Two-point method uncertainty during control and measurement of cylindrical element diameters

To cite this article: V I Glukhov et al 2018 J. Phys.: Conf. Ser. 998 012011

View the article online for updates and enhancements.
Two-point method uncertainty during control and measurement of cylindrical element diameters

V I Glukhov¹, V V Shalay¹ and H. Radev²

¹Omsk State Technical University, 11 Mira av., Omsk, 644050, Russia
²Mechanical Engineering Faculty, Technical University of Sofia, Sofia, Bulgaria

E-mail:mips@omgtu.ru

Abstract. The topic of the article is devoted to the urgent problem of the reliability of technical products geometric specifications measurements. The purpose of the article is to improve the quality of parts linear sizes control by the two-point measurement method. The article task is to investigate methodical extended uncertainties in measuring cylindrical element linear sizes. The investigation method is a geometric modeling of the element surfaces shape and location deviations in a rectangular coordinate system. The studies were carried out for elements of various service use, taking into account their informativeness, corresponding to the kinematic pairs classes in theoretical mechanics and the number of constrained degrees of freedom in the datum element function. Cylindrical elements with informativity of 4, 2, 1 and θ (zero) were investigated. The uncertainties estimation of in two-point measurements was made by comparing the results of of linear dimensions measurements with the functional diameters maximum and minimum of the element material. Methodical uncertainty is formed when cylindrical elements with maximum informativeness have shape deviations of the cut and the curvature types. Methodical uncertainty is formed by measuring the element average size for all types of shape deviations. The two-point measurement method cannot take into account the location deviations of a dimensional element, so its use for elements with informativeness less than the maximum creates unacceptable methodical uncertainties in measurements of the maximum, minimum and medium linear dimensions. Similar methodical uncertainties also exist in the arbitration control of the linear dimensions of the cylindrical elements by limiting two-point gauges.

Keywords. Technical measurements, linear sizes, element informativeness, methodical uncertainty.

1. Introduction

The International Organization for Standardization technical Committee TC213 “Dimensional and geometrical product specifications and their control” updated all terminology to linear and angular values at the level of international standards [1-5] in the first decade of the 21st century without convincing justification. As a result, millions of engineers – users of standards in all processes of the product life cycle – designers, technologists, metrologists, control masters, university and college teachers found themselves in a difficult situation. New terms and definitions did not specify or improve old terms that served for 25-50 years. The new engineering terms abolished the old ones. Users began to note the complexity of the new terminology in their publications [6].

Between the new and old terminology there must be continuity in the development and improvement of terms, including on the following unresolved problems:

- there is no classification of geometric specifications for a functional purpose, coordinating dimensions of the elements of parts are not introduced;
coordinate systems are not used to read the geometrical characteristics of elements, parts and assemblies;
the engineering principles for ensuring the quality of products in terms of the geometric characteristics accuracy are not used: the principle of inversion, the principle of the unity of design, technological and measuring bases, the principle of linear-angular two-dimensionality of geometric characteristics, and the principle of geometric elements informativeness [7];
• systematic functional deviations of the component surfaces shape parts are considered random variables and are estimated by statistical characteristics.

2. Statement of the problem
The possibility of reliable measurements of the component parts dimensions and shape is a necessary condition for manufacturers of precision products [8]. Know-how – to know how to measure – is a basis of knowledge about the measurements required by a designer, a technologist and a metrologist [9]. The evaluation of the uncertainty in measuring geometric characteristics is a prerequisite for products quality control of [10].

Technical measurements make it possible to evaluate the part quality by the accuracy of geometric characteristics in the production process. The quality evaluation is carried out by controlling the dimensional and geometric accuracy of the component parts to meet the requirements of the design project. The transition of international GPS standards to the evaluation of the dimensional accuracy of parts based on the average size of elements using the two-point method requires estimation of the measurements uncertainty, which is the aim of this work.

The specific problem of evaluating the influence of form and joint deviations of cylindrical dimensional elements surfaces of various informative content is stated and solved on the expanded uncertainty of measurements of average, maximum and minimum linear sizes of elements by the two-point method.

3. Theory of elements functional linear sizes
Any workpiece of a technical product consists of geometric elements, which are parts of the material of the workpiece, limited by one or several geometric surfaces, primarily flat and cylindrical. Each element of the part performs certain functions [7]. The set of main design datums performs the functions of positioning the part in the product and identifying its generalized coordinate system. In sliding joints, the set of main datums performs the third function - it provides the kinematics of rotation and (or) the translational movement of the product part. The set of auxiliary design datums performs the functions of positioning the attached part to the considered one and identifying the auxiliary coordinate system for the attached part. The actuating elements perform the working functions of the part. Dimensional elements determine the overall dimensions of the part, and free elements with dimensions without tolerances perform the functions of connecting elements that unite all the geometric elements into a single solid body of the part.

The datum of a geometric element can limit a part by one to six degrees of freedom (up to three linear "t" and up to three angular "r"), which is a characteristic of the information "c" of the element and coincides with the class of kinematic pairs in theoretical mechanics. The maximum informativeness of the cylindrical element datum axis is equal to four and consists of two linear constraints along the normal to the axis in two perpendicular directions and two angular constraints around the same directions (4c = 2t + 2r).

Datums are combined into sets of datums to constraint the detail of the six degrees of freedom (6c = 3t + 3r) and form a generalized or auxiliary coordinate system in which the dimensions and coordinates of the elements should be measured. The parts are joined on sets of datums in order to combine the generalized coordinate system of the attached part with the auxiliary coordinate system of the base part.

The surfaces of all geometric elements have shape deviations in the form of alternating smooth harmonic protrusions and cavities. In addition, elements with informative content less than the maximum have protrusions and cavities of surfaces in the form of location deviations. Surface protrusions form the datum of the elements. Fits in the joints of the shafts and holes are formed by protrusions of the elements real surfaces. Consequently, the dimensions of the elements along the projections of real surfaces are the functional maximum material dimensions of the elements.
The cavities of the element’s real surfaces constraint the shape and location deviations of the, and together with the micro-roughness, they are the containers for the joint lubrication. Therefore, the size of the element along the cavities of the real surface is the functional minimum material size, determining the geometric accuracy of the element.

Thus, each real dimensional geometric element has two boundary functional sizes: the maximum material size and the minimum material size. By definition, these are the sizes of two regular (ideal) elements of the same type as the dimension element, nominally located relative to the coordinate system of the datums set, in which the dimensional element fulfills its service purpose, and covering the real surfaces of the dimension element with a tangent: the first - outside the material element - forms the maximum material size of the; the second - from the material of the element - forms the minimum material size. The dimensions of the maximum and minimum material are constrained by the upper and lower limits of the element size. Their reliable measurement ensures the quality of the joints during assembly.

The average size of the element should be calculated as a half-sum of the maximum and minimum material sizes. The connection with the gap \( S_m \) between the average dimensions of hole \( D_m \) and the shaft \( d_m \) (Fig. 1, a) can provide positive differences in the size of the minimum material hole \( D_{LM} \) with the size of the material maximum of shaft \( d_{LM} \) and the size of the maximum material of the hole \( D_{LM} \) with the material minimum size of the shaft \( D_{LM} \) only for one of the details translational motion. Rotational movement of the shaft in such joint is impossible (Figure 1, b) as the difference in the maximum sizes of hole \( D_{LM} \) and shaft \( d_{LM} \) form the tension \( N_{LM} \).

**Figure 1.** The model of the interference formation along the diameters of the maximum material in the fit with gap on the average hole and shaft diameters with informativeness 4.

**4. The two-point method uncertainty during control and measurement of diameters**

Arbitrary means of reliable control of the outer and inner cylindrical elements diameters are the limiting gauges. American engineer Taylor F W suggested the principles of designing limiting gauges more than a century ago. To control the maximum material size, the go gauge should have a geometrical shape of the mating part-the ring for a shaft and the plug for a hole. Controlling the size minimum material is necessary to be carried out by a no-go two-point gauge - a bracket for a shaft and a two-point internal caliper for a hole.

The control by two different limit gauges of the suitability of the maximum and minimum material sizes confirmed the facts of different service functions of the element two dimensions and the influence of shape deviations on the formation of two boundary dimensions of the element. Limit gauges are designed to control the validity of cylindrical elements with informativeness 4, which have location deviations.
The complex method of controlling the maximum size of the cylindrical elements material by methodical go gauges does not create a methodical uncertainty of measurements.

In connection with the standardization of the term "two-point size" [1], the two-point method was used to control and measure the maximum material size, and the minimum material size of cylindrical elements. When monitoring using two-point gauges - the diameters of the maximum $d_{MM}$ and the minimum $d_{LM}$ of the outer cylindrical element material (fig. 2), methodical uncertainties do not arise for the shape of a cylindrical surface profile such as the ovality $EFV$ (fig. 2, $a$) and the conicity $EFC$ (figure 2, $c$), as well as for deviations of the saddle shape type $EFS$ (Fig. 3, $c$) or barrel-type $EFT$ (figure 3, $b$). The control should be carried out in the two extreme and middle sections of the longitudinal profile and at least six sections of the transverse profile. In this case, the average diameter $dm$ is not controlled by the limit gauges.

1- go gauge to maximum material diameter; 2 – no – go gauge to minimum material diameter.

**Figure 2.** The two-point method uncertainties models of controlling diameters of maximum and minimum material of the outer cylindrical element with informativeness 4 using limit gauges.

The methodical uncertainties of $U_{MM}$ and $U_{LM}$ occur when controlling the diameters of the maximum $d_{MM}$ and the minimum $d_{LM}$ material of cylindrical elements with the shape deviations of the cross-sectional profile with the facet pattern $EFH$ (figure 2, $b$) and with deviations in the longitudinal section shape with the curvature type $EFB$ (straightness of the element axis) (Fig. 2, $d$). Essentially, the control of the element serviceability is carried out on the average diameters instead of the maximum and minimum material diameters. The methodological uncertainties of the two-point control method are equal to the numerical values of the facet $EFH$ and the curvature $EFB$ profiles of the transverse and longitudinal sections and will cause the same parts actual dimensions falling beyond the tolerance interval. Uncertainty of control should be excluded in arbitration control: the diameter of the maximum material should be controlled by a go gauge ring by a complex method; in order to estimate the diameter of the minimum material, the cut and curvature values of the element axis should be additionally measured, corrections should be made to the results of the control, or the diameter of the minimum material should be measured by universal means.
Figure 3. Models of uncertainties in measurements by the two-point method of the average diameter of an inner cylindrical element with informativeness 4.

When measuring two diameters of the maximum $D_{MM}$ and minimum material $D_{LM}$ of cylindrical elements with informativeness 4 using digital or scale measuring means by the two-point method (figure 3), methodological uncertainties are not formed by the profile shape deviations of the longitudinal section of the cone-shaped $EFC$ (figure 3, a), barrel-like $EFT$ (Fig.3, b), saddle-shaped $EFS$ types (figure. 3, c) and the shape deviation of the cross-section profile of ovality type $EFV$ (figure 3, e). However, if the element average diameter $D_m$ is taken as the measurement result, its methodological uncertainty will be determined by the differences in the average diameter $D_m$ and with the maximum material size $D_{MM}$ and with the minimum material size $D_{LM}$. If the element has profile shape deviations of the longitudinal section of curvature type $EFB$ (figure 3, d) and the cross-sectional profile of the facet type $EFH$ (figure 3, g), the methodological uncertainties of the $U_{MM}$ and $U_{LM}$ measurements of the maximum $D_{MM}$ and minimum $D_{LM}$ material of the are numerically equal to the shape deviations values $EFB$ and $EFH$. This means that in any section of the element only the average diameter $D_m$ is measured with the same uncertainty. Consequently, methodical uncertainties of the cylindrical elements diameters when measuring (figure 3) and control (figure 2) by the two-point method coincide.

A cylindrical element can have information content of less than four constraints (figure 4). With informativeness of 2 or 1 (figure 4, a), the element performs a datum function that constrains a detail of two translational ($2t$) or one rotational ($1r$) degrees of freedom, in a system with a flat datum having the informativeness $3$ ($3c = 1t + 2r$). An element with informativeness $\Theta$ (zero) performs the function of actuator, which should not have any point of contact with the attached part (figure 4, b), i.e. ensure the clearance fit.

The sets of $A3B2S1$ component datums have a total informativeness value 6, which allows them to materialize the generalized coordinate systems $OX4Y2Z\Theta$. Unused by the holes, the constraints of degrees of freedom, due to reduced informativeness, form angular $EPE$ and linear $EX$, $EY$ in the of axes and the centers of the holes location deviations. These location deviations reduce the diameters of the maximum material $D_{MM}$ and increase the diameters of the minimum material $D_{LM}$. According to the principle of two-dimensionality of sizes [7], these diameters are formed by two regular cylinders nominally located in coordinate system $OX4Y2Z\Theta$ and tangentially covering real surfaces of holes outside the material and from the parts material.
Therefore, the two-point method cannot measure the diameters of the maximum and minimum of the material and estimate their average diameter $D_{m}$, because the method does not take into account the location deviation of the cylindrical elements centers and axes and can be used for elements with informativeness $\alpha$ that have only shape deviations (Figure 3). The total uncertainty of the accepted value of the mean diameter will be a sum of unaccounted shape deviations of the surfaces and unaccounted location deviations of the elements centers and axes in the generalized coordinate system of the part.

5. Discussion of results
As a result of the of linear sizes two-point measurements accuracy studies, it is established that methodical uncertainties do not arise only in the maximum and minimum sizes with the maximum informativeness of elements having deviations of ovality, conicity, barrel shape, or saddle shape for cylindrical elements. Methodical uncertainty is formed when measuring elements with maximum informativeness for shape deviations of the cut type and the type of curvature of the cylindrical elements. Methodical uncertainty is formed by measuring the average size of the elements for all types of shape deviations. The two-point measurement method cannot take into account deviations in the location of a dimensional element, so its use for elements with informativeness less than the maximum creates unacceptable methodical uncertainties in measurements of the maximum, minimum and average linear dimensions. Similar methodical uncertainties also exist in the arbitration control of the linear sizes of the part elements by limiting two-point gauges.

6. Conclusion
According to the research results, the following conclusion can be made:
1. Each dimensional geometric element limits by a real surface has two linear sizes: two permissible size covers for the normalization of the accuracy class and two functional sizes for the operation of the part in the product: the maximum material size and the minimum material size.
2. According to the principle of sizes two-dimensionality, the size of the material maximum and the size of the material minimum he of the dimensional element are the dimensions of two regular (ideal) elements of the same type as the dimension element, nominally located relative to the coordinate system in which the dimensional element fulfills the service purpose, with the tangentially covering the real surface of the dimensional element: the first - outside the material of the element - materializes the size of the material maximum, the second - from the material of the element - materializes the size of the material minimum.
3. To implement these definitions, when measuring two sizes of an element, we need a coordinate system in which the dimensional element operates, and knowing the base informativeness of an element, i.e. the number of degrees of freedom that the ISO does not use.

4. Measurement of local linear sizes according to ISO standards by the two-point method is carried out by the shortest distance between opposite points of a dimensional element real surface in a set of pairs of points. By the processing of the measurement results the maximum size, the minimum size and the average size, which is preferred as an ordered one and having the biggest methodical uncertainty, are found.

5. The evaluation of the methodical extended uncertainty of two-point measurements of cylindrical elements linear sizes, made by comparison with the dimensions of the maximum and minimum material, showed that measurement uncertainty is not formed only in certain particular cases, when the maximum and minimum dimensions of the elements are located at opposite points of real surfaces.

6. The greatest influence on the uncertainty of two-point measurements of linear sizes has the deviation of a cut-type (roundness with an odd number of faces) and curvature (straightness) of the elements.

7. The uncertainty of two-point measurements of the linear sizes of elements that have information content less than the maximum is influences by location deviations such as positional deviation, perpendicularity, symmetry and alignment of the bases of the measured elements, which leads to unacceptably large values of uncertainties and goes beyond acceptable limits.

8. There is only one way to solve the described problem: the transition of ISO standards to a functional approach with geometric products specifications based on the two dimensionality principle with the classification of elements by informativeness, with the introduction of coordinate systems for reading characteristics, the development of mathematical models for the maximum and minimum material sizes and software for their control.

References

[1] ISO 8015:2011, Geometrical product specifications (GPS) – Fundamentals–Concepts, principles and rules
[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 17450-1:2011, Geometrical product specifications (GPS) – General concepts- Part 1: Model for geometrical specifications and verification
[4] ISO 14405-1:2010, Geometrical product specifications (GPS) – Dimensional tolerancing. Part 1: Linear sizes
[5] Nielsen H S 2013Proceedings of the Institution of Mechanical Engineers, Part B. J. Eng. Manufact 227 643-649.
[6] Wiesner H2015 Journal SKF Evolution I 27-30
[7] Glukhov V I 2014 Dynamics of Systems, Mechanisms and Machines (Dynamics) (IEEE Conf. Pub.) p 1-9
[8] Saunders P, Gludice S and Swart J 2014 Int. J. Metrol. Qual. Eng. 5 p 203-212
[9] Maropoulous P, Ceglarleak D, 2010 CIRP Annal. Manufast. Technol. 59 p 740-759
[10] Vetturi D, Lancini M, Bodini I, and Pasinetti S 2013 Int. J. Metrol. Qual. Eng. 4 p 35-39