Geometrical specifications accuracy influence on the quality of electromechanical devices

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Abstract. To improve the quality of electromechanical products is possible due to the geometrical specifications optimization of values and tolerances. Electromechanical products longevity designates the rolling-contact bearings of the armature shaft. Longevity of the rolling-contact bearings is less than designed one, since assembly and fitting alter gaps, sizes and geometric tolerances for the working parts of the basic rolling bearing details. Geometrical models of the rolling-contact bearing details for the armature shaft and the end shield are developed on the basis of an electric locomotive traction motor in the present work. The basic elements of the details conjugating with the adjacent details and materializing the generalized and auxiliary coordinate systems are determined. Function, informativeness and the number of geometrical specifications for the elements location are specified. The recommendations on amending the design documentation due to geometrical models to improve the accuracy and the quality of the products are developed: the replacement of the common axis of the shaft's technological datums by the common axis of the basic design datums; coaxiality tolerances for these design datums with respect to their common axis; the modifiers for these auxiliary datums and these datums location tolerances according to the principles of datums uniformity, inversion and the shortest dimension chains. The investigation demonstrated that the problem of enhancing the durability, longevity, and efficiency coefficient for electromechanical products can be solved with the systematic normalizations of geometrical specifications accuracy on the basis of the coordinate systems introduced in the standards on geometrical product specifications (GPS).

1. Introduction
The quality improvement of electromechanical products is a complex problem including the issue of increasing service time for electrical and mechanical parts. The issues of increasing service time for electrical parts are studied by a wide range of the scientists and not discussed in the present work. Whereas the issues of increasing the service time for mechanical parts are of design, technological and metrological nature. All investigations in this field are associated with the following scientists: Glukhov V I [1], Kovalev V P , Narodetsky M Z [2], Bell J C, Dyson A [3], Blok H [4], Schabel J S [5], and Tikvicki M [6].
Let us describe the way to construct graphical geometrical models [1] on the example of two details, i.e. an armature shaft and a traction motor end shield of a traction motor for an electric locomotive. The construction schematic of a traction motor is given in Figure 1. A traction motor is one of the most expensive parts of an electric locomotive. Therefore, to cut the number of unscheduled repairs and to increase the periods between them is a topical problem.

2. Problem statement
To investigate the parts convergence and optimization of their geometrical specifications accuracy, the following tasks were solved herein:
- the geometrical models of an armature shaft and an end shield of a traction motor were developed;
- function, informativeness and the number of geometrical specifications (initial errors) for dimensions, location and form of the elements in a generalized coordinate system of the detail are specified;
- the recommendations on making changes to geometrical specifications in the design documentation due to geometrical models of the details are developed.

3. Geometrical model of the traction motor armature shaft
3.1. The shaft elements function is determined by its working drawing and assembly drawing of a traction motor. Shaft and armature 6 rotate on two rolling bearings 7 (Figure 1). The location of the shaft in a traction motor is determined by the axis of cylindrical elements \( G_2 \) and \( I_2 \), each having informativeness 2. Two coaxiality datums \( G_2 \) and \( I_2 \) form together common basic axis \( GI_4 \) with informativeness 4 since they deprive the shaft of four degrees of freedom. Flat frontal datum \( B_1 \) with informativeness 1 is a dimensional supporting datum, and it deprives the shaft of one translation along the basic axis \( GI_4 \). The plane of symmetry for a keyslot on the adjoining taper shank is a supporting datum depriving the shaft of one rotation around the common basic axis of shaft \( GI_4 \). A set of basic datums deprives the shaft of six degrees of freedom: three linear translations and three angular rotations.
A set of basic datums forms a complete generalized coordinate system \( OX2YZ4 \) of the shaft. Axis \( Z4 \) is a common axis of basic cylindrical elements \( G_2 \) and \( I_2 \). It comes through two centers of their midsections \( C_1 \) and \( C_2 \), and has informativeness 4. Origin point \( O \) is located on the intersection of axis \( Z4 \) with flat supporting datum \( B1 \). Coordinate plane \( ZOX \) passes through axis \( Z4 \) and the center of the

1 - end shield on the collector's side; 2 - second end shield; 3 - casing; 4 - traverse; 5 - jacket; 6 - armature; 7 - motor armature rolling bearing; 8, 9 - bearing cup, inner; 10 - bearing cup, outer; 11 - rubber ring

**Figure 1.** Construction schematic of traction motor for electric locomotive
symmetry plane of the keyslot and materializes axis \( X_2 \) with informativeness 2. Axis \( Y \) has informativeness being equal to 0 (zero) since it needs no supplementary datum. Axis \( Y \) starts from origin point \( O \) in perpendicular to \( Z_4 \) and \( X_2 \) of the generalized coordinate system \( OX2YZ4 \).

3.2. The axis of the auxiliary coordinate systems is found. A set of auxiliary design datums to press an armature socket is represented by the axis of basic cylindrical elements \( J_2 \) and \( N_2 \). The datums form common basic axis \( JN4 \) with informativeness 4 and deprive the armature socket of 4 degrees of freedom. The armature socket is deprived of another two movements along and around the axis \( JN4 \) because of its tight fit on the shaft. A complete set of auxiliary datums is supplemented by a frontal datum collar \( E_2 \), closest to origin point \( O \), and basic design datum of the keyslot together with datum \( JN4 \) materializing auxiliary coordinate system \( O'X'2Y'Z'4 \).

A set of auxiliary design datums for the attached cogwheel from the side of the collector is represented by the axis of conical surface \( Q_5 \) with informativeness 5 depriving the cogwheel of 5 movements and the supporting base, i.e. the plane of symmetry for the keyslot with informativeness 1 deprives the cogwheel of one rotation around axis \( Q_5 \). The same prismatic datum of the keyslot functions both as basic and auxiliary design datums and mediates between two sets of datums and their coordinate systems - generalized \( OX2YZ4 \) and auxiliary \( O''X''2Y''Z''4 \). A complete set of auxiliary datums materializes a complete auxiliary system \( O''X''2Y''Z''4 \). The similar set of datums materializes an auxiliary coordinate system \( O'''X'''2Y'''Z'''4 \) for the second cogwheel.

![Geometrical model of the shaft](image)

3.3. Thus, as a generalized coordinate system for an armature shaft we choose coordinate system \( OX2YZ4 \) from a set of basic design datums. An auxiliary coordinate system of the first order is represented by coordinate system \( O'X'2Y'Z'4 \), materialized by the basic shaft elements intended for pressing an armature socket. Auxiliary systems of the second order \( O''X''2Y''Z''4 \) and \( O'''X'''2Y'''Z'''4 \) are materialized by conic surfaces for cogwheels and their keyslots. Figure 2 demonstrates the graphical model of an armature shaft for a traction motor. The geometrical model specifications of the shaft are given in Table 1 representing a table form of the shaft geometrical model.
3.4. The number and the type of the elements location initial errors are determined by the number and the kind of degrees of freedom not used by the element under consideration for a generalized coordinate system of the detail. This rule is applied both to basic (BD) and auxiliary datums (AD).

Table 1. The geometrical model parameters for the shaft

| Number and modifier, the detail element, and the coordinate system | Type, function, informativeness and the number of initial errors in element location | Dimensions and initial errors of location, dimensions and forms | Datums, dimensions, and location, dimension and form tolerances due to drawing | Suggestions, design parameters, and variants on the geometrical model basis |
|---|---|---|---|---|
| 1 | G2 OX2YZ4 | Cyl, BD, 2l 2l+2a=2l-2a | 0°±AEY1, 0°±AEY1, d1-Ed1, EF1 | 0.08 0.02 0.006 |
| 2 | J2 OX2YZ4 | Cyl, BD, 2l 2l+2a=2l-2a | 0°±AEY2, 0°±AEY2, d2-Ed2, EF2 | 0.08 0.02 0.006 |
| 3 | J2 OX2YZ4 C34 | Cyl, AD, 0d 2l+2a=2l-2a | 0°±AEY3, 0°±AEY3, d3-Ed3, EF3 | 0.08 0.02 0.006 |
| 4 | N2 OX2YZ4 E4 | Cyl, AD, 0d 2l+2a=2l-2a | 0°±AEY4, 0°±AEY4, d4-Ed4, EF4 | 0.08 0.02 0.006 |
| 7 | C7 OX2YZ4 | Con, AD, 0d 3l+2a=3l+2a | 0°±AEY7, 0°±AEY7, d7, EF7 | 0.08 0.02 0.006 |
| 8 | C7 OX2YZ4 | Con, AD, 0d 3l+2a=3l+2a | 0°±AEY8, 0°±AEY8, d8, EF8 | 0.08 0.02 0.006 |
| 11 | S1 Q | Pr, BD, 11 2a+11=11=2a | 0°±AEY11, 0°±AEY11, W11=EW11 | 62° 10 |
4. Geometrical model of the traction motor end shield

4.1. Functionality of the end shield elements is determined by working and assembly drawings of the traction motor.

End shields 1 and 2 (Figure 1) are mounted into the motor casing 3. A set of basic design datums determining the location of the end shield in the casing is represented by: flat supporting frontal datum $A3$ with informativeness 3, since it deprives the end shield of 3 degrees of freedom: one linear and two angular; cylindrical datum $I2$ with informativeness 2, depriving the end shield of two translations; the axis of cylindrical surface of fixation hole $B1$ with informativeness 1, depriving the end shield of one rotation around basic axis $I2$. Since the number of deprived degrees of freedom equals to six ($3+2+1=6$), the basic datums form a complete generalized coordinate system $OX4Y2Z$ to the end shield: axis $X4$ is located on flat datum element $A3$, corresponds to its plane, passes through origin point $O$, axis of base hole $B1$ and has informativeness 4.

Origin point $O$ is located on the intersection plane datum $A3$ with the axis of cylindrical datum $I2$. Coordinate axis $Y2$ with informativeness 2 is located on the datum surface $A3$ in perpendicular to axis $X4$. Axis $Z$ has informativeness equal to 0 (zero) since it is a perpendicular starting from origin point $O$ to coordinate plane $XOY$, containing axis $X4$ and $Y2$ with total informativeness 6.

4.2. Auxiliary design datum for outside ring of the rolling bearing is the axis of the cylindrical datum $G4$ with informativeness 4 depriving the inside bearing ring of four movements. Since in traction motor assembly the inside ring abuts labyrinth ring from the inside, its abutting end is a flat supporting datum depriving the ring of one translation. When in operation, the inside ring should rotate slowly since the bearing is designed for circulation loading. So, a set of auxiliary datums deprives of 5 degrees of freedom. To construct complete auxiliary coordinate system $O'X'2Y'Z'4$ one should use basic datum $B1$ which brings the informativeness of an auxiliary coordinate system datum set to six degrees of freedom.

4.3. A coordinate system of a basic datum set is chosen as a generalized coordinate system $OX4Y2Z$ to the end shield. Figure 3 shows the geometrical model of the end shield.

4.4. The number and the type of the geometrical specifications of the end shield elements location are determined by the number and the type of the movements not used by its elements for generalized coordinate system $OX4Y2Z$. The specifications of the geometrical model of the end shield are given in Table 2 representing a table form of the model.

5. Results and discussion

The systematic approach to normalization of the detail accuracy specifications on the basis of geometrical models constructed in coordinate systems of design datums sets allows the quantity, values and tolerances of geometrical specifications to be optimized. These specifications guarantee the quality and estimate indicators of the rolling-contact bearing longevity. The systematic approach is based on the engineering principles providing the quality of engineering products: uniformity principle of design, technological, measurement and construction datums, principle of the shortest dimension chains, and inversion principle. According to the inversion principle, operating conditions for each product detail in a design project should correspond to the operating conditions of the product both during the production and the verification. Operating conditions primarily include location, kinematics, acting forces and temperature.

Judging from the title of Technical committee for Standardization ISO/TC 213 - Dimensional and geometrical product specifications and verification, - standard ISO 5459:2011 - Datums and datum systems - developed by the committee includes only measurement datums for the verification process. Absence of engineering principles of quality control, refusal from systematic approach and materialization of datums sets coordinate systems lowers the standard quality and, subsequently, the quality of the products and puts the brake on the rate of technical progress.
Based on the results of validating the working drawings of an armature shaft and an end shield for a traction motor with the help of geometrical models, the following recommendations for basic elements and geometrical specifications optimization were formulated:

- common axis of basic design datums of an armature shaft for inside bearing rings fitting (Figure 2) should be introduced as initial axis $OZ4$ with informativeness 4 of a generalized coordinate system instead of the common axis of central shaft holes as technological datums are not used in product operation. This non-conformity results from contravention of the datums uniformity principle. Systematic approach allows enhancing the location accuracy for basic design datums of the shaft by 4 times (Table 1);
- improved location accuracy for basic design datums of the shaft will result in decreased misalignment of the axes for inside bearing rings at rolling-contact bearing assembly and will increase the bearing longevity;
- inside bearing ring should mate with bearing collar by its abut instead of intermediate detail abut (Figure 1), its abut run-out being much higher because of the contravention of the shortest dimension chains principle. The removal of this non-conformity will call for changing the design of the shaft, the rolling-contact bearing and the product itself;
- fitting plane for an end shield and a traction motor casing is a basic design datum with informativeness 3. All its informativeness is used for main coordinate system $X4OY2$ with informativeness 3 in a generalized coordinate system (Figure 3). This datum can have no location tolerance, therefore, the perpendicularity tolerance on the working drawing should be assigned to an auxiliary datum, i.e. the axis of the hole for an inside bearing ring. This tolerance will limit the misalignment of the axis for the inside bearing ring in a rolling-contact bearing. The basic plane with informativeness 3 of the shield will have only the flatness tolerance (Table 2);
- similar recommendations are formulated for all details of the traction motor.

![Figure 3. Geometrical model of the end shield a) in plane OXZ0; b) in plane OY2Z0; c) in plane OX4Y2](image)

6. Summary
6.1. Further improvement of the electromechanical products quality is possible due to systematic approach and geometrical modeling of the geometrical product specifications for the details in order to optimize their composition, values and tolerances.
6.2. An adequate geometrical model of the real detail shows relations of all geometrical specifications for working detail elements (coordinates, location deviations, the elements dimensions and their surfaces form deviations) in a generalized coordinate system formed by a set of basic construction datums. Functionality of every element (basic datum, auxiliary datum, executive element, binding element) and element informativeness (as a constraint sum of linear and angular degrees of freedom) are taken into account. The adequate geometrical model of the real detail has two forms - graphical and table ones, complementing each other.
6.3. The number of geometrical specifications affecting the quality of electromechanical products is 20-30% larger than the number of the electrical specifications.

7. Conclusion
The problem of enhancing the durability, longevity, and efficiency coefficient for electromechanical products can be solved with the systematic normalizations of geometrical specifications accuracy on the basis of coordinate systems introduced in the standards on geometrical product specifications (GPS).

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