect precision. In geometric understanding, the real form of the workpiece surface is always more or less different from the nominal form. Differences from the nominal form are called deviations. Current standards in contrast to previous standards do not define the term of deviations. Deviations occur in the production process and are detected by measuring. Exact definition of deviation is indicated by the size of the minimum space which is formed by the virtual covering element of the tolerated shape. This element is of the same type (form) as the tolerance zone of a tolerated shape (Dovica, 2006).

The form tolerances define only the deviation of the real characteristics of a form. So, in addition to keeping the required dimensional accuracy and form, it is necessary to keep the orientation and location of the individual elements. Some geometric tolerances require a reference base. The base is made up of theoretically exact geometric shape (axis, plane, line, etc.) to which the positions of geometric characteristics of individual elements are determined.
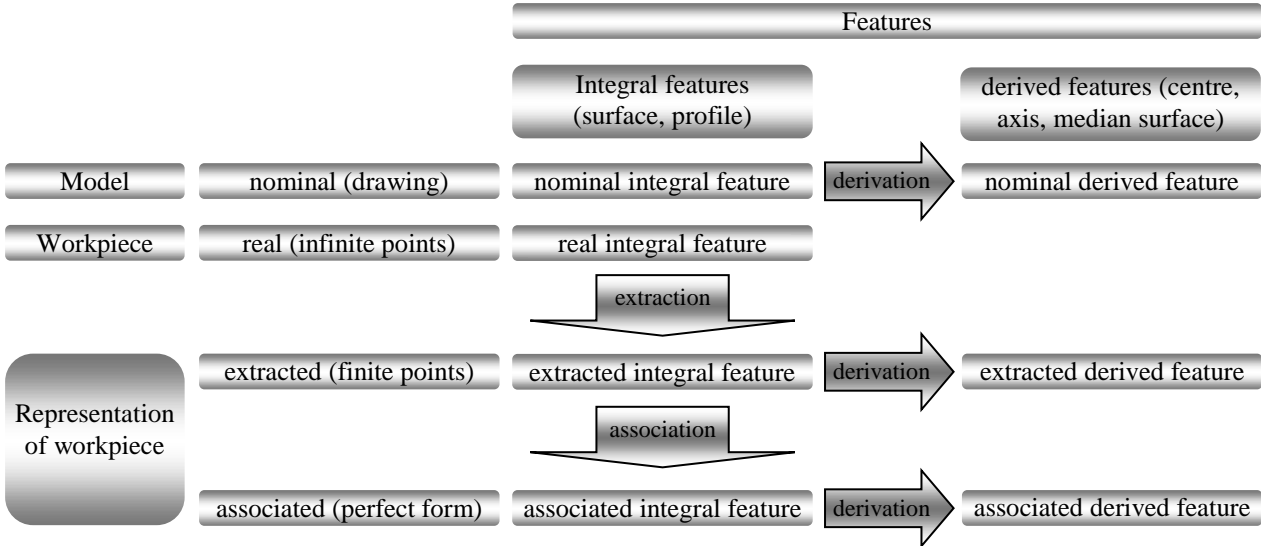
Fig. 1 Matrix structure of geometrical feature definitions

Geometric tolerance is prescribed by EN ISO 1101:2006 standard. Geometrical tolerance can be determined according to the functional requirements for the specific components. Too large tolerance does not provide the functionality of component; on the other hand, too small tolerance significantly increases the cost of production. In practice, it means determination of

the tolerances that ensure the functionality of components at the lowest cost. Production and inspection requirements can therefore also affect geometric tolerance. On the other hand, data of geometric tolerances specified in the technical documentation do not necessarily determine the usage of certain method of production, measurement or control.

Geometric tolerance is applied to the element, which is a specific point, line or surface. Elements (Fig. 1, 2) may be integral (e.g. outer surface of the cylinder), or may be derived (e.g. centre line or mean surface) (Humienny, 2001).
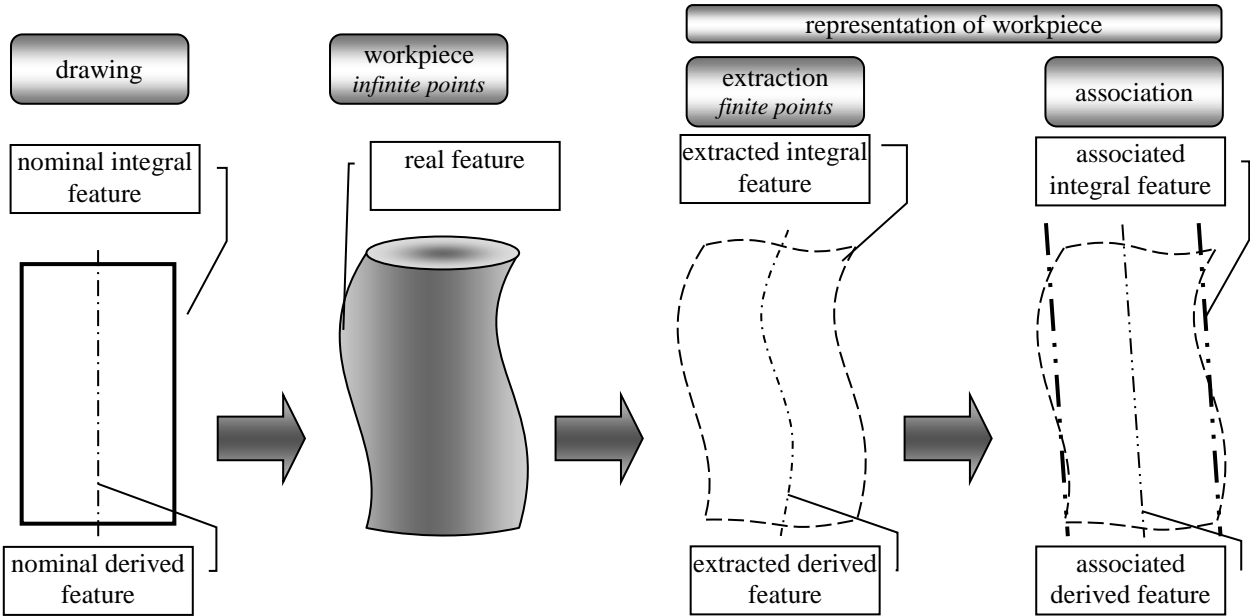

Fig. 2 *Terms of geometrical features for the example of a cylinder*

Geometric tolerance defines the tolerance zone on the element - the area bounded by one or more geometrically precise lines or surfaces. Tolerance zone is characterized by a linear dimension, which is called tolerance. It is always defined as perpendicular to the specified geometric shape, unless it is specifically prescribed in some direction.

GEOMETRIC CHARACTERISTICS (STN EN ISO 1101 (01 4401), 2013)   Table 1

Tolerance	Characteristic	Mark	Requirement base
Form	Straightness	−	No
	Flatness	▱	No
	Roundness	○	No
	Cylindricity	⌀	No
	Profile any line	⌒	No
	Profile any surface	⌓	No
Orientation	Parallelism	//	Yes
	Perpendicularity	⊥	Yes
	Angularity	∠	Yes
	Profile any line	⌒	Yes
	Profile any surface	⌓	Yes

	Position	⊕	Yes or No
Location	Concentricity (for centre points)	◎	Yes
	Coaxiality (for axes)	◎	Yes
	Symmetry	═	Yes
	Profile any line	∩	Yes
	Profile any surface	∩	Yes
Run-out	Circular run-out	↗	Yes
	Total run-out	↗↗	Yes

According to the element type and according to the method of listing, the tolerance zone can be:
- the space within a circle,
- the space between two concentric circles,
- the space between two equidistant lines or two parallel straight lines,
- the space within a cylinder,
- the space between two coaxial cylinders,
- the space between two equidistant surfaces or two parallel planes,
- the space within a sphere.

If there is any restrictive requirement (e.g. explanatory note registered under the tolerance frame), tolerated element may have the tolerance zone of arbitrary form and orientation.

DEFINITIONS OF FORM TOLERANCES

The grant project will evaluate the engineering parts connected with shape tolerances. Below are the definitions of tolerance zones for the following characteristics:

Straightness (STN P CEN ISO/TS 12780-1:2008, STN P CEN ISO/TS 12780-2:2008) – the tolerance zone in the considered plane is limited by two parallel straight lines with a distance "t" in the specified direction. It can also be formed by two parallel planes (with distance of the tolerance) or by a cylinder (with diameter of the tolerance) (Fig. 3).
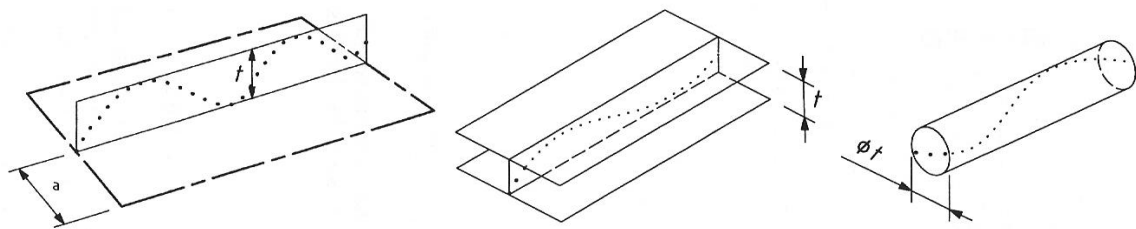

Fig. 3 *Tolerance of straightness*

Flatness (STN P CEN ISO/TS 12781-1:2008, STN P CEN ISO/TS 12781-2:2008) – the tolerance zone is limited by two parallel planes with distance "t".

Roundness (STN P CEN ISO/TS 12181-1:2008, STN P CEN ISO TS 12181-2:2008) – the tolerance zone in the considered cross-section is limited by two concentric circles with a difference in radii of "t".

Cylindricity (STN P CEN ISO/TS 12781-1:2008, STN P CEN ISO TS 12781-2:2008) – the tolerance zone is limited by two coaxial cylinders with a difference in radii of "t".
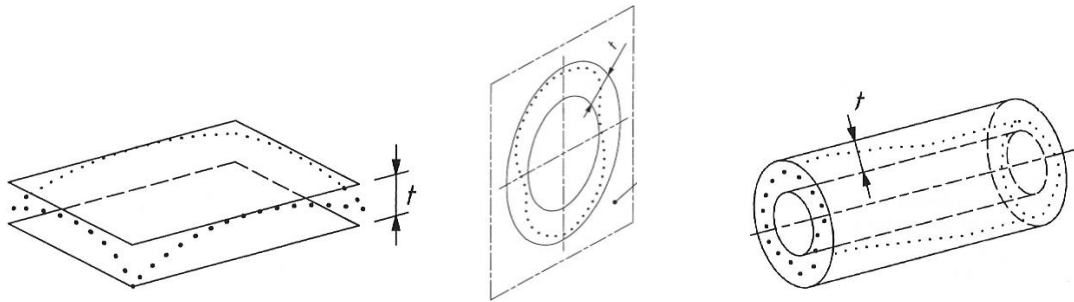
Fig. 4 *Tolerance of flatness, roundness and cylindricity*

Profile of any line (STN EN ISO 1660:1998) – the tolerance zone is limited by two lines enveloping circles of diameter "t", the centres of which are situated on a line having the theoretically exact geometrical form.

Profile of any surface (STN EN ISO 1660:1998) – the tolerance zone is limited by two lines enveloping circles of diameter "t", the centres of which are situated on a line having the theoretically exact geometrical form with respect to datum.
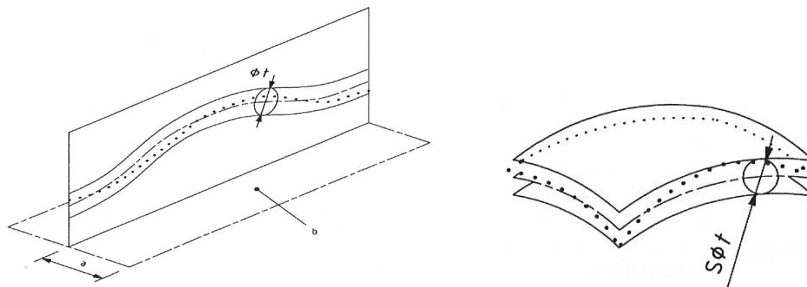
Fig. 5 *Tolerance of profile of any line and of any surface*

REQUIREMENTS FOR GEOMETRIC TOLERANCING

Various requirements which are prescribed in the technical documentation together with marks and geometric tolerances in the tolerance frame can be ascribed to geometric tolerancing, also. These requirements are governed by standards (e.g. EN ISO 2692:2007). Requirements are set out in the relevant tolerance frame on technical drawing.

Maximum Material Condition (MMC) is considered the state of the extracted element in which the dimensional element is everywhere in the border dimension which corresponds to the maximum of material requirement (e.g. minimum bore diameter and the maximum diameter of the shaft). The dimension determining the maximum material condition of geometric element is called a Maximum Material Size (MMS) (Fig. 3).


Fig. 6 *Maximum Material Size (MMS) for internal and external dimension*
DMR – lower limit size, HMR – upper limit size, T – tolerance

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Similarly defined is a <u>Least Material Condition (LMC)</u> – considered state of the extracted element in which the dimensional element is everywhere in the border dimension which corresponds to the minimum of material (e.g. maximum bore diameter and the minimum diameter of the shaft). The dimension determining the least material condition of geometric element is called a Least <u>Material Size (LMS)</u>.

Another requirement used in the technical documentation is a RPR (Reciprocity Requirement). It is the additional requirement for dimensional element which is used as a supplement to the maximum material requirement MMR (or least material requirement LMR) and expresses that the dimension tolerance is enlarged by the difference between geometric tolerance and geometric deviation.

Fig. 7 shows an example of the conditions for the maximum material along with the requirement of reciprocity. Extracted geometric element of the tolerated pins must not exceed the Maximum Material Virtual Condition MMVC having a diameter of 10.3 mm. Local average of tolerated pins must be everywhere greater than LMS = 9.8 mm. Reciprocity requirement RPR allows enlarged dimensional tolerance. Location of both MMVCs is theoretically precise – a distance of 25 mm from each other and they are theoretically exactly perpendicular to the A datum.
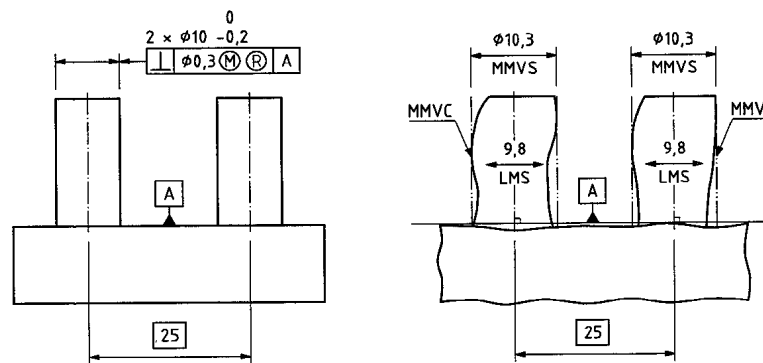
Fig. 7 *Maximum material condition MMC along with reciprocity requirement RPR*

CONCLUSION

The article presents an overview of the most widely-used terms and definitions in the field of geometric tolerance. At present, it is not possible to properly evaluate and interpret the measurement results without the knowledge of the applicable standards in the field. This knowledge can be also used in the computer-aided measurement technology (3D scanners, coordinate measuring machines ...). This contribution should therefore also contribute to the new concept of measurement and evaluation of the results attained.

ACKNOWLEDGMENT

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