Research accuracy of final formation profile of rolling ball bearings by various methods.

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Abstract. An important role in the further operation of rolling bearings is played by the shape of the grooves of the ball bearing rings. That is why it is necessary to pay special attention to the formation of their profile. To study the shape of the trough, we studied a batch of ball bearing rings using the method of measuring the size of the stamps. Since the bearing also works with small radial loads, it is necessary to press in not only at right angles. Additionally, we propose to strengthen the effect of indentation. From the experiments it can be seen that there is a different distribution of stresses along the contact area for bearings of the same size. Based on this, it can be argued that the accuracy of the machining process is insufficient. Therefore, there is a need to improve the accuracy of shaping the profile of ball bearing rings by advanced technologies. To do this, we propose to use imitation completion. After this procedure, after conducting experiments, one can again see how the characteristics of the raceway profile of ball bearings have qualitatively changed, and, accordingly, their durability.

1. Introduction

As shown by numerous tests of rolling bearings for durability, their performance is random. Even during bench tests, when the operating conditions of the bearing are approximately the same, the durability dispersion coefficient in the test batch often exceeds one hundred fold level. This, obviously, is associated with a variety of random factors that arise during the manufacturing, assembly and operation of bearings, which have a significant impact on the conditions of interaction of the working surfaces of their parts.

The level and distribution of contact stresses on the contact areas of bodies and raceways have a significant impact on the performance of rolling bearings [1]. In addition to operational factors of operation (strain, speed), these parameters are largely determined by the profile shape of the contacting parts formed at the final stages of machining of their working surfaces [2]. Therefore, it is of practical interest to study the accuracy of shaping the grooves of ball bearing rings in real production.

2. Methods

As the object of research, we used finally machined inlying rings of an angular contact ball bearing №306, which is produced serially in the conditions of a bearing plant. 50 rings processed on the same equipment were subjected to control.

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In order to more clearly fix the size of the prints, before pressing the ball onto the raceway of the ring being tested, a very thin layer of soot was applied.

Indentation of the ball was carried out using a special device and a hydraulic press calibrated to ensure normal pressure, respectively, of 100, 200, 300, 400 and 500 kg.

The device used allows for normal and inclined indentation. Since ball bearing №306 is angular contact and allows operation under the action of slight axial loads, the inclined indentation was performed at a contact angle of 6°.

Imprint were measured using an optical length meter. In this case, the size of the large \((b)\) and small \((a)\) axes of the contact ellipses was fixed during successive pressure with forces of 100, 200, 300, 400 and 500 kg.

Based on the analysis of the size of the ball’s prints for various indentation efforts, the raceways were approximated by exponent curves of the form \(y=Ax^n\) and the exponent was determined \((n)\). The data obtained for the five studied rings are presented in tables 1 and 2.

### Table 1. The size of the semi-large axis of the contact ellipse of the raceway and ball with normal and inclined pressure.

| № | The size of the semi-large axis \((b)\) of the contact ellipse, mm | Index forms \((n)\) |
|---|-------------------------------------------------|-----------------|
| 1 | 100 kg | 200 kg | 300 kg | 400 kg | 500 kg |   |
| 1 | 2,214 | 2,395 | 2,540 | 2,582 | 2,659 | 6,1 |
| 2 | 2,009 | 2,161 | 2,355 | 2,413 | 2,543 | 5,6 |
| 2 | 2,030 | 2,271 | 2,438 | 2,485 | 2,598 | 5,9 |
| 3 | 2,084 | 2,229 | 2,440 | 2,493 | 2,610 | 5,7 |
| 3 | 1,834 | 2,085 | 2,283 | 2,346 | 2,471 | 4,6 |
| 4 | 1,819 | 2,100 | 2,219 | 2,340 | 2,457 | 4,7 |
| 4 | 2,063 | 2,363 | 2,466 | 2,483 | 2,648 | 7,9 |
| 5 | 2,112 | 2,260 | 2,393 | 2,402 | 2,618 | 7,8 |
| 5 | 1,496 | 1,661 | 1,842 | 1,965 | 2,034 | 3,9 |
| 5 | 1,465 | 1,589 | 1,748 | 1,782 | 1,924 | 5,1 |

### Table 2. The size of the semi-small axis of the contact ellipse of the raceway and ball with normal and inclined pressure.

| № | The size of the semi-small axis \((a)\) of the contact ellipse, mm |
|---|-------------------------------------------------|
| 1 | 100 kg | 200 kg | 300 kg | 400 kg | 500 kg |
| 1 | 0,250 | 0,262 | 0,283 | 0,309 | 0,330 |
| 2 | 0,181 | 0,191 | 0,199 | 0,214 | 0,246 |
| 2 | 0,145 | 0,191 | 0,227 | 0,242 | 0,262 |
| 3 | 0,151 | 0,210 | 0,230 | 0,248 | 0,249 |
| 3 | 0,156 | 0,231 | 0,238 | 0,259 | 0,271 |
| 4 | 0,172 | 0,208 | 0,248 | 0,265 | 0,272 |
| 4 | 0,206 | 0,213 | 0,239 | 0,243 | 0,261 |
| 5 | 0,160 | 0,218 | 0,234 | 0,246 | 0,310 |
| 5 | 0,171 | 0,236 | 0,267 | 0,285 | 0,296 |
| 5 | 0,166 | 0,231 | 0,261 | 0,269 | 0,362 |
As can be seen from the presented measurements, the sizes of the large and small axes of the contact areas of the bodies and the raceways of the rings of ball bearings of the same size significantly differ from each other. In some cases, for example, for rings №1 and №5, the size of the contact areas is 46-48%. Moreover, the shape of the raceway profile itself, which is characterized by the shape indicator \((n)\), differs significantly from the arc (when \(n=2\)) and has a pronounced random character. This fact is confirmed by the different sizes of the contact areas during normal and inclined pressure, which should be the same in the case when the raceway profile has an arc shape. This suggests that the accuracy and stability of the formation of the profile of the raceways of ball bearing rings in the final operations of the machining process is insufficient and technological measures are required to improve the accuracy and stability of the processing of working surfaces.

The revealed significant differences in the size and shape of the contact areas for rings of the same type indicate different contact conditions that occur during the operation of the same bearings in the nodes of machines and mechanisms. A different level of contact stresses, as well as their different distribution over the contact area of bearings of the same size when working under the same conditions, leads to a significant spread in their durability.

The values of contact stresses \((P_0)\) in the center of the contact area for the studied rings are presented in table 3.

| №  | Contact stresses \((P_0)\), kg /mm² |
|----|----------------------------------|
|    | 100 kg | 200 kg | 300 kg | 400 kg | 500 kg |
| 1. | 48,6   | 70,6   | 92,5   | 111,1  | 126,3  |
|    | 66,5   | 116,8  | 146,2  | 176,9  | 182,6  |
| 2. | 73,6   | 103,5  | 121,7  | 149,3  | 164,9  |
|    | 72,1   | 96,9   | 121,3  | 146,8  | 173,9  |
| 3. | 86,6   | 102,9  | 136,9  | 163,2  | 185,1  |
|    | 78,04  | 111,8  | 133,1  | 157,4  | 182,7  |
| 4. | 48,3   | 81,6   | 104,5  | 127,7  | 148,6  |
|    | 60,9   | 83,6   | 110,4  | 139,4  | 126,8  |
| 5. | 105,3  | 137,5  | 172,8  | 207,9  | 223,8  |

In tables 1, 2 and 3, the numerator contains data obtained with normal pressure, and the denominator - with the inclined.

Contact stresses in table 4 were calculated according to the following form [1]:

\[
P_0 = \frac{P(n+1)}{2\pi a b(n-1)}
\]

where \(P\) – is the pressure force of the ball on the raceway, kg;

\(n\) – raceway profile shape indicator;

\(a\) – semi-small axis size contact area, mm;

\(b\) – semi-large axis size contact area, mm.

As can be seen from table 3, due to the low stability of the formation of the profile of the raceways, contact stresses in rings of the same size can have different values and differ from each other by more than two times. Accordingly, the dispersion of the durability of ball bearings will be great. Therefore, one of the ways to ensure a consistently high durability of rolling bearings is to provide increased
accuracy of forming the profile of their working surfaces based on the use of new advanced technologies.

To verify the assumptions made earlier, we imitated the experimental bearings in assembled form for 30 seconds in an abrasive medium [2].

After disassembling and washing parts in a vibro-acoustic chamber, we carried out the procedure of pressing the ball into the modified raceway of the inner ring according to the method described above.

The dimensions of the semi-large axes of the contact ellipse are presented in Table 4. Also in Table 4 presents the indicators of the shape of the raceway of the inner rings processed by the imitation method. As can be seen from the table, the shape indicators of the inlying rings after the imitation of the experimental bearings in assembled form changed and assumed the same values. This suggests that in the process of imitation refinement, a new profile was formed within the contact of the ball with the raceway, which is close to that formed during the running-in of bearing parts at the initial stage of operation. At the same time, the same values of the shape index for the modified bearings indicate that the different dimension of the raceway profile for all modified bearings is minimal.

Table 4. The size of the semi-large axis of the contact ellipse of the raceway and ball with normal pressure at various loads.

| № | The size of the semi-large axis (b) of the contact ellipse, mm | Index forms (n) |
|---|---|---|
| 1. | 100 kg | 200 kg | 300 kg | 400 kg | 500 kg |
| 1. | 2.315 | 2.360 | 2.69 | 2.796 | 2.942 | 5.7 |
| 2. | 2.310 | 2.6 | 2.65 | 2.73 | 2.86 | 5.7 |
| 3. | 2.312 | 2.64 | 2.71 | 2.78 | 2.88 | 5.7 |
| 4. | 2.315 | 2.56 | 2.69 | 2.79 | 2.94 | 5.7 |
| 5. | 2.314 | 2.52 | 2.65 | 2.76 | 2.81 | 5.7 |

Table 5 presents the dimensions of the semi-small axes of the contact ellipse of the ball and raceway of the inlying rings of the modified bearings.

Table 5. The size of the semi-small axis of the contact ellipse of the raceway and ball with normal pressure at various loads.

| № | The size of the semi-small axis (a) of the contact ellipse, mm |
|---|---|
| 1. | 100 kg | 200 kg | 300 kg | 400 kg | 500 kg |
| 1. | 0.215 | 0.25 | 0.28 | 0.301 | 0.35 |
| 2. | 0.186 | 0.210 | 0.240 | 0.290 | 0.300 |
| 3. | 0.206 | 0.218 | 0.246 | 0.297 | 0.312 |
| 4. | 0.220 | 0.236 | 0.253 | 0.310 | 0.326 |
| 5. | 0.189 | 0.211 | 0.242 | 0.293 | 0.302 |

Table 6 presents the values of normal contact stresses that occur when the ball contacts the raceway of the inlying ring at various loads in the modified bearings.

Table 6. Values of contact stresses in the center of the contact area after joint completion of ball bearings in assembled form.

| № | Contact stresses (P), kg /mm² |
|---|---|
| 1. | 100 kg | 200 kg | 300 kg | 400 kg | 500 kg |
| 1. | 45.6 | 70.9 | 90.4 | 108.1 | 110.2 |
| 2. | 52.8 | 83.1 | 107.1 | 114.7 | 132.3 |
| 3. | 47.6 | 78.9 | 102.1 | 109.9 | 126.3 |
| 4. | 44.6 | 75.3 | 100 | 104.8 | 118.3 |
| 5. | 51.9 | 85.4 | 106.3 | 112.3 | 133.7 |
From table 6 it is seen that the contact stresses for all experimental rings at the same loads have close values. This suggests that the imitation allows you to form the contact surface of the raceways of the rings with almost the same geometric parameters. And this, in turn, will provide more stable performance indicators for bearings, after imitation completion in assembled form.

It should be noted that after the imitation of the bearings assembled, the contact stresses on the raceways are significantly reduced, which helps to increase their durability.

3. Results and Discussion
The use of assembled imitation ball bearings as a final processing method allows to increase the stability of the accuracy of the raceway profile, provide a significant reduction in contact stresses and, due to this, increase the durability of the bearings.

4. Conclusions
1. As a result of the analysis of the accuracy of forming the profile of the raceways of the rings of standard ball bearings by the method of measuring ball prints, it was found that the shaping of the profile of the raceways by standard technological methods does not provide the necessary stability of geometric parameters, which leads to the appearance of different values of contact stresses in the bearings of one batch and to a significant spread in their durability.
2. One of the ways to ensure a consistently high durability of rolling bearings is to ensure increased accuracy in the formation of the profile of their working surfaces based on the use of new advanced technologies.

References
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