RELIABILITY ANALYSIS OF ROLLING BALL BEARINGS CONSIDERING THE BEARING RADIAL CLEARANCE AND OPERATING TEMPERATURE

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Abstract:
The aim of the research conducted in this particular paper was related to a comprehensive reliability analysis of SKF 626 Open Deep Groove ball bearings, conducted under controlled laboratory conditions. The experimental research consisted of: measurements of radial internal clearance (RIC) in ball bearings, measurement methods for the detection of bearing operating temperature and rolling element bearing wear, complete with the cage deformation of the the damaged bearing, the failure of which was revealed after the examination. The inspected SKF 6206 open deep groove ball bearings operating under laboratory conditions – simulated the model of dynamic behavior under real conditions by using the crankshaft of an air compressor.
The results of research conducted based on the inspected samples of rolling bearings, showed that there was a significant dependence of the predictors of internal radial clearance on operating bearing temperature. Out of five test samples of rolling bearings, there was only one rolling ball bearing detected to be with failure after the bearing inspection. The examination of the damaged bearing revealed the final radial clearance value of 0.045 mm, i.e. operating temperature of 75 °C.

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1. INTRODUCTION

Complex operating conditions along with such a large equipment burden are only some of the key challenges posed to to the machinery in modern industry today. Exploitation characteristics of the aforementioned industrial machines indicate the benefits of all working conditions. The key operating elements of these industrial machines are rolling bearings [1-4].

The most common type of a technical system with rolling bearings is, by all means, an air compressor which is used for the activation of a wide range of machines and installations. Piston air compressors use pistons which are directly triggered by the piston mechanism, thus converting the circular rotary motion into a reciprocating or oscillating motion of the piston [5]. During the air compressor exploitation as a technical system, irreversible changes in the system arise, resulting from a number of various processes such as the following [6]: friction, wear, corrosion, deformation [7,8]. The condition assessment of such a diagnostified object is defined by boundary values of particular parameters, whereas each deviation of system parameters, when compared to the projected values, is considered as the system failure. Rolling bearings represent the most common case of such rolling elements failure in the piston air compressor [9]. The values which are inherent

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characteristics of the normal bearing operating system are conditioned not only by the system project design, manner of its development and operation, but also by the alteration of environmental conditions as well [10-15].

Monitoring the exploitation characteristics of the aforementioned mechanical system is reduced to the visual assessment of the (bearing) system behavior complete with the measurement of vibration responses, clearances and system temperatures during the exploitation by applying designed dynamic process parameters and likewise [13-16]. Numerous research are focused on the analysis of the tribological properties of ball bearings [17-19]. The leading causes of the development of these tribological properties most commonly result from the geometrical, kinematic and dynamic occurrences [20].

According to the research results [21], the statistical parameters indicate that the reliability of rolling bearings is affected by the position of localized defect on the outer ring, the exact number of defects and their locations, whether they are on a bearing inner ring or rolling element bearing, along with crankshaft speed. Damages at rolling element bearings are mostly caused by, for instance, rolling-element bearing defects, growth of cracks at rolling contact fatigue, or breaking, spalling and cracking of the *rolling elements.* Alterations in the bearing surface geometry produce an impulse response at the damaged contact surfaces [21].

2. MATERIALS AND METHODS

The aim of the research conducted in this particular paper was related to a comprehensive reliability analysis of rolling bearings, undertaken under controlled laboratory conditions. The experimental research were based on the following:

- ✓ The radial clearance measurement,
- ✓ The measurement of operating bearing temperature and
- ✓ Rolling element bearing wear, complete with the cage deformation of the damaged bearing.

For the purpose of this research, we used the SKF 6206 radial ball bearings which are utilized in the compressor system. Five bearings were examined in total, during the time interval of 20,000 work hours. Based on the measured values of monitored parameters (radial clearance and operating temperatures), we came to the conclusion on reliability of the aforementioned technical system.

2.1. The measuring methods of radial internal clearance of rolling bearings

Laboratory testing of reliabilty of rolling bearings conducted at the rolling bearing test stand and by using dynamic and static load testing machines for rolling bearings measurements in the *Factory for the Manufacturing of Automobile Parts* (*FAD*)*,* Gornji Milanovac. The rolling bearing test stand developed by FAD, Gornji Milanovac, was constructed in the cooperation with the American company O&S in accordance with all the requirements necessary for testing of ball joints of type SAE 193 (Fig. 1a and 1b). The examination of reliability of rolling bearings was performed at the rolling bearing test stand (Fig. 1a and 1b).

a)

b)

Figure 1. Layout of machine for testing axial and radial clearance

The rolling bearing test stand was constructed for the purpose of examination of rolling bearings with alternating loads, angular oscillation and rotation angle, with the parameters alternating according to the specific frequency. During the examination, the process was run automatically, whereas the life cycle numbers were noted in each of the testing phases and in total as well. At the end of specific cycle phases, the measuring of output parameters was performed, primarily of axial and radial clearance complete with the bearing operating temperatures.

Bearing internal clearance is defined as the total distance through which one bearing ring can be moved relative to the other in the radial direction (radial internal clearance) or in the axial direction (axial internal clearance), from one final position to the other. Internal deviation of rolling bearings is considered to be relative deviation of the inner or outer ring movements and can be divided into two groups (axial and radial movement).

The measurement of radial clearance was obtained for the purpose of creating relative movement of the bearing crankcrafts.

The radial clearance measurements were conducted in such a manner so that relative crankshaft movement could be obtained. The given force *F* used to be defined via the force sensor-bearing units, whereas reading of their movement was performed via the movement sensors. The force size was defined in accordance with the bearing diameter. As for the inspected single row SKF 6206 deep groove ball with bearing internal radial clearance of 0.020 mm, inside diameter of 30 mm and 9 rolling elements, deformation values under load factor were the following: $3.31 \cdot 10^5$ $N/mm^{3/2}$.

For the research conducted so far, we used a simple method based on direct measurements of radial clearance by using simple means and without using an etalon bearing.

The measurements of bearing radial clearance and its wear (of the inner raceway, outer raceway and ball bearings, etc.) were performed for the purpose of assessment of tribological processes in rolling bearings under controlled laboratory conditions. Our research made use of the following measuring equipment:

- ✓ a geometric micrometer (with a diameter of 0÷0.025 mm) was used for the purpose of measuring ball bearing diameter,
- ✓ digital scales named *Sartorius Precision Scale, Model* PT 600, used for the measurement of weight of rolling element bearings,
- ✓ measuring leaves for the adequate bearing clearance of 0.03 mm,
- ✓ radius was measured by using control radius tolerance pattern of type IT1-IT3.

Alternating diameters of rolling elements inside one bearing plays a significant role in influencing dynamic behavior of bearings in exploitation. The inner ring raceway represents a measurement of geometrical accuracy of the raceway and a ball bearing in a plane passing through the axis of all the rolling bearings given, the line of which is going through the bearing centre at right angles to the abovementioned plane and transversaly to the raceway. The inner raceway radius (Fig. 2), shows the relation between the inside radius of the groove raceway and a cross-section of a ball bearing and it can be expressed by using Eqn.1, [22]:

$$f = \frac{r}{D} \tag{1}$$

where:
f - inside radius of the groove raceway (mm),
r - inside radius of curvature of the groove (mm),
D - ball diameter (mm).

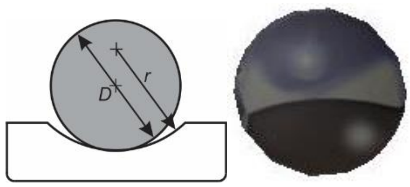

Figure 2. Cross section of the ball and the outer track

2.2. Measurement Method of Bearing Temperature

For the purpose of measuring bearing operating temperature, we used the ultimate bearing failure criterion which referred to the minimum rise of 10° C in temperature, i.e. the point when a bearing temperature rose to 73° C [23-25]. The temperature of bearings was measured by using the *TP7* pyrometer – the infrared thermometer.

3. THE ANALYSIS OF RESEARCH RESULTS

The results of inspection of rolling bearing radial clearance are shown in Fig. 3. The research results revealed only one bearing failure (the rolling bearing No. 5) occurring before the set deadline date. Radial clearance of the ball bearing was 0.010 mm prior to the examination. Initial constructive bearing clearance was 0,005÷0,020 mm, whereas planned boundary (final) limitation clearance was up to 0.040 mm in the exploitation conditions. Radial clearance, as observed on the damaged rolling bearing (the rolling bearing No. 5), exceeded the values of limitation clearance and was considered to be 0.045 mm, as shown in Fig. 3.

The results of measuring the operating temperature in rolling bearings are shown in Fig. 4. The research revealed the higher temperature values on the surface of outer raceway than those observed on the surface of inner raceway. The final operating temperature of the damaged rolling bearing (the rolling bearing No. 5) was 75 °C, as shown in Fig. 4.

The greatest increase in operating temperature was observed in the first operating time interval (after 10 minutes) and it is considered to be 28.9 °C in 900 °/min until it reaches stationary temperature of 52.3 °C (for the increased number of revolutions). The examination results showed that the increase in the prestressing from the middle number of revolutions from 900 min^{-1} to the higher number of revolutions of 2900 min^{-1} – led to exceeding the maximum allowed temperature limits, and in this particular research operating temperature reached 73 °C. The research results showed the increased values of operating temperatures on the outer surface of the outer ring. The aforementioned temperature values are higher by 3 to 5 °C than those of the operating temperature observed on the mounting of the outer surface of the threaded spindle.

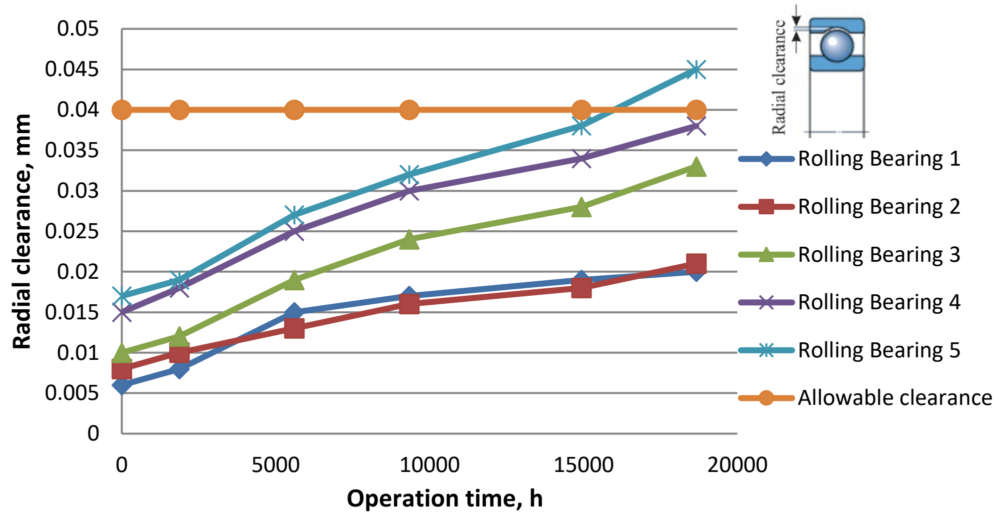

Figure 3. Diagram of radial clearance

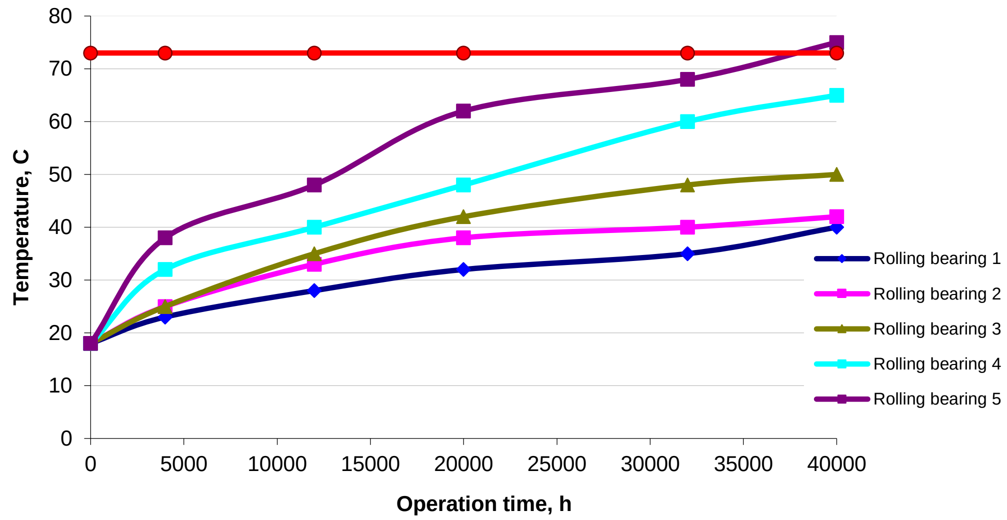

Figure 4. Diagram of temperature change on bearings

The research results of basic geometry of a cross section of a radial ball on the damaged rolling bearing (of the rolling bearing no. 5) are shown in Fig. 5. In addition, the dimensions of a ball bearing diameter, i.e. an outside diameter of a ball bearing are shown in Fig. 5. The results of measuring showed the dimensional deviation of the inspected ball bearing in comparison to the standard ball bearing dimensions – 9. 525 mm, as shown in Fig. 5.

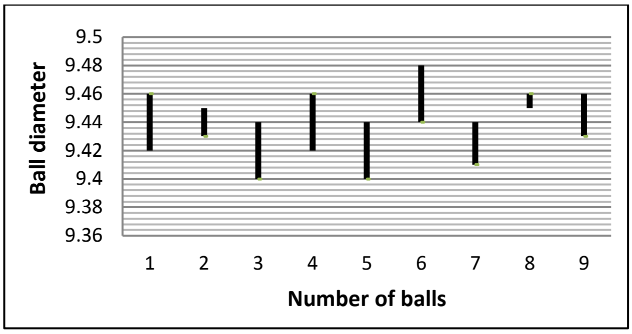

Figure 5. Changing the dimensions of the balls after dismantling the bearing

The main damage features in the examined rolling bearing in comparison to the new rolling bearing are shown in Table 1. The rolling bearing geometry is affected by the following factors: the quality of a bearing's raceway and rolling element materials, the quality of processed surfaces of a bearing's raceways and rolling elements, the manner of their maintenance, types of bearing lubricants, rolling bearing exploitation conditions, etc. In order to include the effects of specific damage on the SKF 6206 ball bearing by means of the examination of rolling bearing in the piston compressor, we demonstrated individual examples of damage (occurred during the exploitation process) on the inner and outer ring complete with their rolling elements, which were observed after dismounting of the rolling bearing at the rolling bearing test stand (Table 1).

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Table 1. Shows the values of the new geometry of the bearing, as the deformed bearing

Geometry the bearing Property According to SKF	Standard values	Values after defect
Bearing outside diameter–D	62 mm	61.995 mm
Bearing bore diameter–d	30 mm	29.998 mm
Bearing width– B	16 mm	16.01 mm
Ball diameter–d_k	9,525 mm	9.441 mm
Contact angle – β	0°	0.8°
Number of balls – n	9	9
Weight balls –G	3.55 gr	3.48 gr
The inner diameter of the outer ring track –$D_{a\ max}$	55.53 mm	55.56 mm
The diameter of the bearing outer track opening– $d_{a\ min}$	36.5 mm	36.46 mm
Mass-bearing weight–G_1 –Mass m	200 gr	195 gr
Internal radial clearance	e = 20 µm	

The main dimensions of the outer ring (of the rolling bearing No. 5) were Ø55.53 mm prior to the examination, whereas the same dimensions were shown to be Ø55.56 mm after the detection of wear in the rolling bearing. The main dimensions of the inner ring of the new rolling bearing were Ø36.5 mm, whereas the dimensions of the ring of the damaged rolling bearing were Ø36.46 mm due to the rolling wear. Based on this particular bearing analysis, we came to the conclusion relating to the presence of wear on the bearing inner ring raceway surface, as shown in Fig. 6.

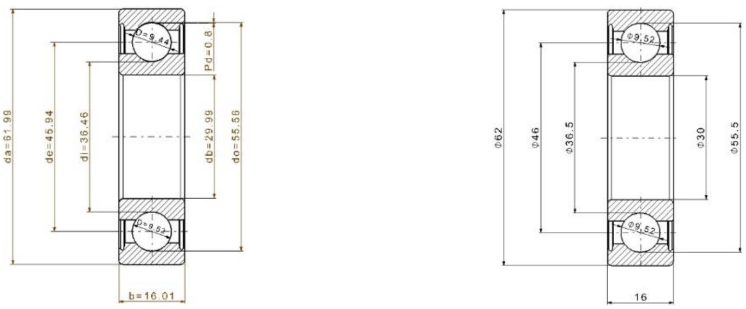

Figure 6. Radial cross-section of one single-row ball bearing

4. CONCLUSION

The examination of reliabilty of rolling bearings conducted under controlled laboratory conditions was represented in this particular paper. During the laboratory testing, diagnostic parameters of the radial clearance and operating temperature were being monitored. The examined diagnostic parameters showed high levels of dependence of reliability of rolling bearing technology. The research finding results are affected not only by the given examination parameters, but they are also significantly influenced by the quality of a bearing's raceway and rolling element materials as well, the quality of processed surfaces of a bearing's raceways and rolling elements, the manner of their maintenance, types of bearing lubricants, rolling bearing exploitation conditions, etc.

The demonstrated methods for the assessment of rolling bearing damage degree are considered to be high-precision tools used for the purpose of assessing the reliability of rolling bearings. Therefore, it is possible to enhance and simplify the technology of rotary equipment maintenance, which leads to reducing operating expenses acummulated due to machine stoppages, ultimately allowing organizations to react in a timely manner.

5. LITERATURE

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