Tolerance system for linear maximum material sizes and their inspection by calibers

V I Glukhov, V A Grinevich and V V Shalay
Omsk State Technical University, 11, Mira Ave., Omsk, 644050, Russia

Abstract. The paper deals with the topical issue of quality assurance of technical products according to precise geometrical specifications. The aim of this work is to develop proposals for improving the system of tolerances and fits for linear sizes in the international standard ISO 286-1. The objective of this work is to increase the level of adequacy of the linear size tolerance model to the real dimensional elements of the parts. Two sizes of dimensional element - maximum material size and minimum material size are basic concepts of F. W. Taylor principles. The difference between the size of the maximum material holes (the minimum size) and maximum material size of shaft (maximum size) determines the type of the pair fit. In the ISO system of tolerances the ideal model of a dimensional element without form deviations of the surfaces is applied to linear dimensions. The ideal model is inadequate to the real dimensional element. The rejection of the form deviations resulted in the loss of the dimensional element minimum material size. The tolerance interval limits the upper and lower limits and the deviations of only the maximum material size. Validity inspection of the maximum material size by the upper and lower limit dimensions shall be provided by complete through and no-go gauges. Such monitoring will provide a fit with the required limiting values of clearances and tightness. Form tolerances in the diameter expression that is joined to the dimension tolerance for maximum material size increase the tolerance interval and make the minimum material limit that should be monitored by the no-go two-point gauge. Inconsistencies of the international tolerances system can be eliminated if to move from an inappropriate ideal model of a dimensional element to to the adequate real model considering the form deviation.

Keywords – products geometrical specifications, tolerance and fit system for linear sizes, maximum and minimum material sizes, tolerance models.

1. Introduction
The most common size elements, which make the technical workpieces, are cylindrical elements and parallel prismatic elements (elements of type "cylinder" and "two parallel opposite planes" according to the international standards ISO geometric product specifications GPS). The sizes of these elements are expressed in units of length and standardized as the linear dimensions [1]. The accuracy of the linear dimensions is regulated by the International tolerance and fit system [2, 3]. High efficiency of the system is proved by almost a century of its use without significant changes in the of technical product design. Based on the numeric values of linear dimensions tolerances, and F. W. Taylor principles, half century ago a system of limit gauges for precision inspection of dimensional elements [4], which is used at present was created [5]. Gauges are arbitration means for linear dimensions inspection.

Two sizes of dimensional element – maximum material size and minimum material size are basic concepts of F. W. Taylor principles. The workpieces dimensional elements are real material objects, limited to one or more surfaces that have form deviations. The projections of the surfaces make the maximum material size, while waves – the minimum material size of the dimensional element. These
concepts are common sizes for interior and exterior dimensional elements, holes and shafts. Two sizes have different functionality. The maximum material sizes of a hole and a shaft make a fit in conjunction with a clearance or interference due to the difference between the minimum hole size and the maximum shaft size. The minimum material size - maximum for the hole and minimum for the shaft – provide strength and limit the surface form deviations of the dimensional elements (Fig. 1).

![Fit model with zero clearance between the maximum material size of the hole $D_{MM}$ and shaft $d_{MM}$ with a guaranteed clearance between the size of the minimum material of a hole $D_{LM}$ and shaft $d_{LM}$ are equal to the sum of the form deviations $EFD$ and $EFd$ in the longitudinal (a) and cross (b) sections](image)

**Figure 1.** Fit model with zero clearance between the maximum material size of the hole $D_{MM}$ and shaft $d_{MM}$ with a guaranteed clearance between the size of the minimum material of a hole $D_{LM}$ and shaft $d_{LM}$ are equal to the sum of the form deviations $EFD$ and $EFd$ in the longitudinal (a) and cross (b) sections

The problem of providing technical products quality considering the accuracy of the geometric characteristics is widely discussed by researchers. Among recent publications of interest are the works about ensuring dimensional and geometric accuracy of products in additive manufacturing [6], the extended system approach in the regulation of positional tolerances of real surfaces points [7], improving the accuracy of geometric characteristics coordinate measurements on the basis of the normal vectors orientation of dimension elements surfaces [8].

2. Statement of the problem

In a previous article [9], the authors solved two problems for improving the system of tolerances and fits for linear sizes. In the first task, there is justified the assignment of the dimensional elements linear coordinating sizes to linear dimensions with standardizing their accuracy by the only one tolerance interval with symmetric deviations $JS$ - for coordinates of holes - and $js$ for shafts coordinates is justified. Secondly, a fundamental change is justified: that is to consider a major deviation of all intervals of the tolerances of linear sizes – a maximum deviation corresponding to the maximum limit of material: $EI$ -is lower deviation for hole sizes and $es$ – the upper deviation for shaft sizes.

The objective of this work is to increase the level of linear sizes model tolerances adequacy of holes and shafts to the real dimensional elements by taking into account form deviations of the surfaces. The aim of this work is to provide the precision requirements to the elements fit.
3. Ideal model of tolerances and fits for linear sizes and real model with consideration of dimension elements surfaces form tolerances

In ISO 286-1 the terminology of size limits is changed. Instead of functional sizes of the material maximum and minimum altitude terms of size of hole and shaft are proposed: upper limits $D_{ULS}$, $d_{ULS}$ and lower limits $D_{LLS}$, $d_{LLS}$ (Fig. 2, a)

Figure 2. The model of tolerances intervals of the of linear dimensions of ideal (a) and real (b) hole and shaft with maximum information value at fitting in the system of hole and shaft with consideration of the surfaces form deviations (b)

Dimensional elements lost material content, now they are made by geometric surfaces that lack geometrical tolerances. That is the overview of the ideal models of dimensional elements, standard intervals of hole tolerances $ITD$, shaft $ITd$ and their fit with a clearance in the system of the holes with minimal clearance $S_L$ and maximum clearance $S_M$. The exclusion of the form deviations from the ideal models made them inadequate to real dimensional elements that led to the loss of the minimum material size. As a result, the intervals of tolerances began to limit only the maximum material of a hole and a shaft between its upper and lower limit sizes. To withstand the range requirements of the limiting clearances of the landing, must be applied to control the size of the maximum material passing the full and no-go gauges. However, due to the form deviations of the real elements surfaces the minimum material size will go beyond the boundaries of the intervals of tolerance, which is unacceptable.

If to inspect the minimum material size we use two-point gauges, the minimum material size will be included in the boundaries of the tolerance intervals, but tolerances of maximum material size will be reduced that will also reduce the maximum clearance $S_M$ and lead to the disturbance of limit requirements for fitting precision.
Real models, taking into account the form deviation of the dimensional elements (Fig. 2, b), help to overcome these inconsistencies of ideal models. To do this, the material minimum of a hole and a shaft limits of standard tolerances intervals $ITD$ and $ITd$ should be added to the tolerances of the form $TFD$ and $TFd$ of dimensional elements surfaces in diameter terms. However, all the inconsistencies of the ideal models will be removed, despite the fact that the intervals of the tolerances of the elements dimensions will be complex ($TDc$ and $Tdc$) and extended to the regions of the elements minimum material.

4. Experimental results
An experimental study of the maximum and minimum materials sizes was conducted at various measurement objects such as a piston pin, a pinion, a bearing roller and a pin. All these parts are cylindrical dimensional elements with different roundness deviations in the cross sections.

![Figure 3](image_url)

**Figure 3.** Protocols of measurements of the diameters of the maximum and minimum material in 24 points, cross sections of cylindrical dimensional elements

The measurements were performed by two-point or three-point methods, depending on odd or even number of faces at the stationary unit and a monitoring configuration on the size of cylindrical measures. The measurement protocols (Fig. 3) of diameter dimensions show that in each of the 24 measurement points the diameter has specified values. Maximum and minimum values of measurement results are the dimensional element diameters of the material maximum $d_{MM}$ and minimum $d_{LM}$.

Thus, each actual size element has two valid values.
5. Discussion
The main result of the study is developing a new model of linear size tolerance of a dimensional element for the system of tolerances and fits for international standard ISO286-1.

In the standard, the ideal model of the surface dimensional element which does not have geometrical tolerances is used. For a perfect element, that uses an ideal model of tolerance linear dimension, which also includes some variation in the structure of tolerance. The perfect element has only one valid value, which is limited to the upper and lower limit dimensions of the ideal tolerance. This approach runs counter to F. W. Taylor principles according to which two extreme sizes of the dimensional element of a various functional purposes – the maximum material size and minimum material size are controlled by different inspection methods: by a full gauge and no-go point-to-point movement, which took into account the real parts deviations. The ideal model cannot provide the real requirements of fitting holes and shafts, always having form deviations, which can take up to 60% of the linear dimensions tolerances, which is confirmed by the experimental results. In this new adequate model of size tolerance, geometrical tolerances of element surface are incorporated into the tolerance structure.

6. Conclusion
1. The ideal model of tolerances of linear sizes in the International standard ISO286-1 does not take into account the form deviations of the surfaces and is inadequate to real dimensional elements.
2. Standard tolerance of linear size is only the maximum deviations of the dimensional element maximum material size.
3. With the aim of improving the accuracy of the fit, it is recommended to introduce the structure of the tolerance of size tolerances of the surfaces form and the minimum material size is the second size dimension of the workpiece.

References
[1] ISO 14405-1:2010 Geometrical product specifications (GPS) Dimensional tolerance – Part 1: Linear sizes
[2] ISO 286-1:2010 Geometrical product specifications (GPS) – ISO code system for tolerances on linear sizes – Part 1: Basis of tolerances, deviations and fits
[3] ISO 286-2:2010 Geometrical product specifications (GPS) – ISO code system for tolerances on linear sizes – Part 2: Tables of standard tolerance classes and limit deviations for holes and shafts
[4] ISO/R 1938:1971 ISO system of limits and fits - Part 1: Inspection of plain work pieces
[5] ISO 1938-1:2015 Geometrical product specifications (GPS) – Dimensional measuring equipment – Part 1: Plain limit gauges of linear size
[6] Moroni G, Stefano Petro S and Polini W 2017 Geometrical product specification and verification in additive manufacturing CIRP Annals - Manufacturing Technology 66 (1) pp 157-160
[7] Yiging Yan, Martin Dohn, Steven, Pters Uwe Heisel 2018 Complementing and enhancing definitions of position tolerance for a real point based on the ISO Geometrical Product Specifications (GPS) CIRP Journal of manufacturing Science and Technology
[8] Mario Drbul, Andrej Czan Michal Sajgalik, Marianna Piesova, Kizysztof Stepien 2017 Influence of Normal Vectors on the Accuracy of Geometrical Products Specification Procedia Engineering 192 pp 119–123
[9] Glukhov V I, Grinevich V A, Shalay V V 2018 The linear sizes tolerances and fits system modernization IOP Conf.Series Journal of Physics 998 pp 1-8