Geometrical product specifications. Datums and coordinate systems

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Abstract. The work is devoted to the relevant topic such as the technical products quality improvement due to the geometrical specifications accuracy. The research purpose is to ensure the quality indicators on the basis of the systematic approach to the values normalization and geometrical specifications accuracy in the workpiece coordinate systems in the process of design. To achieve the goal two tasks are completed such as the datum features classification according to the number of linear and angular freedom degrees constraints, called the datums informativeness, and the rectangular coordinate systems identification, materialized by workpiece datums sets. The datum features informativeness characterizes the datums functional purpose to limit product workpiece linear and angular degrees of freedom. The datum features informativeness numerically coincides with the kinematic pairs classes and couplings in mechanics. The datum features informativeness identifies the coordinate system without the location redundancy. Each coordinate plane of a rectangular coordinate system has different informativeness $3 + 2 + 1$. Each coordinate axis also has different informativeness $4 + 2 + \Theta$ (zero). It is possible to establish the associated workpiece position with three linear and three angular coordinates relative to two axes with the informativeness $4$ and $2$. is higher, the more informativeness of the coordinate axis or a coordinate plane is, the higher is the linear and angular coordinates accuracy, the coordinate being plotted along the coordinate axis or plane. The systematic approach to the geometrical products specifications positioning in coordinate systems is the scientific basis for a natural transition to the functional dimensions of features position - coordinating dimensions and the size of the features form - feature dimensions of two measures: linear and angular ones. The products technical quality improving is possible due to the coordinate systems introduction materialized by datums sets in GPS standards and national standards. Standards on the datums and datums systems should cover all the geometrical specifications and all the processes of the products life cycle: designing, manufacturing, verification and exploitation.

1. Introduction
The regional standard "Locating and datums in mechanical engineering" [1] has been in operation in Russia since 1976. It has proved its working ability and effectiveness since then. According to this standard, datums are all real contacting surfaces of mating work pieces datum features. Contacting datums are divided into two types: main and auxiliary ones. The main datums specify the considered workpiece position in the product, the auxiliary datums specify the associated workpiece position to the given one. Auxiliary datums perform the support function for the main datums. A set of the main datums forms the workpiece generalized coordinate system. A set of auxiliary datums forms the auxiliary coordinate system for an associated workpiece. In the generalized coordinate system each
auxiliary coordinate system position is given by six coordinates: three linear coordinates of the coordinate point of origin and three angular coordinates of the auxiliary system coordinates axes.

To form a rectangular coordinate system, each set of datums should limit workpiece six degrees of freedom - three linear and three angular ones. Datums vary in their functional purpose and cover all processes of a product life cycle. A set of design datums specifies the workpiece position in the designing project. A set of technological datums specifies the workpiece position in the manufacturing process. A set of measurement datums specifies the workpiece position in a meter in the geometrical specifications verification process. A set of construction datums specifies the workpiece position in the construction and the product exploitation process.

2. Problem statement
According to the principle of datums unity [2] the design, technological, measuring and construction datums of a workpiece should coincide, in other words they should be unified for all life cycle processes. The principle of datums unity ensures the high-quality products production with the lowest cost in the shortest possible time. However, the standard [1] has found its application as the basis of the workpiece locating theory only in the standards system for technological documentation. Six datum coordinates \((3 + 2 + 1)\) are the theoretical datums in mechanical engineering technology. The coordinates are located in three perpendicular planes forming the workpiece datum system. The standard is not included in the standards system for the construction documentation due to the influence of the previous versions on the international standard on datums and coordinate systems [3].

The renewal of the latest version of international standards on geometrical product specifications GPS [4] has not improved the standard quality [3] on datums and datum systems:
- the standard applies only to the geometrical tolerances of position and form normalization, it does not cover the feature dimensions regulation;
- the standard uses the datum features classification according to the number of degrees of freedom (invariance), which does not correspond to the datums functional purpose to limit normalized features degrees of freedom;
- the standard does not use the coordinate systems formed by datums - this has resulted in many cases in datum redundancy, or vice versa, to its deficiency.

The aim of this research is to provide the required quality of technical products in all life cycle processes based on the values normalization and geometrical specifications accuracy in a datum system, materialized by datums sets.

The following tasks are completed in this research:
- the classification of the products datums features on the degrees of freedom constraints number is performed;
- the rectangular coordinate systems identification rules of datums sets are developed;
- the dimensional geometrical specifications alternative classification, normalized in the product rectangular datum system in accordance with the informativeness priorities of coordinate axes and planes of the Cartesian coordinate system is proposed.

3. Classification of Workpiece Datum Features
The workpiece positioning accuracy in the product space in operation is achieved due to the constraint of all six degrees of freedom: three translational \((t)\) and three rotational \((r)\) along the movement \((t)\) and round \((r)\) three perpendicular directions. This positioning is done by associated workpiece main construction datums sets relative to an auxiliary construction datums set of a locating workpiece under the forces in the product operation.
Table 1. Classification of datum features on information content

| Pair class | Datums locating | Information content | Invariance |
|------------|----------------|---------------------|------------|
| 0          | ![Image](image1) | \(0t+0r\)           | 0          |
| I          | ![Image](image2) | 1                    | 5          |
| II         | ![Image](image3) | 2                    | 4          |
| III        | ![Image](image4) | 3                    | 3          |
| IV         | ![Image](image5) | 4                    | 2          |
| V          | ![Image](image6) | 5                    | 1          |
| VI         | ![Image](image7) | 6                    | 0          |
In Theoretical mechanics contacting main and auxiliary datum features form the couplings - moveable kinematic pairs or fixed locating joints (see Table 1). Depending on the coupling datum features surface type (plane, sphere, cylinder, cone, torus, screw, geometrically complex surface), the dimensions and the datum features number, the couplings are divided into six classes according to the number of datums limited degrees of freedom (from one to six) which contain linear \((t)\) and angular \((r)\) constraints \((c)\).

Limited degrees of freedom of datum features have more informativeness than invariance, they define couplings classes, therefore, it is proposed to call the degrees of freedom sum limited by a datum feature as "the informativeness". The informativeness numerical value is specified by the degrees of freedom number limited by a datum feature (Table 1), which coincides with the coupling pair class number. The informativeness verification and datum invariance accuracy is simple: their sum must be equal to six.

The informativeness of datum features coincides with the kinematic pairs first-fifth classes number formed by main and auxiliary datums moveable joints of associated and datum features of a moveable workpiece relative to the fixed one. The kinematic pair class number is specified by the linear and angular freedom degrees sum limited by the associated features being the main and auxiliary datums.

It is proposed to supplement the classification of the.

The Cartesian coordinate system formed by three perpendicular planes also has the excessive informativeness
\[9c = 3(1t + 2r)\]
instead of six
\[6c = 3t + 3r\].
This requires three angular tolerances normalization of the coordinate planes perpendicularity:
\[3(1t + 2r) - (3t + 3r) = 3r\].

The rectangular coordinate system formed by planes, therefore, requires the position tolerances normalization two times less than that formed by axes.

In (Figure 1b) an alternative rectangular coordinate system is presented which takes account of the different coordinate planes informativeness
\[3 + 2 + 1\] and coordinate axes
\[4 + 2 + \theta(\text{zero})\] and different directions of positive angles reading from the coordinate axis with the maximum informativeness
\[4\] (two angles A and B) and one angle C from the coordinate axis with informativeness
\[2\]. Precisely this workpiece coordinate system should be used for the workpiece geometrical specifications normalization: position and form tolerances, linear and angular coordinates, linear and angular workpiece dimensions.

![Figure 1](image_url)

**Figure 1.** Right-hand Cartesian coordinate system:

a) for machine tools with CNC in accordance with ISO 841: 2002;

b) for geometrical products specifications (alternative).
A set of datums can form a coordinate system, if it limits a workpiece by six degrees of freedom: three linear and three angular ones. Set datums should not duplicate the constraints of the same degrees of freedom. The real coordinate systems models are shown in Figure 2.

A set of three flat datums G3, K2, N1 (see Figure 2a) limits the workpiece of six degrees of freedom set on a datums indicator
\[ (1t + 2r) + (1t + 1r) + 1t = 3t + 3r. \]
If the datums dimensions of K and N are not limited, the datums set informativeness is
\[ (1t + 2r) + (1t + 2r) + (1t + 2r) = 3t + 6r. \]
Such informativeness leads to the locating redundancy and the need to increase normalization of three additional perpendicularity tolerances between the datums materializing a rectangular coordinate system.

Similarly, a set of two cylindrical datums J4 and S2 (Figure 2b) forms a rectangular coordinate system without redundant locating due to reducing the datum length S2:
\[ (2t + 2r) + (1t + 1r) = 3t + 3r. \]
Without the datum length reduction the datums informativeness will be
\[ (2t + 2r) + (2t + 2r) = 4t + 4r. \]
This results in the datum redundancy: \[ (4t + 4r) - (3t + 3r) = 1t + 1r \] and the need to normalize two geometrical tolerances: the datum axes intersection and the perpendicularity between the axes.

In the geometrical product specifications verification process it is impossible to materialize theoretically exact nominal right angles between the coordinate planes and the coordinate axes. The accuracy of the rectangular coordinate system should be rated by three angular coordinates \( 90^\circ \pm EA, 90^\circ \pm EB, 90^\circ \pm EC \), shown in Figure 2.

A set of datums can form a coordinate system, if it limits a workpiece of six freedom degrees: three linear and three angular ones. Set datums should not duplicate the same freedom degrees constraint. Real coordinate systems models are shown in Figure 2.

Such information content leads to the locating redundancy and the need to increase three additional perpendicularity tolerances normalization between the datums materializing a rectangular coordinate system.
A set of three flat datums G3, K2, N1 (see Figure 2a) limits the six freedom degrees workpiece dimensioned on a datums indicator $4(1t + 2r) + (1t + 1r) + 1t = 3t + 3r$. If the datums dimensions of K and N are not limited, the datums set informativeness is $(1t + 2r) + (1t + 2r) + (1t + 2r) = 3t + 6r$. Such information content leads to the locating redundancy and the need to increase three additional perpendicularity tolerances normalization between the datums materializing a rectangular coordinate system.

Similarly, a set of two cylindrical datums J4 and S2 (Figure 2b) forms a rectangular coordinate system without redundant locating due to reducing the datum length S2: $(2t + 2r) + (1t + 1r) = 3t + 3r$. Without the datum length reducing the datums informativeness will be $(2t + 2r) + (2t + 2r) = 4t + 4r$. These results in the locating redundancy: $(4t + 4r) - (3t + 3r) = 1t + 1r$ and the need to normalize two geometrical tolerances: the datum axes intersection and the perpendicularity between the axes.

Products geometrical specifications verification process does not allow theoretically exact nominal right angles between the coordinate planes and the coordinate axes to be materialized. The accuracy of the rectangular coordinate system should be rated by three angular coordinates $90° ± EA$, $90° ± EB$, $90° ± EC$ shown in Figure 2.

4. Conclusions

- The datum features informativeness characterizes the datums functional purpose to limit linear and angular freedom degrees of a product workpiece. The basic elements informativeness numerically coincides with the classes of kinematic pairs and couplings in mechanics. The datum features informativeness identifies the coordinate system without the datum redundancy.

- Three planes intersecting at right angles are producers of the solid rectangular coordinate system in which the coordinate axes are the plane intersection lines and the origin is the planes intersection point.

- Each coordinate plane of the Cartesian coordinate system has different informativeness $3 + 2 + 1$. It is sufficient to establish the associated workpiece position by three linear and three angular coordinates, depriving a workpiece of all six degrees of freedom. Coordinate planes informativeness specifies their priority.

- Each coordinate axis has different informativeness $4+2+\Theta$ (zero). This means that relative to two coordinate axes with informativeness 4 and 2 located in a coordinate plane with informativeness 3 it is possible to specify the associated workpiece position by three linear and three angular coordinates. The coordinate axes informativeness specifies their priority.

- Linear coordinates are measured on the coordinate axes from the origin point and the angular coordinates are determined in the coordinate planes. The coordinate axes with informativeness 4 and 2 are the origin of angular coordinates. The vertexes of coordinate angles lie at the coordinate system origin.

- The more informativeness the coordinate axis or a coordinate plane has, the higher is the linear and angular coordinates accuracy, the coordinate being rated relative to the coordinate axis or a coordinate plane.

- The systematic approach to the products geometrical specifications positioning in the coordinate systems is the scientific basis for a natural transition to the functional dimensions of features positioning - coordinating dimensions and features form dimensions - two measures features dimensions: linear and angular ones.
5. Summary

- The products technical quality improvement is possible due to the coordinate systems introduction materialized by datums sets in GPS standards and national standards.
- The standards on the datums and datums systems should cover all the geometrical specifications and all the processes of products life cycle such as designing, manufacturing, verification and exploitation.

References

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