Geometric modeling in the problem of ball bearing accuracy

V I Glukhov 1, V V Pushkarev 1 and V G Khomchenko 1

1 Omsk State Technical University, 11, Mira ave., Omsk, 644050, Russia

E-mail: mips@omgtu.ru

Abstract. The manufacturing quality of ball bearings is an urgent problem for machine-building industry. The aim of the research is to improve the geometric specifications accuracy of bearings based on evidence-based systematic approach and the method of adequate size, location and form deviations modeling of the rings and assembled ball bearings. The present work addressed the problem of bearing geometric specifications identification and the study of these specifications. The deviation from symmetric planar of rings and bearings assembly and mounting width are among these specifications. A systematic approach to geometric specifications values and ball bearings tolerances normalization in coordinate systems will improve the quality of bearings by optimizing and minimizing the number of specifications. The introduction of systematic approach to the international standards on rolling bearings is a guarantee of a significant increase in accuracy of bearings and the quality of products where they are applied.

1. Introduction

Rolling bearings are characterized by high manufacturing accuracy. Manufacture of bearings is one of the fundamental criteria for the national industry development. Ball bearings have been in use for over a century. There is lot of experience accumulated in the ball bearings design and application. The issue of ball bearings quality increase is currently a priority for producers and consumers. The efforts of producers are focused on the improvement of production technology, search for and application of new materials, methods of calculation, defects diagnostics.

When analysing the requirements of international standards [1, 2] on tolerances of geometric specifications of rings and bearing assemblies some discrepancies associated with normalization of optimum accuracy of geometric specifications and complexity of utilization of presented definitions emerge. For example, to describe the tolerance diameter of the outer ring there are 11 various specifications. Even experts on rolling bearings have no clear confidence in the correctness of interpretations and applications of tolerances [3].

In the latest version of the international standard [1], it was decided to use the standard notation GPS “Geometrical product specification” to indicate the accuracy of the tolerances on the specifications of the rolling bearings (Fig. 1). However, these innovations also do not fully meet the requirements of high-quality standard normalization. Such important specifications as symmetry raceway profile, width of the ball bearing assembly are absent in the standard, as well as in its earlier versions [1, 2].
2. Problem statement
Despite a large number of studies carried out by researchers from different countries, some inconsistencies in the field of geometric specifications of ball bearings accuracy normalization still remain. Standard requirements [1, 2] do not fully solve the problem of high accuracy of bearing specifications due to the lack of systematic approach to their normalization.
The purpose of the present work is to provide high quality of ball bearings based on geometric modeling of real specifications of rings and bearing assembly in the coordinate systems formed by the datum features.
The objectives of the research are as follows:
1) Identification of geometrical specifications of bearing and its rings based on system geometric modeling;
2) Experimental study of non-standardized geometric specifications of bearings and rings;
3) Optimizing and minimizing the number of geometric specifications of bearings and rings for alternative standardization.

3. Geometric Modeling of Study Subject Accuracy Specifications
The study subject is a single-row radial ball bearing. The total output of such bearings is more than 50% of all manufactured types of bearings. A tight ring determines a bearing position in the connection. The inner ring is a tight ring in 95% of the products. The position and orientation of the bearing ring in the product space occurs by means of the balls which are disposed in raceways. The accuracy of the location of the raceways profile with respect to the datum ends directly affects the accuracy of the bearing rings, bearing mounting width and durability of bearing compounds. In practice the location of the ball bearing rings raceways symmetry plane is provided by the coordinating size relative to the datum end. However, the coordinating size control requires identification of the ring datum end and racetrack symmetry plane materialization, which is irrational.
Ring datum ends belong to the same geometric plane-parallel prismatic feature. The ends flat datums of ball rings are functionally symmetrical which makes the prismatic feature symmetrical with a plane of symmetry available, which becomes a datum feature of the ring. The raceway of the ring is a geometric feature - a torus which also has a plane of symmetry. Two symmetrical geometric features of the bearing rings in combining symmetry planes make them symmetrical parts. This property of the rings defined the symmetry of the ball bearings assembly.
Geometric model of the rings and bearings assembly constructed according to method [4] is shown in (Figure 2 ... 4). The model of geometric specifications of the internal tight ring (Figure 2a) is
constructed in a generalized $OX4Y2Z\theta$ Cartesian coordinate system formed by a set of key datum features: the plane of symmetry $E3$ of the plane-parallel prismatic feature ends, the axis of symmetry of the cylindrical feature $F2$, and indicator $G1$ of the eccentricity vector of the raceway center. The set of the main datums positions the ring on the shaft. The digits after the letter designation of datums reveal their informativeness and mean the sum of the constraints of linear degrees of freedom (the first figure in the box after the datum case) and angle (the second figure) on the projection of the model. Specific datums limits are shown on the indicator of the main datums set (Figure 2b). The auxiliary set of datum features determines the position of the inner ring of the outer ring via the balls through the center and the plane of symmetry $H5$ of the raceway and indicator $G1$ of the eccentricity vector, together forming the auxiliary coordinate system $O'X'4Y'2Z'\theta$. The indicator of the outer ring tolerance by the set of auxiliary datums is shown in (Figure 2c).

![Figure 2](image)

**Figure 2.** Ball bearing inner ring - the model of geometric specifications
a) geometric model in three projections; b) indicator of the main datums set; c) indicator of auxiliary datums set.

The outer free ring is the part attachable to the basing detail – inner ring – through the balls. The model of geometric specifications of the outer ring (Figure 3a) is built in generalized coordinate system $OX4Y2Z\theta$ formed by the set of main datum features of the ring: $E5$ – the center and the raceway plane of symmetry and $F1$ – eccentricity vector indicator of the actuating cylindrical surface center $G4$, fulfilling the main functionality of the cylindrical shaft datum. The actuating surface $G4$ together with the datum features $H1$ – the plane of symmetry of the prismatic feature ends and $F1$ –
the indicator of the eccentricity vector of the actuating surface $G4$ center form an auxiliary coordinate system $O'X'2Y'\theta Z'4$. The indicators of tolerance of linear and angular degrees of freedom for the generalized system of coordinates are shown in (Figure 3b) and for the auxiliary system of coordinates in (Figure 3c).

**Figure 3.** Ball bearing outer ring-model of geometric specifications

- a) geometric model in three projections; 
- b) indicator of main datums set; 
- c) indicator of auxiliary datums set.

The geometric model of the bearing assembly (Figure 4) is built in the generalized coordinate system $OX4Y2Z\theta$ of the tight inner ring basing the bearing on one of the two main datums of the cylindrical shaft.

The inner ring forms an interference fit with the rotary shaft restricting the ring with its main datums of all six degrees of freedom: three - by one of two datum ends of the $E3$; two – by the axis of cylindrical hole $F2$, and one – by the eccentricity index $G1$, displaceable in phase by 180° with respect to the eccentricity vector of the main cylindrical shaft datum under the assembly.

The free outer ring has only one-rotation motion around axis $Z$. The location of the outer ring relative to the inner ring should be normalized by five coordinates: three linear and two angular. Standard [5] declares only one deviation – the radial clearance of bearing which restricts the ring of two translational displacements along axes $X$ and $Y$, expressed in linear coordinates with zero nominal values. Translational displacement along axis $Z$ is limited by the linear error $\theta \pm EZ_5$, but in standards...
it is not regulated by the tolerance despite the deviation of the axial gap, which is in the empirical dependence on the radial gap. Standards [1; 2] also do not regulate two angular coordinates of the outer ring relative to the inner bearing assembly $90^\circ \pm AEX_4$, $90^\circ \pm AEY_4$.

![Diagram of a single row radial ball bearing]

**Figure 4.** The single row radial ball bearing, model of geometric characteristics

- a) geometric model in three projections;
- b) indicator of main datums set;
- c) indicator of auxiliary datums set.

Tolerances perpendicularity axes and cylindrical features are normalized with respect to the ends of the outer ring, not to the datum end of the inner ring.

Due to geometrical deviations from the symmetry of the bearing rings and gaps existing between the rolling features and the rings the mounting width of ball bearing assembly $b- Eb$ will differ from the width of the inner ring and the width of the outer ring, but in standards [1; 2] the mounting width of the ball bearing assembly is not specified.

4. Research Results

To evaluate deviation of the rings raceway symmetry from the symmetry plane with respect to the plane of symmetry of the prismatic feature formed by the two flat ends of the ball bearing the experimental research of the distance difference from the raceway plane of symmetry to the datum ends of the ball bearing ring were carried out.
The measurements of the ring bearing were carried out on the control unit with the transmitter scale division of 1 µm. The difference between the measured values of the distances to the raceway plane of symmetry in 24 points on the angle of rotation of the ring characterizes its deviation from the symmetry of the track relative to the track ends and is represented on a graph (Figure 5).

In order to establish the mounting width of the ball bearing assembly the measurements have been performed with successive installation of rings on the basic surface in a horizontal plane. In the course of measurement one of the rings was hang out in the free state and under the influence of gravity it shifted vertically. The results of measurement of the bearing assembly mounting width in the six end points of the free ring without rotation is described in graph (Figure 6).

**Figure 5.** Protocol of measurement the racetrack plane symmetry deviations relative to the plane of symmetry of the outer ring ends.

**Figure 6.** Protocol of measurements of ball bearing assembly mounting width.
5. Results Discussion
On the basis of adequate geometric modeling and experimental studies the optimal geometric specifications and dimensional tolerances and deviations of the bearing rings and arrangement assembly installed in rectangular coordinate systems have been established. A systematic approach has minimized the number of standardized geometric specifications. Simultaneously, new geometric specifications affecting the accuracy of the bearing have been determined. These include symmetry tolerances of the raceways, symmetry planes tolerance of the rings symmetry, and the mounting width of the ball bearing.

Figure 7. Rings of ball bearing 310, normal accuracy class - system setting of geometric specifications values and tolerances
a) inner ring; b) outer ring; c) informativeness indicators of main datums set of ring.
Figure 8. Single row radial ball bearing 310, normal accuracy class - system setting of geometric specifications values and tolerances

a) Indicator of main datums set; * – mounting width.

System setting of the rings values and geometric specifications is shown in (Figure 7), and the ball bearing assembly is presented in (Figure 8). The tolerances of geometric sizes limit all primary errors in the coordinate systems of main datums in full compliance with the geometric models of rings and ball bearing assembly (Figure 2...4).

The eccentricity vectors of the rings raceways identify one of the axes of the Cartesian rectangular system of coordinates and the bearing assembly. The experimental studies of the geometric specifications of the rings and the bearing assembly have confirmed the existence of deviations from the plane symmetry and the ball bearing mounting width.

6. Summary

• Adequate geometric models allow the optimal composition of geometric specifications in the rings and bearing assembly coordinate systems to be identified.
• Coordinate systems of rings and bearing assembly are materialized by the datum features sets performing as primary design datums, defining the position of the bearing in operation.
• Eccentricity vectors of the rings raceways identify one of the axes of the Cartesian coordinate system and should be marked on the face of the ring with the indicator.
• The coordinate system allows one to optimize and minimize the number of geometric specifications that determine quality performance of bearings.
• The flat ends of the bearings have the same function and form a symmetrical plane-parallel prismatic feature, plane of its symmetry being the datum feature.
• Experimental studies have confirmed the presence of deviation of rings raceways and the ball bearing mounting width symmetry exceeding the width of the rings.

7. Conclusion

A systematic approach to the normalization of values and tolerances of ball bearings geometric specifications in the coordinate systems can improve the quality of the bearings by optimizing and
minimizing the number of specifications. The introduction of a systematic approach to the international standards on rolling bearings is a guarantee of significant increase in accuracy of the bearings and the quality of products in which they are applied.

References
[1] ISO 492:2014 Rolling bearings – Radial bearings – Geometrical product specifications (GPS) and tolerance values
[2] ISO 492:2002 Rolling bearings – Radial bearings — Tolerances
[3] H Wiesner 2015 ISO 199:2014 and ISO 492:2014 standards – complexity versus unambiguity journal SKF Evolution 1 pp 27-30
[4] V I Glukhov 2014 Geometrical product specifications: Alternative standardization principles, coordinate systems, models, classification and verification Dynamics of Systems, Mechanisms and Machines (Dynamics) (IEEE Conf. Pub.)
[5] ISO 1101:2012 Geometrical product specifications (GPS) – Geometrical tolerancing - Tolerances of form, orientation, location and run-out
[6] ISO 5459:2011 Geometrical product specifications (GPS) – Geometrical tolerancing – Datums and datum systems