Coordinate planes for main types of product drawing

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Abstract. The international organization for Standardization has developed a series of standards for the implementation of electronic geometrical models of products, where coordinate systems have been introduced for the first time. However, it is not considered in the electron models that the different functional purposes of both the coordinate planes and axis are differed. In order to improve the quality of project documentation developed with the help of electronic models, the geometric specifications of coordinate systems were determined, coordinate planes and axes were established to perform six basic 2D projections of the product. A new geometrical specification "informativeness" is introduced as the number of product degrees of freedom restricted by the base, coordinate plane or axis. The coordinate system of the product is materializes by a set of its design datums with a total informativeness of 6. Coordinate planes of the rectangular coordinate systems have the informativeness of *3,2* and *1,* the coordinate axes -4,2 and θ *(zero).*

1. Introduction

The international organization for standardization (ISO) has made a significant contribution to the development of the fourth industrial revolution *"Industry-4.θ "*, having developed the series of international standards "Systems of production automation and integration" for the implementation of electronic geometrical models of engineering products and instrumentation in the early XXI century. Standards [1-5] are developed with the use of digital 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 reference frame 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 reference frame 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 reference frames are sets of design databases, operating in the Russian national standardization system for half a century [9]. In ISO standards [10] databases 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 databases and part reference frames are not applied.

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

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

2. Problem statement

In order to improve the quality of design documentation based on the use of coordinate systems for the normalization of the geometrical product specifications, it is necessary to solve two problems:

1. To determine the geometrical specifications of a rectangular coordinate system.

2. To set the coordinate planes and coordinate axes of a rectangular coordinate system to build all six kinds of flat product projections.

3. Geometrical specifications of the rectangular coordinate system

The right rectangular coordinate system *OXYZ*, standardized in ISO [20], is shown in figure 1, a. The coordinate system has been set up to design CNC machines and develop control programs for machining processes. The coordinate system is ideal: its three coordinate straight axes *X,Y,Z* are mutually perpendicular, translational displacements (coordinates) of the machine units are counted on them, and the axes intersect at one point *O* – the origin. The angular coordinates *A,B,C* are counted counterclockwise around *X,Y, Z* axes. The axis of rotation is the axis *Z*.
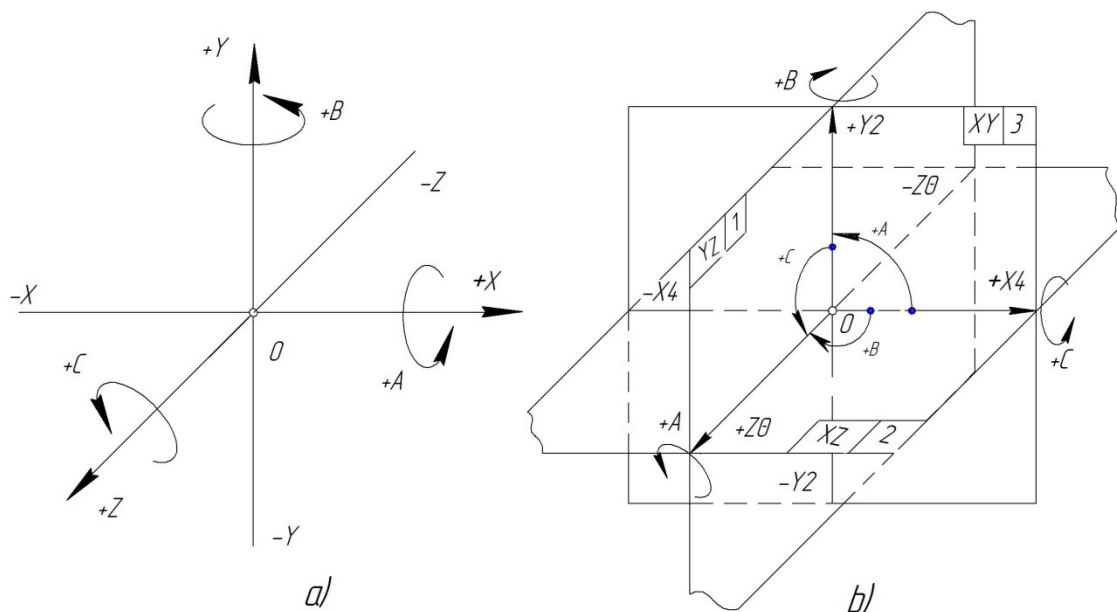

Figure 1. Right rectangular coordinate systems: a) for CNC machines;
b) for counting geometrical product characteristics.

In the coordinate system for counting geometrical specifications of parts and assembly units (Figure 1, b), the coordinate axes *X4,Y2, Zθ* form three mutually perpendicular coordinate planes as three lines of intersection of planes, and the origin *O* is the point of intersection of three coordinate planes. The main (primary) coordinate plane is the *XY3* plane, which restricts the entire coordinate system of three degrees of freedom: one linear *1t* along the normal *Zθ* to the plane and two angular *2r* around the axes *X4 and Y2* located in the coordinate plane.

The second coordinate plane is *XZ2* plane, which forms *X4* coordinate axis as the intersection line with *XY3* plane and restricts the entire coordinate system of two degrees of freedom: one linear *1t* along the axis *Y2* and one angular *1r* around the axis *Zθ*, spending the second angular degree of freedom on the formation of a right angle with the first coordinate plane *XY3*. Finally, the third coordinate plane *YZ1* intersects two coordinate planes *XY3* and *XZ2* at right angles and forms the second and third coordinate axes *Y2, Zθ* and the origin *O* with their lines of intersection, spends its two angular degrees of freedom to the formation of two direct coordinate angles and restricts the whole spatial coordinate system of only one linear degree of freedom *1t* along the axis *X4*.

Consequently, the three coordinate planes of the rectangular system and the three coordinate axes have different functional significance in the number of restricted degrees of freedom, which coincide with the number of linear and angular coordinates counted from them. If the number of degrees of freedom, restricted by the coordinate plane or axis, is called as the informativeness in contrast to non-functional invariance[10], the geometrical specifications of the rectangular coordinate system *OX4Y2Zθ* are:

•the informativeness of the coordinate planes

$XY3_{inf} =1t+2r; XZ2_{inf}=1t+1r; YZ1_{inf}=1t+\theta r(zero);$

* informativeness of coordinate axes

$X4_{inf} =2t+2r; Y2_{inf}=1t+1r; Z\theta_{inf}=\theta t+\theta r;$

* total informativeness of coordinate planes

$\Sigma CP_{inf} =(1t+2r)+(1t+1r) +(1t+\theta_r)=3t+3r=6_{iinf;}$

* total informativeness of coordinate axes

$\Sigma CA_{inf} =(2t+2r)+(1t+1r) +(\theta t+\theta_r)=3t+3r=6_{inf};.$

Thus, the three coordinate planes with informativeness *3,2*, and *1* or two coordinate axes with the informativeness *4* and *2* or their combination (planes and axes with a total informativeness *6*) can specify the location and orientation of any solid object using three linear and three angular coordinates. The angular coordinates *A* and *B* with the sign "+" should be counted from the axis *X4* with the informativeness *4* in the coordinate planes with the informativeness *3* and *2*, respectively, and the angular coordinate *C* – from the axis *Y2* with the informativeness *2*, regardless of clockwise.

Turning to the standardized coordinate system (Figure 1 a), the coordinate axis *Z* should be assigned the informativeness *4* as the rotation axis, the axis *X* -the informativeness *2* as the axis, located in the same horizontal plane with the axis *Z4*, and the axis *Y* – the informativeness *θ(zero)*, because the first two axes have already exhausted the informativeness *6*.

In addition, it is necessary to associate the positive directions of angular coordinates with the informativeness of the coordinate axes and abandon the designations of angular coordinates with Latin letters, since in drawings and electronic models of parts and assembly units these letters denote the datums (Figure 2, b).

So, each product has at least one generalized coordinate system, materialized by a set of basic design datums that determine the placement and orientation of the part in the assembly unit or in the final product during operation. In addition, the product may have one or more auxiliary coordinate systems formed by sets of working actuating elements or auxiliary datums for the attached parts or products. The most common are flat datums of prismatic elements and axes of basic cylindrical elements [9].
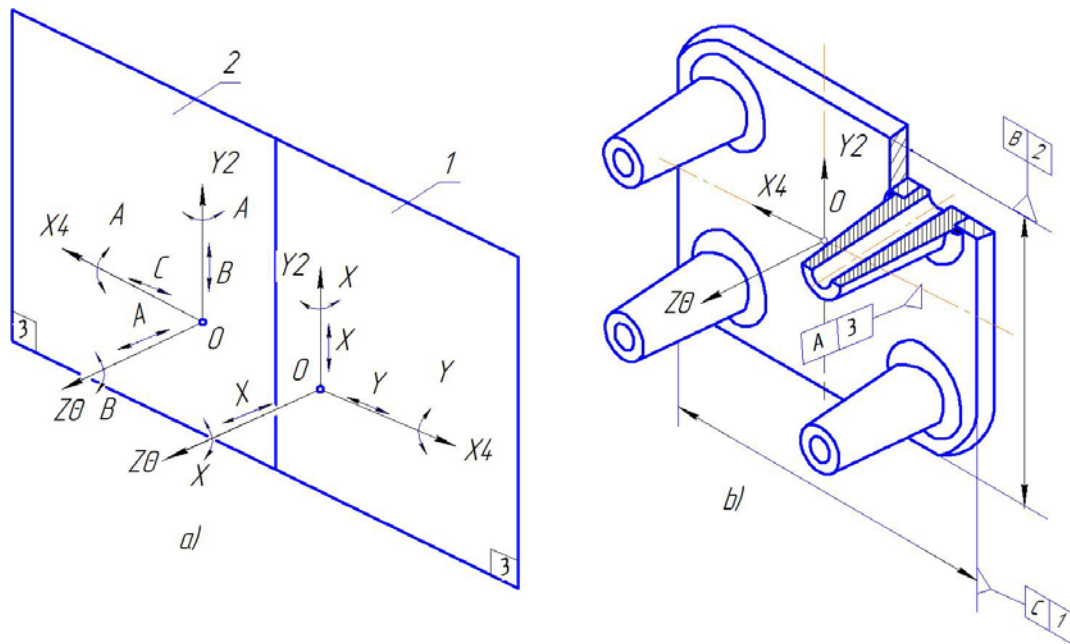
Figure 2. Coordinate system of the product: a) on the display screen for right 1 and left 2 coordinate systems; b) the left coordinate system of the electronic model.

Figure *2, b* shows the electronic model of the assembly unit, where the left rectangular coordinate system $OX4Y2Z\theta$ is formed by a set of three main design datums: flat datum *A3* of the base with informativeness *3*, the plane *B2* of the symmetric datum contour with the informativeness *2* and the symmetry plane of the contour *C1* with the informativeness *1*. The display screen *2* (Figure 2,a) shows the datum indicator of the left coordinate system, demonstrating that all three datums *A3,B2* and *C1* restrict the product of six degrees of freedom without duplicating limits. This indicates the absence of locating.

On the display screen *1* with the right coordinate system there is the informativeness indicator of the coordinate axes, proving that the two coordinate axes *X4* and *Y2* can limit all six degrees of freedom of the product - three linear and three angular - without duplicating the restrictions. This example shows that instead of designations of datums, in their framework it is possible to place designations of the coordinate axes and planes materialized by datums as option for standardization, with hope that in new standards the informativeness will be covered [23]. And the last thing is the location of the axis *Z* in the horizontal plane on the electronic model of the product (Figure 3, b) is unnatural and should pass into the vertical plane (Figure 3, a) as a historically natural position for axonometric projections [21] and spatial coordinate systems in mathematics.
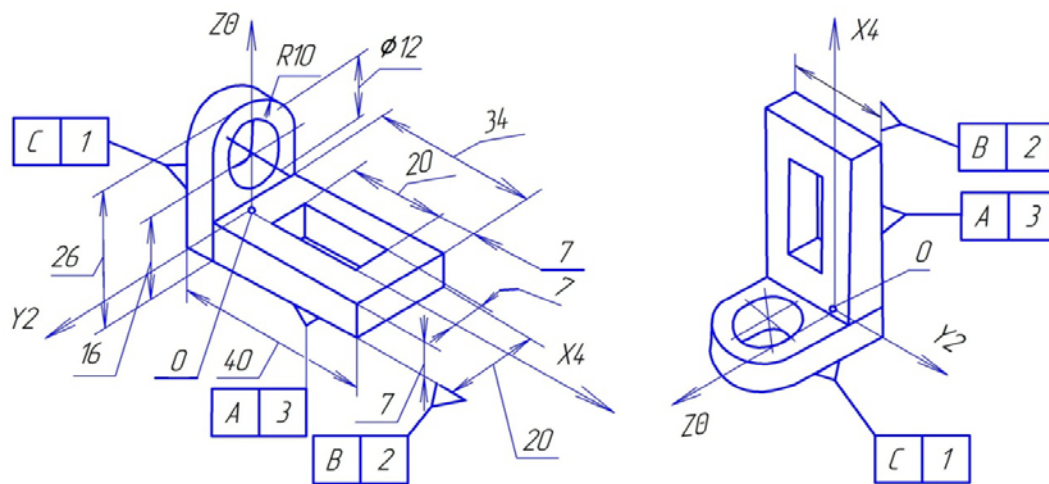
Figure 3. Natural position of the axis Z in the axonometric projection (a) and
the unnatural one in the electronic model (b).

4. Practical application of the coordinate system in the product drawing

According to the national standard of the Russian Federation [22] the part image has 6 main types
three of which are the main – they are frontal, horizontal and profile projections. Since each part has a
coordinate system formed by three coordinate planes, one main projection is represented on each
coordinate plane (Figure 4): frontal projection is on the coordinate plane *OX4Y2* (a), the horizontal
projection is on the coordinate plane *OX4Zθ* (b), and the profile one is on the coordinate plane *OY2Zθ*
(c). The informativeness indicator of the main design datums (d) confirms that a set of flat datums
A3,B2 and *C1* limits the part of the six degrees of freedom and forms a right rectangular coordinate
system *OX4Y2Zθ*.

   If axis informativenesses of coordinate planes add together for each projection, the total
informativeness of the coordinate axes for the frontal projection will be $6_{inf,}$ for horizontal one – $4_{inf,}$
and for profile one - $2_{inf,}$. The more informativeness, the more coordinates can be set on the projection
plane. Therefore, the frontal projection of the part will be the first among the main one, horizontal
projection is the second one and profile projection is the third one.
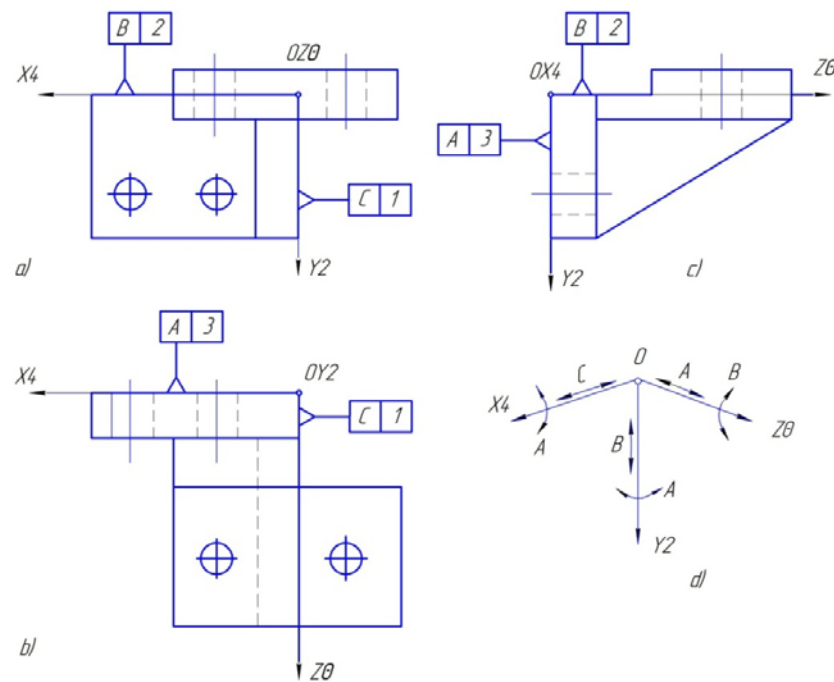
Figure 4. Main types of product image: a) frontal projection; b) horizontal projection; c) profile projection; d) indicator of datum informativeness.
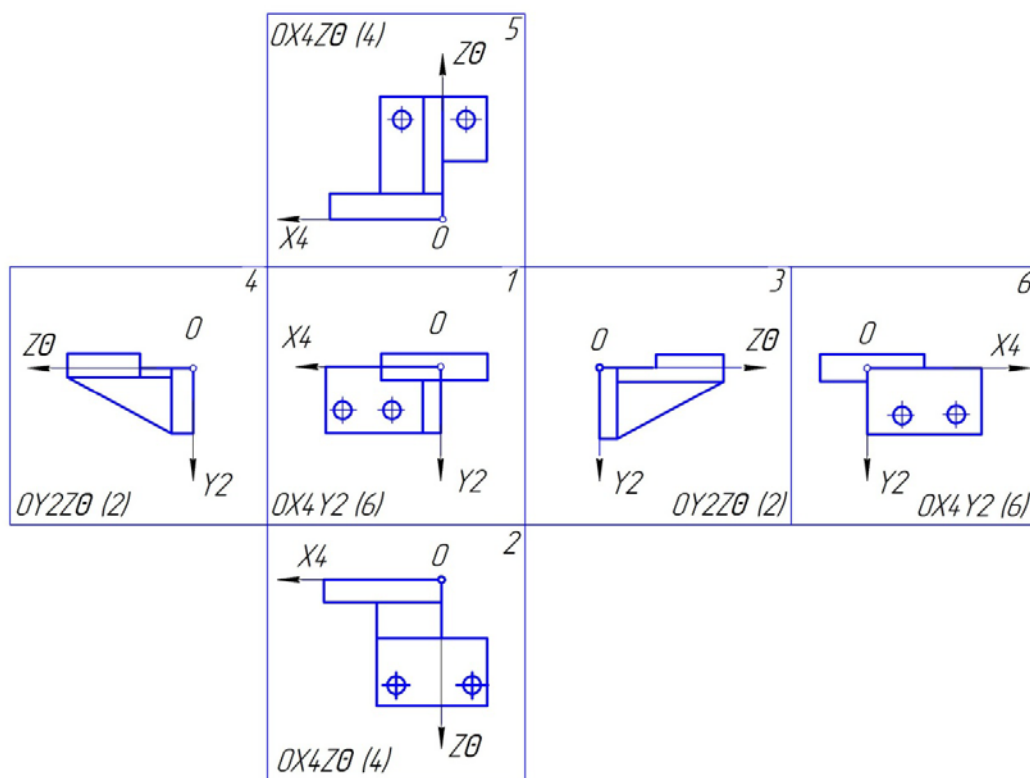

Figure 5. Total informativeness of the coordinate axes for six main types of part projections (1-6).

Comparison of the total informativeness of the coordinate axes for all six main types of products projection image (Figure 5) showed that each main type has a twin with the same total informativeness, but differing only in the opposite direction of one of the coordinate axes. This means that the image is projected onto the back of the coordinate plane using method A (third angle method) instead of method E (first angle method).
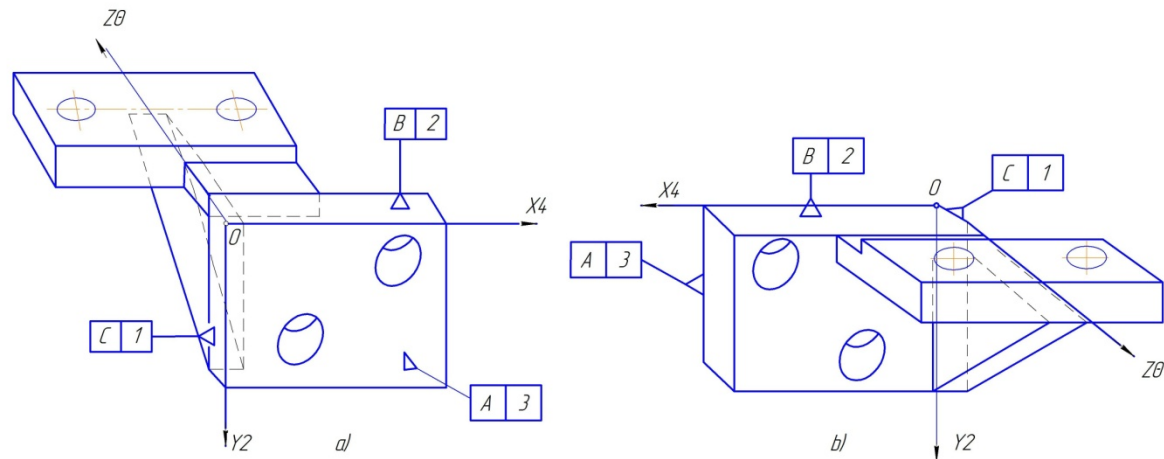

Figure 6. Axonometric product projections of the main type (a) by method E and the main type (b) by method A.

Comparison of axonometric projections (Figure 6) for two types of parts (back (a) and front (b)) with the same maximum total informativeness of coordinate axes 6_{inf} , (Figure 5, front view 1 and back one 6) shows that the back view reveals all three design datums A3,B2 and C1 of the part giving it advantages in the materialization of the coordinate part system $OX4Y2Z\theta$. The electronic geometrical model allows one to display any projection of the part for visualization and to print the drawing. Each part projection should have two axes with the designation of informativenesses *4.2* or *θ*.

5. Conclusion

The task of effective development of the fourth industrial revolution *"Industry-4.θ"* is to transfer all life cycle processes of technical products to digital technology. To solve this problem successfully, a series of international standards "Industrial automation systems and integration" for *3D* – electronic geometrical product models based on rectangular coordinate systems has been developed. Taking into account that earlier *2D* design documentation of products was carried out on a coordinate-free basis and in order to improve the quality of *3D* and *2D* documentation based on the coordinate electronic product model, it is proposed to implement the following results:

1. A rectangular coordinate system should restrict six degrees of freedom of a material object by using three linear and three angular coordinates. The restriction of six degrees of freedom is a geometrical specification of the system, called "*informativeness 6*".

2. The primary geometrical elements of a rectangular coordinate system are three mutually perpendicular coordinate planes. Their intersection lines form three coordinate axes and the origin point.

3. Informativeness *6* of the coordinate system is distributed unevenly and for the coordinate planes is *3,2* and *1* and for the coordinate axes is *4.2* and *θ* (zero). The same number of linear and angular coordinates can be specified to place an object in coordinate system space from each coordinate plane or coordinate axis.

4. The coordinate system of the part (assembly unit) is materializes by a set of basic design datums having a total informativeness of 6 and determining the position of the part (assembly unit) in the product during assembly and operation.

5. The coordinate system as well as the main design datums belongs to the part.

6. Basic *2D* part projections are performed in the coordinate planes with a total informativeness of *6* for axes (frontal), with a total informativeness of *4* for axes (horizontal) and the total informativeness of *2* for axes (profile).

All these results should be included in a new international standard, "Geometrical product specifications (GPS) – Coordinate system of the part", based on the national standard of the Russian Federation "Locating and bases in machine building industry" (GOST 21495-67), used in the production and science for 50 years and covering design, technology and measuring datums.

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