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UNCERTAINTY RANGES RESULTING FROM THE APPLICATION OF THE GPS RULES IN TECHNICAL PRODUCT DOCUMENTATION

The paper presents the state of ignorance as a result of the analysis of the present GPS rules in drawing, interpretation and verification of geometrical features of a construction. On the basis of the fragments of production drawings of connections which are applied in mechanical engineering, it was proved that the knowledge of the application rules and interpretation of the tolerance of form in engineering practice is insufficient. The author presents the proposals of unification of specifications and application rules for the tolerance of straightness, roundness and cylindricity. These proposals should guarantee the expected functional features, constructional requirements and preferred applications of the construction in technical product documentation. On the basis of the tolerance of cylindricity, it was stated that the present specification rules of the tolerance of form require continuous improvement of determination of measuring conditions in production drawings which will allow to check the geometrical structure of the manufactured products.

Keywords: geometrical product specification (GPS), design uncertainty, metrological uncertainty, form deviation

1. INTRODUCTION

This paper is a result of examination of the production of axisymmetric connections which are manufactured in aircraft, automotive and machine-tool industry. The straightness, roundness and cylindricity deviations which occur during the manufacturing process are the reason of decreasing the contact area between mating parts. This restricts considerably the dedicated capacity of load transmission and the assumed constructional features of the connection. Therefore, there is a wide interest of searching of new possibilities of improvement of notation rules

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of the tolerance of form which will allow to decrease the specification uncertainty and measurement uncertainty.

The designed geometrical profile of a construction is defined as a perfect profile with the shape of line, circle or cylinder. The products macrogeometry can be distorted in many ways because of the manufacturing process, and number of permutations of the geometry is unlimited [1, 3]. The examples of the actual geometry of cylindrical elements are presented in Fig. 1.

![Fig. 1. Examples of the actual geometry of cylindrical elements](image)

A direct measure of the actual deviation of the part profile from its nominal shape (i.e. designed one) is a form deviation. This deviation should be placed in the area which is limited by two perfect lines or surfaces defined by the tolerance. The classification and graphical denotations of the tolerances of cylindrical elements, as per the standard PN-EN ISO 1101:2006 are presented in Fig. 2.

![Fig. 2. The tolerance of form: a) straightness of generating line, b) straightness of axis, c) roundness, d) cylindricity](image)

The analysis of the state of notation of the form tolerance and manufacturing accuracy was conducted for the group of ca. 200 connections and other axisymmetric constructions. The following elements were analysed:

- assembly elements of a crankshaft, pistons and connecting rods,
- valves and valve guides,
- conical connections,
- assembly of pipes for aircraft industry,
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- spigot joints,
- turbine shafts,
- splined connections,
- screw joints,
- guidance apparatus of compressors and turbines.

The examples of notations of the selected form tolerances for the assembly of a crankshaft, pistons and connecting rods of a combustion engine are presented in Fig. 3. The presented form deviations have an influence on oil consumption, variations of resistance to motion, vibrations and volumetric wear.

![Fig. 3. Examples of notations of the selected form features of elements of the assembly of a crankshaft, pistons and connecting rods of a combustion engine: a) cylinder liner, b) piston, c) gudgeon pin, d) connecting rod](image)

The conducted investigations of operation of combustion engines have proved that thermal and mechanical stresses are the reason of 75% of defects of valves and valve guides (Fig. 4 and 5). These stresses are caused among other things by the straightness and roundness deviations between mating surfaces: external surface of valve spindle and internal surface of valve guide.
Fundamental technical problems during the forming process of pipes with the required geometry (Fig. 6 and 7) are the profile deformation (ovalization) of pipe cross-section and the deformation of the bending radius – these deformations are the reasons of variations of the flow velocity of medium and its whirls.
2. DESIGN UNCERTAINTY

Up to now the term of uncertainty – defined in VIM [4] and GUM [5] – was generally applied in a metrology only (measuring accuracy is described by the measuring uncertainty). The Technical Committee ISO/TC 213 has extended the application of this term for the needs of interpretation of the geometrical product specification (Fig. 8).

Fig. 8. Components of a general model of the uncertainty during the measurement of geometrical features according to ISO/TS 17450-2
The knowledge of application rules and interpretation skills of notation of the geometrical tolerance is generally insufficient. Some fragments of the production drawings have proved the above mentioned statement, because the analysis of these drawings during manufacturing process has generated many doubts and questions. The interpretation and comments of the proposed solutions and consequences of incorrect notations for different constructional features are presented in paper [2].

The tolerances of form (according to general provisions in PN-EN ISO 1101) should be specified in accordance with the expected functional requirements for an element or assembly. There is a lack of information on the rules which should be applied during selection of the particular tolerances of form for defined functional features – both in literature and industrial guidelines. The tolerances of straightness, roundness and cylindricity are applied interchangeably for the same type of elements – this fact was shown in the paper. Table 1 presents the examples of notations of different tolerances of form and their value ranges applied for description of the macrostructure of cylinder liner holes which are used in Heavy Duty Diesel engines.

A majority of engine producers apply straightness and roundness tolerances simultaneously with the value of 10 µm. Companies at EU market allow to enlarge the tolerance of straightness to 20 µm, and producers at Japan market decrease the tolerance of roundness to 7 µm. The tolerances of straightness and roundness are related to the part of the surface of the sleeve hole which is located between GMP and DMP. On the other hand, the companies from the EU (e.g. DC, MAN and Volvo) apply the tolerance of cylindricity of 5 µm, 10 µm and 10 µm respectively – this tolerance refers to the entire surface of the sleeve hole.

<table>
<thead>
<tr>
<th>Inner diameter of the sleeve [mm]</th>
<th>Region</th>
<th>Form tolerances [µm]</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Roundness</td>
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<tr>
<td>115-137</td>
<td>USA</td>
<td>10</td>
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<tr>
<td></td>
<td>EU</td>
<td>10</td>
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<td></td>
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<tr>
<td></td>
<td>Japan</td>
<td>7–10</td>
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</tbody>
</table>

The author has made an attempt to establish the principles of application of some form tolerances related to the desired functional features, design requirements and preferred application in the mechanical engineering drawings. As a result of this analysis the following tolerances were proposed to use:
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− *straightness tolerance of the generating line*, it can be used when accurate positioning and transmission of rectilinear motion are required, cylindrical profile is incomplete – margins are present in the profile (making problems in measuring the roundness deviation);

− *roundness tolerance*, it can be used when fitting accuracy of the elements and leakproofness are a primary consideration and when a specific type of lobing is defined for the transverse section (e.g. 3-angular profile) or when the reduction of the allowable lobing tolerance of the lower order is required (e.g. for oval profile, three-angular profile);

− *tolerance of generating line straightness and roundness*, these tolerances can be applied together in order to keep the stiffness of mounting of the components, alignment, accuracy of displacement and also when measuring the cylindricity tolerance is hindered by the component height;

− *tolerance of cylindricity*, it should be used for mating cylindrical surfaces of components for which high operation and reliability requirements are specified to ensure the desired radial clearance and to avoid vibrations and high and/or variable motion resistance, it is also recommended when a specific cylindrical shape of the component is specified, e.g. barrel shape of bearing rollers.

3. METROLOGICAL UNCERTAINTY

Yet another problem for the manufacturers of the mechanical engineering products is a lack of methodological requirements for notation of the form tolerance in the mechanical engineering drawings related to the procedure of the measurement of the straightness, roundness and cylindricity deviations and to the method of analysis and evaluation of the obtained measurement results. Figure 9 specifies the cylindricity tolerance of a shaft at $T = 0.010$ mm for the outer diameter.

![Fig. 9. Notation of the tolerance of cylindricity for the shaft in accordance with the current notation rules](image)

Table 2 presents the influence of selection of variable devices, strategy and parameters on the values of the tolerance of cylindricity. The investigations were conducted with the application of CMM Prismo 7. The shaft with the nominal diameter $\phi 52.34$ mm was chosen for the measurements.
During the measurement of the cylindricity deviation the particular parameters were changed, and the measurement results were related to the average circle – i.e. Gauss circle. This element of approximation is applied in the industry.

It was showed that the values of the cylindricity deviation are dependent on:

– applied measuring device (Tab. 2, no. 1),
– measuring strategy and number of sections and their location (Tab. 2, no. 2),
– measuring method (Tab. 2, no. 3),
– applied filter and filtering conditions (Tab. 2, no. 4),
– selection of the radius of the gauging point (Tab. 2, no. 5),
– measuring velocity (Tab. 2, no. 6),
– measuring tension (Tab. 2, no. 7),
– applied reference feature (Tab. 2, no. 8).

Among the provisions of the EN ISO 1101 one can find the note that the denotation of the form tolerance does not impose the application of any specific of
manufacturing, measuring and verification of conformity. Besides, it states that the requirements concerning the methods of manufacturing and verification of conformity may have an influence on the tolerancing method of the product shape. The specification principles connected with the form tolerance, as defined by the above-mentioned standard require continuous improvement of the notation system used on the mechanical engineering drawings and measuring conditions.

The author has made an attempt of such improvement of notation of the cylindricality tolerance. This effect is presented in Fig. 10.

![Fig. 10. Improved system of notation of the tolerance of cylindricality for the shaft](image)

The drawing has been supplemented with the following information:
- measuring strategy (SOZO.3.5 – strategy of roundness profiles observation with the application of three evenly distributed profiles, the outlines of the outermost circles should be measured at a distance of 5mm from the shaft faces),
- reference circle (MCCI – minimum circumscribed circle which presents mating of a shaft in a joint),
- filter (G150÷10 – Gauss band-pass filter 150÷10 UPR).

The proposed notation of the form tolerance, obtained as a result of this research allows to significantly reduce the specification uncertainty.

### 4. SUMMARY

The application of GPS rules allows to achieve the perfect designer's vision of the element of a mechanical device and assembly. The real shape of element is always deformed in some degree because of the manufacturing process. But this deformation should be kept in the allowable area of geometrical features which are defined in the technical product documentation. To achieve this aim, it is necessary to conduct further studies on elaboration and supplementation of the GPS rules for the form tolerances in the direction of determination of measuring conditions and the form of their notation in project documentation.
REFERENCES


OBSZARY NIEPEWNOŚCI WYNIKAJĄCE Z ANALIZY STOSOWANIA ZASAD GPS W ZAPISIE KONSTRUKCJI

Streszczenie

Na podstawie fragmentów rysunków wykonawczych do produkcji połączeń używanych w budowie maszyn dowiedziono, że znajomość zasad GPS i interpretacji tolerancji kształtu jest niewystarczająca w praktyce przemysłowej. Przedstawiono propozycje ujednolicenia zasad specyfikacji i stosowania tolerancji prostoliniowości, okrągłości i walcowości w celu zapewnienia oczekiwnych cech funkcjonalnych, wymagań konstrukcyjnych i preferowanych zastosowań w zapisie konstrukcji. Na przykładzie opracowanego i przedstawionego zapisu tolerancji walcowości wykazano, że obecne zasady specyfikacji tolerancji kształtu wymagają określenia warunków wykonania pomiarów sprawdzających geometryczną strukturę wytworzonych elementów.