New matrix for geometrical product specifications on coordinate basis

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Abstract. This study is devoted to the recent problem of quality assurance of technical products in the design process. However, it is impossible to solve this problem by using international standards ISO and geometrical product specifications developed by ISO technical Committee ISO/TC 213. They lack a reference system of geometrical characteristics, i.e. the coordinate systems of the products are not applied. On the other hand, the technical committee ISO/TC 184 – "Industrial automation systems and integration" introduced in their standards coordinate systems for the design of machine tools with numerical control, which made parts of products, 40 years ago, since neither design nor manufacture, nor the development of control programs or the control of parts after processing can be without coordinate systems. At the beginning of the XXI century, the same technical committee developed a series of international standards for the implementation of electronic geometrical 3D models of products, in the structure of which coordinate systems were introduced. Consequently, the coordinate system of products should be introduced in the standards for geometrical specifications ISO-GPS. With that study purpose, a new matrix of common GPS standards of a higher level on a coordinate basis was recommended.

1. Introduction

Technical Committee ISO/TC 184 in International Organization for Standardization has made a significant contribution to the development of digital technologies, having developed the series of international standards "Industrial automation systems and integration" on the implementation of electronic geometrical models for machine building and instrument making products in the early XXI century. Standards [1-5] are developed with the use of computer technology and cover all processes of the product life cycle: design, construction, control, assembly, operation, repair, disposal. Based on international standards, national standards of the Russian Federation [6, 7] for electronic documentation of technical products have been developed.

The main advantage of the new digital standards series is the introduction of a coordinate system to the structure of the electronic geometrical model of the product, for the first time in two and a half centuries since (1770) the pioneer of projection drawings Gaspard Monge [8]. The coordinate system of the product is a reference system of linear and angular coordinates of parts in the electronic model of the assembly unit and the coordinates of geometric elements in the electronic model of the part. Tangible media of coordinate systems are sets of design datums, operating in the Russian national standardization system for half a century [9]. In ISO standards [10] datums and datum systems are measuring ones to control geometric tolerances of shape, location, orientation and run-out [11], which do not always coincide with the design datums and part coordinate systems are not applied. The absence of coordinate systems in the drawings of parts and assembly units, in the technological processes of product manufacturing and assembly, leads to a decrease in the measurement accuracy on coordinate measurement machines (CMM).

Electronic geometrical models allow obtaining 2D projection drawings of products in electronic and paper form. Consequently, the coordinate systems of products will move to flat images, changing the entire structure of the geometrical product specifications. However, neither GPS Matrix [12] nor ISO strategic plans [13] provide for the transition to GPS coordinate systems (Figure 1).

Geometrical specification of the product (GPS)	Chain links						
	A	B	C	D	E	F	G
	Symbols and indications	Feature requirements	Feature properties	Conformance or non-conformance	Measurement	Measurement equipment	Calibration
Size	+	+	+	+	+	+	+
Distance		+	+		+	+	+
Form	+	+	+		+	+	+
Orientation	+	+	+		+	+	+
Location	+	+	+		+	+	+
Run-out	+						
Profile surface texture	+	+	+		+	+	+
Texture of the surface site	+	+	+		+	+	+
Surface defects	+	+					

Figure 1. Matrix of geometrical product specifications according to ISO 14638:2015.

With the absence of coordinate systems of products, many researchers are faced with non-conformance in applying geometrical specifications: when normalizing the accuracy of assembly units [14], under the influence of location and orientation tolerances on linear dimensions [15], when calculating dimension chains [16], under the influence of orientation tolerances on shape deviations [17], when measuring geometrical specifications in additive manufacturing [18], when developing the theory of linear dimensions from the point of view of computer science [19].

2. Problem statement

In order to improve the quality of design, technological and metrological documentation on the basis of the introduction of coordinate system to regulate and control the geometrical product specifications, it is necessary to solve the problem of developing a new matrix for the standardization of geometrical products specifications on a coordinate basis.

3. Theory of geometrical specifications in product coordinate systems

When designing a new product, the designer first develops an assembly drawing, and then the working drawings of the product parts. As a rule, development is carried out in the right rectangular main coordinate system (Figure 2), formed by a set of basic design datums of an assembly unit or part [9], limiting each of the six degrees of freedom: three linear and three angular [20].

Basic coordinate systems become the main geometrical product specifications, where linear and angular coordinates of assembly parts and geometrical features of each part are counted. In addition to the basic coordinate system, a complex product can have one or more auxiliary coordinate systems that are materialized by sets of auxiliary design datums for the connecting parts, sets of working executive elements performing the operational functions, sets of technological data and sets of measuring datums.

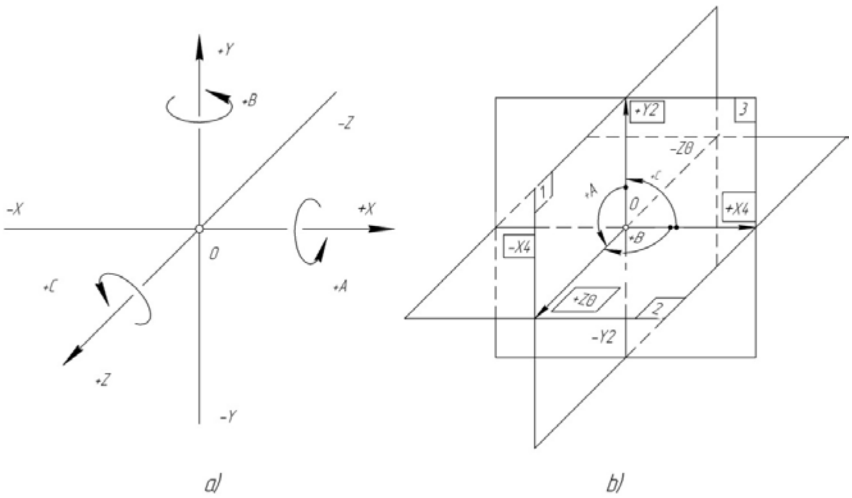


Figure 2. Right rectangular coordinate system: a) for metal-cutting machine tools according to ISO 841: 2001; b) for geometrical product specifications (alternative).

Three linear and three angular coordinates are required to position each auxiliary coordinate system in the main part system. This will eliminate all deviations of the location, which are inherently coordinating dimensions, including coordinates with zero nominal values of lengths and angles (Figure 3).

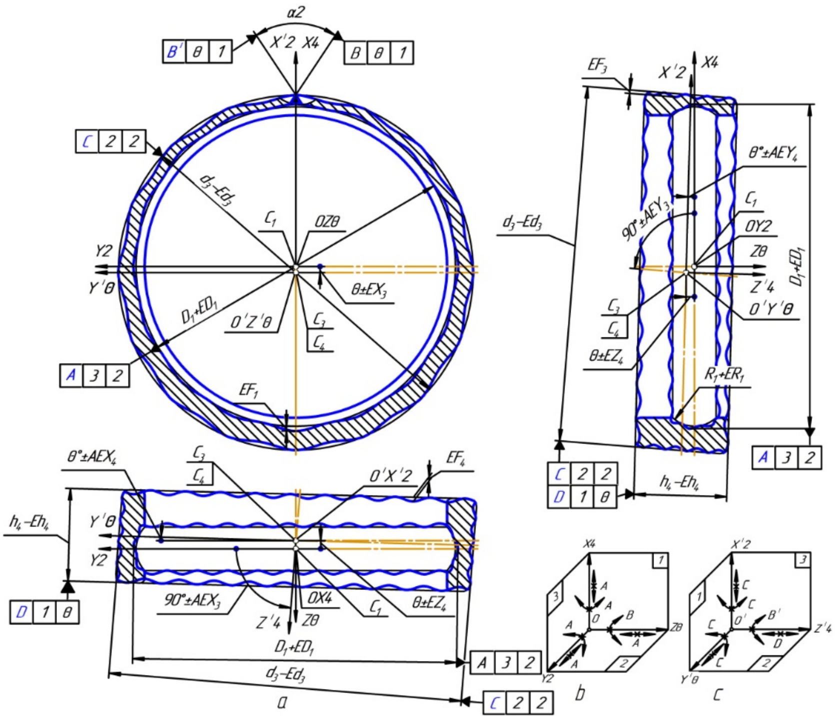


Figure 3. Geometrical model of the real part: a) model; b) informativeness indicator of the set of basic design datums; c) informativeness indicator of the auxiliary design datums.

The number and type of coordinates (linear or angular) of each part feature depends on its informativeness (Figure 4), i.e. on the number of bounded linear and angular degrees of freedom in the function of the design datum minus the degrees of freedom spent on the formation of the basic coordinate system.

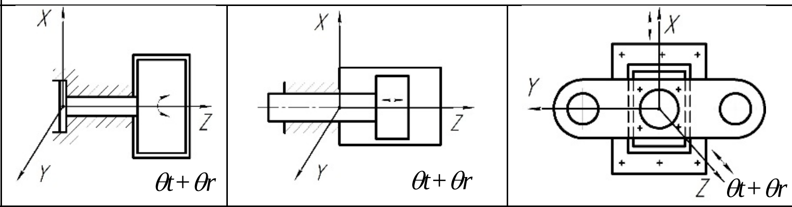
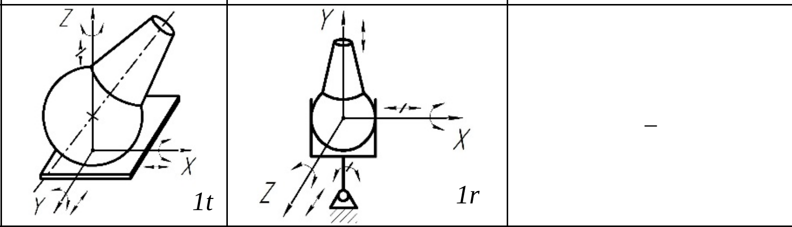
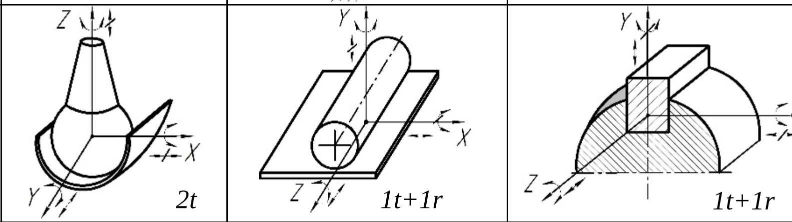
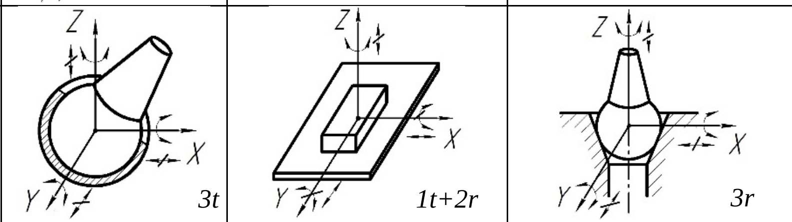
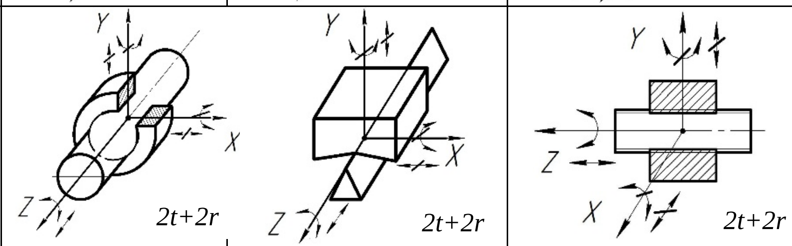
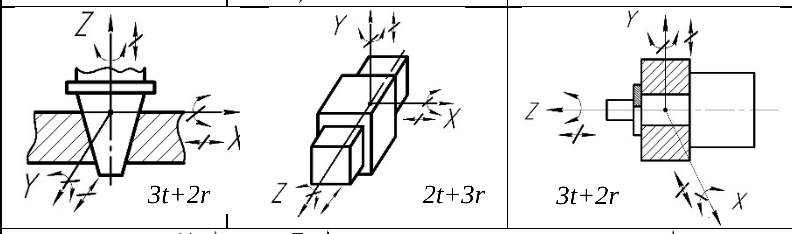
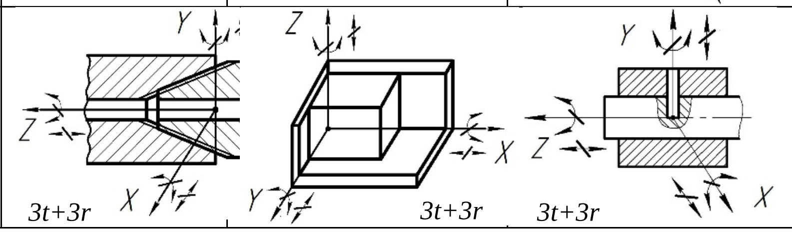
Class of compounds	Conjugation of datums	Informativeness	Invariance
θ		θ	θ
I		1	5
II		2	4
III		3	3
IV		4	2
V		5	1
VI		6	θ

Figure 4. Classification of the basic features in terms of informativeness.

Tolerances for coordinating dimensions can be normalized according to the system of linear dimensions tolerances [21] for the linear coordinates and angular dimensions tolerances [22] for the angular ones.

Since the coordinate system are materialized by datums with different information content, the coordinate planes have different informativeness: $3inf = 1t + 2r$; $2\,inf = 1t + 1r$; $1inf = 1t + \theta r$,

as well as coordinate axes: $4inf = 2t + 2r$; $2inf = 1t + 1r$; $\theta\,inf = \theta\,t + \theta\,r$, where t is the restriction of the linear freedom system; r is the restriction of the angular degree of freedom.

The structure of feature size tolerances also depends on the informativeness of the feature datums.

At the maximum information content of the features, the size tolerance structure includes only deviations of the surface form. If the feature information content is less than the maximum, the size tolerance structure will include the tolerances of the coordinating dimensions. On 2D principle the feature always has two sizes: the maximum and minimum material sizes [20].

When assembling the parts, basic coordinate systems of the attached parts are connected with auxiliary coordinate systems of the based parts (Figure 5).

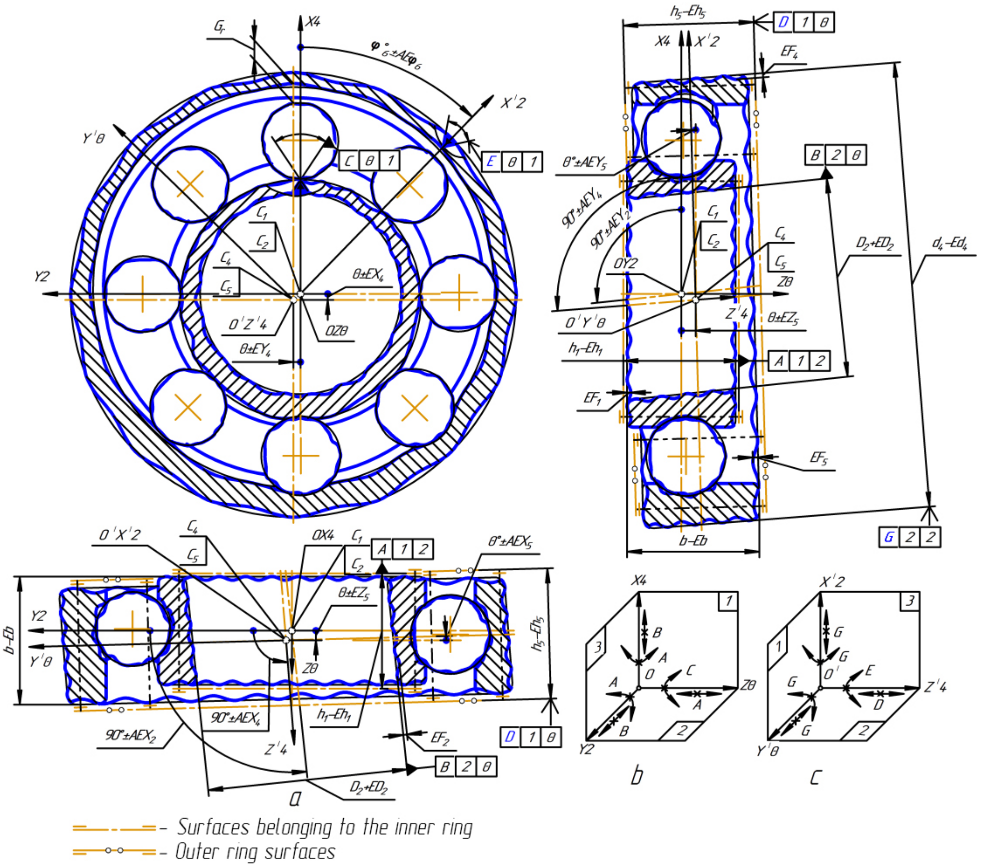


Figure 5. Model of geometrical specifications for the assembly unit: a) model; b) informativeness indicator of the set of basic design datums; c) informativeness indicator of the set of executive features.

In this case, there are linear and angular deviations of the executive features positioning of the attached parts, which should be limited in the technical requirements of the assembly unit. If the executive features move, kinematic deviations of the linear displacement and angular rotation must be taken in the technical requirements of the assembly units. Geometrical part specifications after assembly should provide the technical requirements of the product by full interchangeability. The tolerances for product positioning and kinematic deviations should be included into a new Matrix as required geometrical specifications of assembly units [23, 24].

4. New matrix for geometrical specifications

The transition to digital electronic design of all technical products documentation in coordinate systems required the development of a new matrix of ISO standards for geometrical specifications (Figure 6).

Geometrical product specifications GPS	Chain links						
	A	B	C	D	E	F	G
	Terms and definitions. Designations in documentation: design, technological, metrological	Functions and requirements of assembly unit, part, geometrical feature	Numeric values and tolerances	Real geometrical model Sets of datums. Informativeness of datums	Acceptable measurement accuracy	Measurement technique	Estimation of measurement accuracy
Products technical	+	+	+	+			
Features geometrical	+	+	+	+			
Classification GPS	+	+	+	+			
Coordinate systems	+	+		+			
Linear coordinates	+	+	+	+	+	+	+
Angular coordinates	+	+	+	+	+	+	+
Position deviations	+	+	+	+	+	+	+
Kinematic deviations	+	+	+	+	+	+	+
Linear feature dimensions	+	+	+	+	+	+	+
Angular feature dimensions	+	+	+	+	+	+	+
Location deviations	+	+	+	+	+	+	+
Orientation deviations	+	+	+	+	+	+	+
Surface form deviations	+	+	+	+	+	+	+
Surface roughness	+	+	+		+	+	+
Surface defects	+	+					

Figure 6. Project of a new matrix for geometrical product specifications.

The new matrix includes:

- standardization objects - products and geometrical features of the parts;

- standardization subjects – classification of geometrical products specifications and coordinate system, the materialized products datums;

- new geometrical features – linear coordinates, angular coordinates, deviation of position during product assembly, the kinematic deviations of the moving products including run-out.

The matrix chain links received new names and new content:

A - Terms and definitions. Designations in documentation: design, technological, metrological.

B - Functions and requirements of assembly unit, part, geometrical feature.

C - Numeric values and tolerances.

D - Real geometrical model. Sets of datums. Informativeness of datums.

E - Allowable measurement accuracy.

F - Measurement technique.

G - Estimation of measurement accuracy.

5. Conclusion

1. The coordinate system is the main geometrical product specifications, as it performs the function of the reference system of linear and angular geometrical specifications of assembly units, parts and parts features.

2. The product coordinate system is an implicit system. A rectangular coordinate system is materialized by a set of datums, the total information content of which is equal to six – the sum of the bounded three linear and three angular degrees of product freedom. Different datum informativeness determines the informativeness of different coordinate planes: three, two and one. Different informativeness of the coordinate planes at the intersection creates a different axes informativeness: four, two and zero.

3. Three axes of a rectangular coordinate system have three linear coordinate scales, where linear coordinates of the base points of parts and product features are counted. The accuracy of the scale is higher, if the axis is more informative.

4. The angular coordinates of parts and features are counted by the coordinate scales located in the three coordinate planes of the coordinate system. The accuracy of the scale is higher, if the plane is more informative. The origin of angular scales coincides with the coordinate axes with the informativeness of four (two scales) and informativeness of two (one scale).

5. The product coordinate system has the following advantages:

- compliance with the principle of consistency is ensured, turning the product into a system of parts and features coordinated in a single coordinate system;
- implementation of the principle of unity of design, technological and measuring datums is observed;
- compliance with the principle of inversion, giving preference to the main design datums in the operation of the product to form a coordinate system;
- the principle of the shortest dimensional chains is implemented by reducing the nominal linear and angular coordinates to zero values;
- check of redundancy or insufficiency of datum set informativeness to form coordinate system is provided.

6. The structure of the dimensional tolerances of the features depends on the information content of datum features and their impact on kinematic requirements and deployment of parts and assembly units.

Finally, in order to improve the quality of the matrix of standards for the geometrical GPS products specifications, ISO/TC 213 technical committee should be recommended to coordinate its projects with related ISO technical committees: 184 - industrial automation, 39 - machines, 4 -rolling bearings and others.

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