Study of defects of the surface of rolls of rolling bearings under grinding

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Abstract. The article proposes a new approach to the method of assessing the surface defects of the raceway of instrument bearings after profile grinding. The surface defects of the bearing raceways were studied on an optical-electronic complex on the basis of calculating the parameters of the autocorrelation function obtained as a result of computer processing of the video image of the surface. The purpose of this study is improving the profile grinding technology of bearings through the construction of an optical-electronic information-measuring system for monitoring the defects of raceways.

1. Relevance
The introduction of new and the development of classical machining technologies is associated with the need to control the level of defects in finished products [1, 2]. Tests show that quality control of surfaces after mechanical processing by contact methods is common [3, 4]. However, new requirements for the configuration of production require a transition to high-speed processes [5, 6]. A review of current sources confirms this conclusion [7, 8]. Optical methods are becoming increasingly important [9, 10]. This type of methods can be useful when choosing significant roughness parameters [11, 12]. In addition to the roughness parameters, according to these types of methods, it is possible to assess the level of product defects, identify defects in metal products [13].

2. Research methods
The considered method allows determining surface defects on the raceway of instrument bearings in the course of profile grinding using optical-electronic means and information technologies, measurement theory and digital image processing, correlation analysis theory, probability theory and mathematical statistics. The applied method is based on computer processing of the image of the raceways of the surface under study using quasi-optimal correlation algorithms.
3. Results and discussion

The process of profile grinding of the raceways of instrument bearings was carried out on a Bryant M-1 machine with the following adjustments of rigid supports: the angle between the supports was $\beta=105^\circ$, angle of the adjustable support relative to the horizontal axis of the ring $\alpha$ was 7° (according to theoretical studies, the optimal angle $\alpha=5^\circ–10^\circ$), the displacement coordinates of the center of rotation of the ring relative to the center of rotation of the faceplate were $\Delta x=0.2$ mm, $\Delta y=0.3$ mm.

**Figure 1.** Sketch of instrument bearing inner ring.

Grinding wheel used 1–355x16x127 91A F320 M 9 V2, periodically during the grinding process. Practice has shown that the editing period was 20 - 30 parts. Grinding wheel wear limit – 280x16x127. Editing was carried out with a diamond pencil C2 with modes: $V_k = 25.6 – 34.4$ m/s, $S = 0.2$ mm/lead, $S_{fin} = 15$ mm/min. The process is carried out with a constant supply of lubricant-coolant in the treatment area.

Grinding modes varied within the following limits:

- Grinding speed - constant $V_k = 25.6 – 34.4$ m/s,
- The circumferential speed of rotation of the part was determined by the formula $V_z = 60 \cdot V_k$, where $q = 60–100$. In process charts at the factory $V_z = 8.4 – 10.3$ m/min. which is significantly less than the calculated values, so for the study, the speed of rotation of the workpiece increased to $V_z = 20.4-34$ m/min.

- Cross feed during rough grinding varied from $S_{rough} = 0.4–0.9$ mm/min, when grinding $S_{fin} = 0.2–0.4$ mm/min.
- Sparkout ranged from $T_m = 2-5$ sec.

Defect control under production conditions was carried out on microscopes. Analysis of the technology for monitoring the defects of the inner rings of instrument bearings after grinding operations at the instrument bearings plant showed that optical inspection methods do not give significant results.

In the work, the surface defects of the raceways of the bearing rings were investigated using an optoelectronic complex and the developed technique. The method is based on the comparative correlation processing of the halftone image of the raceway texture and a special set of halftone images of the reference textures with known surface texture parameters. A database on the connection of the arithmetic average deviation of the surface profile has been created $R_a$ with an average amplitude of oscillation of the autocorrelation function $A_{avg}$ depending on the level $r$ ($r = 0.61$) and the size of the base window [14].

Figure 2 on the left shows a reference surface with parameters $A_{avg} = 13.42$, $R_a = 0.058 \mu$m and the surface of the raceways of the rings with a defect $A_{avg} = 14.03$, $R_a = 0.098 \mu$m on the right.
Figure 2. Defect on the raceway of the instrument bearing.

It was established that the defect during processing using autocorrelation analysis changes the value of Ra from 0.058 μm to 0.098 μm, which cannot be determined using other measurement methods.

Studies have shown that surface defects appeared as a result of contact interactions of abrasive grains and grinding waste with the workpiece surface. To assess the defects, the degree of the relative importance of the defects was adopted, which was determined by the results of their pair-wise comparison between themselves according to a certain combination of features. It is proposed to use a prioritization method based on collective peer review.

The sequence of procedures performed during this process is as follows:

Let there be a defect on the surface of the raceway of the bearing - X, the formation of which occurs under the influence of the Y - factors by which these objects will be compared in pairs.

The value of the relative importance (or priority by i attribute) of each object in the total amount is determined by the method of iteration of the first level [15]:

\[
K_i = \frac{Z_i}{\sum B_{ij}} \cdot 100\%,
\]

where \(Z_i\) – object priority value by specific attribute, \(B_{ij}\) – coefficient, which is analogous to the idea of the superiority of an i object over j.

Each such element \(K_i\) means the relative number of priorities for this defect. Found \(K_i\) will be defect parameters.

Experimental studies have shown that the main factors affecting the formation of defects during grinding are as follows: the speed of rotation of the workpiece, m/min (1); cross roughing, mm/min (2); cross fair feed, mm/min (3); nursing, with (4); cross feed during dressing, mm/double pass (5); coolant grade (6); coolant purity (7).

The study of the surface texture of the raceways of the inner rings of instrument bearings on the optoelectronic complex was carried out under the following modes: frame format 120x140 pixels, basic window with a standard size of 9x9 pixels, angle of inclination of the light source 45°, 10 frames were taken along the ring arc if defects were detected on one image, the ring was considered defective.

A total of 500 rings, which underwent the profile grinding operation with the use of oil coolants, were investigated; this made it possible to identify typical defects.

Figure 3. Typical defects during profile grinding.
According to the results of the research, the following signs of defects on the working surface of the raceway of the bearing rings were identified (figure 3):

1. interspersed fragments of grains in the surface;
2. the influx;
3. discontinuities;
4. microcavities;
5. sticking of the processed material (chips) on the surface;
6. plowing;
7. hole formation;
8. chipping;
9. local destruction.

The depth of the defect was determined by the difference of parameters \( A_{\text{avg}} \) obtained in the presence of a defect \( (A_{\text{avg}}) \Delta A_{\text{avg}} = A_{\text{avg}i} - A_{\text{avg}j} \).

The resulting value was substituted into the formula for calculating the depth risks:

\[
R_{zd} = 0.14 + 0.07 \times \Delta A_{\text{avg}} \text{, } \mu m
\]

For example, when grinding, a defect appeared on the surface, which affected the \( A_{\text{avg}i} = 14.0 \), and \( A_{\text{avg}j} = 13.4 \), then the depth of the defect \( R_{zd} = 0.182 \mu m \), if \( Ra = 0.058 \mu m \) [16].

From the data in table 1, it can be seen that the most significant defects are 1, 4, 8 and 9, and the factors dominating are 2, 5, 6, 7, i.e. cross feed when dressing the grinding wheel, cross feed feed when grinding, the type and quality of cleaning coolant.

### Table 1. The results of determining the value of relative significance \( K_i, \% \).

| Defects | 1  | 2  | 3  | 4  | 5  | 6  | 7  | \( K_i, \% \) |
|---------|----|----|----|----|----|----|----|---------------|
| 1       | +  | +  | +  | +  | +  | +  | 4.9          |
| 2       | +  | +  | +  | +  | +  | 3.7         |
| 3       | +  | +  | +  | +  | +  | 2.5         |
| 4       | +  | +  | +  | +  | +  | 6.2         |
| 5       | +  | +  | +  | +  | +  | 2.5         |
| 6       | +  | +  | +  | +  | +  | 3.7         |
| 7       | +  | +  | +  | +  | +  | 3.7         |
| 8       | +  | +  | +  | +  | +  | 6.2         |
| 9       | +  | +  | +  | +  | +  | 6.2         |
| \( K_i, \% \) | 3.7 | 7.4 | 2.5 | 2.5 | 6.2 | 6.2 | 11.1 | 39.6           |

According to the results of the research conducted on the surface defects of the raceways of the inner rings of bearings during profile grinding, the following reasons for their formation were identified:

Reason 1. Defects in the form of traces (dents) from the introduction of abrasive grains on the working surface of the raceway are due to the fact that during the grinding process technological processing modes are not performed, in particular, there is no sparkout, or the duration of this process is insufficient.

Reason 2. The appearance of defects in the form of scratches is associated with poor-quality cleaning of coolant. After hitting the cutting zone, the abrasive particles are instantly fixed between the surface of the wheel and the workpiece and perform the cutting work until the cutting forces crush the grain fragment, forming a dent at the end of the movement.

Reason 3. Defects in the form of clots of chips indicate poor-quality magnetic separation of the liquid.

Reason 4. Defects located at the edges of the surface of the raceway are associated with the effect of free abrasive, which is in liquid, on the surface of the raceway of the bearings.

### 4. Conclusions

1. The use of an optoelectronic complex for the study of defects in the raceways of the bearing rings made it possible to identify defects that are not fixed by contact measurement methods.
2. An analysis of defects by the magnitude of relative importance is proposed and the causes of their occurrence are identified.

3. It has been established that defects are formed as a result of poor-quality cleaning of an oil coolant.

4. It is necessary to develop a technology for defect-free grinding of the raceway of the inner bearing rings.

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References

[1] Grigoriev S N, Bobrovskij N M, Melnikov P A and Lukyanov A A 2017 IOP Conf. Ser.: Earth Environ. Sci. 50 012015
[2] Grigoriev S N, Bobrovskij N M, Melnikov P A and Bobrovskij I N 2017 IOP Conf. Ser.: Earth Environ. Sci. 66(1) 012013
[3] Grigoriev S N, Bobrovskij N M, Bobrovskij I N, Lukyanov A A and Seitkulov A R 2017 Testing of external cylindrical surfaces of car parts after wide burnishing processing Key Engineering Materials 746 126-31
[4] Grigoriev S N, Bobrovskij N M, Bobrovskij I N and Jiang C –P 2017 Technological parameters forming the surface texture in hyper productive surface Plastic deformation processing Key Engineering Materials 746 KEM pp 114-9
[5] Bobrovskij N M, Melnikov P A, Grigoriev S N and Bobrovskij I N 2015 IOP Conf. Ser.: Mater. Sci. Eng. 91(1) 012034
[6] Bobrovskij N M, Levashkin D G, Bobrovskij I N, Melnikov P A and Lukyanov A A 2017 The IOP Conf. Ser.: Earth Environ. Sci. 50 012013
[7] Bobrovskij I N 2018 Burnishing Systems: a Short Survey of the State-of-the-art ATCES 2017 IOP Conf. Series: Materials Science and Engineering 302 012041
[8] Bobrovskij N M, Melnikov P A, Grigoriev S N and Bobrovskij I N 2015 IOP Conf. Ser.: Mater. Sci. Eng. 91(1) 012035
[9] Lukyanov A A, Grigoriev S N, Bobrovskij I N, Melnikov P A and Bobrovskij N M 2017 IOP Conf. Ser.: Earth Environ. Sci. 66 012020
[10] Grigoriev S N, Bobrovskij N M, Melnikov P A, Bobrovskij I N and Zaborowski T 2017 Research of Tool Durability in Surface Plastic Deformation by Wide Burnishing of Cast Iron without Metalworking Fluids Key Engineering Materials 746 pp 120-5
[11] Grigoriev S N, Bobrovskij N M, Melnikov P A, Bobrovskij I N and Levitskih O O 2017 IOP Conf. Ser.: Mater. Sci. Eng. 66 012012
[12] Abramov A D and Nosov N V 2016 The Analysis and Correlation Method of Elimination Errors of OptiCal-Electronic Determination of Microrelief Parameters Herald of computer and information technologies 9 19-25
[13] Abramov A D, Nikonov A I and Nosov N V 2006 Method of monitoring article surface roughness Patent RF, no. 2413179 (Moscow: Rospatent)