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INFLUENCE OF ABRASIVE WEAR ON BALL BEARING INTERNAL GEOMETRY

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Abstract: *When the machine environment is contaminated with dust, sand or minerals, small solid abrasive particles could be involved into rolling bearing lubricant. Sharp hard particles cause intensive abrasive wear of bearing parts. This process leads to change of rolling bearing internal macro geometry and contact surfaces micro geometry. Consequently, the bearing looses its operational ability and do not achive predicted service life. An influence of abrasive particles size and concentration on the rolling bearing internal micro- and macro geometry is analyzed in this paper. The presented results are emphasizing the importance of both sealing and lubrication system development keeping rolling bearing operational ability during its predicted service life.*

Keywords: *abrasive wear, ball bearing, internal geometry, roughness, radial clearance.*

1. INTRODUCTION

Under real operational conditions, rolling bearing lubricant contains some quantity of debris. The material of debris particles, their form, size and its concentration in lubricant depend on technology of bearing manufacturing, operational environment conditions, lubrication, sealing and lubricant filtration. The abrasive wear of rolling bearing parts can be caused by acting of sharp, solid and very hard particles of minerals, coal, sand, dust, cement, etc. Consequently, the bearing internal geometry is changed. It leads to improper operation of the bearing and decreasing of its service life in relation to predicted value. In many cases, the abrasive wear of rolling bearing can not be avoided, but could become predictable thanks to investigation of this phenomenon.

2. DEEP GROOVE BALL BEARING GEOMETRY

2.1. Micro geometry of bearing parts

The ball bearing micro geometry is geometry of bearing parts surfaces. Topography of contact surfaces is defined by roughness, which appears during the manufacturing process and exploitation. The roughness of bearing parts surfaces depends on technological process of manufacturing and mechanical properties of material.

During bearing exploitation, the micro geometry of bearing parts surfaces may be changed due to wear caused by acting of abrasive particles from lubricant. A modification of ball bearing contact surfaces due to micro cutting by abrasive particles is experimentally analyzed in this paper.

2.2. Macro geometry of bearing

The rolling bearings external geometry is defined by appropriate standards. Main characteristics of external deep groove ball bearing geometry are (Fig.1): d – bore diameter; D – outside diameter; B – width.

Internal deep groove ball bearing geometry is defined by diameters of rolling elements and diameters of raceways in two perpendicular cross sections. Rolling elements are balls with diameter D_w. Raceways have toroidal form. Dimensions of raceways are: groove cross section radius r_e for outer ring and r_i for inner ring and groove diameters D_e for outer ring and D_i for inner ring (Fig.1). The internal radial clearance e, significant geometrical and functional characteristic of the bearing, is determined by diameters of raceways and balls:

$$e = D_e - D_i - 2D_w \,. \qquad (1)$$

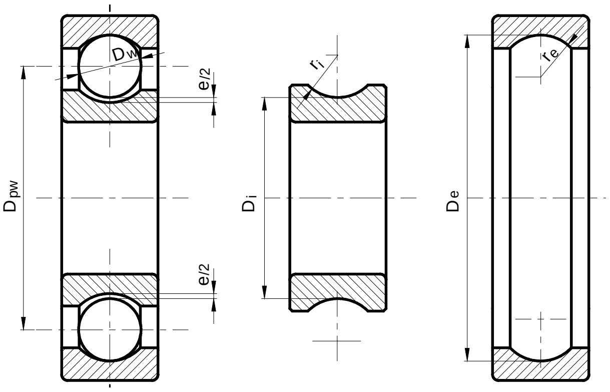


Figure 1. Deep groove ball bearing internal geometry

The internal geometry of rolling bearing is very complex and has significant influence on the load distribution between rolling elements, contact stresses and deformations, vibrations and noise, as well as bearing service life.

3. LUBRICANT CONTAMINATION

If the bearing environment is contaminated with big quantity of „aggressive“ (small, hard, sharp...) abrasive particles, it is not possible to prevent lubricant contamination and debris particles entrainment into the bearing. In such case, sealing and lubricant filtration are not efficient enough and their applications are not useful or not possible. Debris particles entrapped in contact between bearing balls and raceways cause abrasive wear – multiple microscopic damage of contact surfaces.

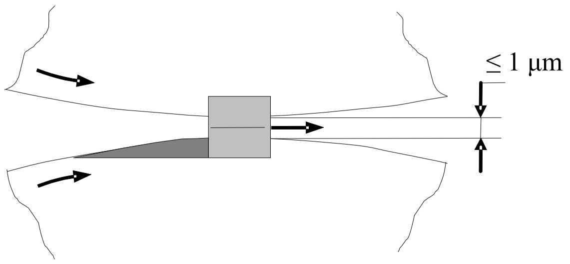


Figure 2. Abrasive particles within EHL contact between rolling element and raceway

Rolling bearings operate under the elastohydrodynamic (EHL) lubrication regime. Thickness of lubricant film between rolling elements and raceways is usually less than one μm. Debris particles dimension less than lubricant film thickness pass with oil through EHL contact and do not harm bearing parts surfaces. However, the most of particles entrained in bearing lubricant are larger than lubricant film thickness and they wear rolling bearing contact surfaces (Fig.2). Qualitative and quantitative properties of surface damage depend on material, form, size and concentration of debris particles [1].

4. EXPERIMENTAL DETAILS

4.1. Test rig and specimen

Scheme of test rig used for rolling bearing investigations is shown in the Fig.3.

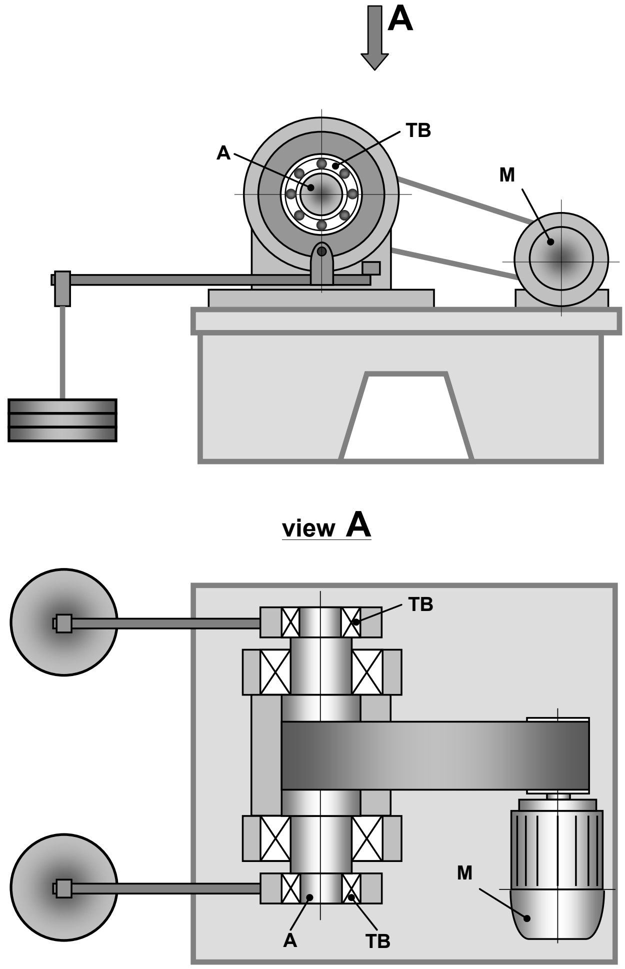


Figure 3. Test rig

There are two test rolling bearings **TB** – 6306 (Fig.4) on the ends of axle **A**. Electric engine **M** (1.5 kW; 2835 min^{-1}) with belt transmission is driving the rig. Shaft rotational speed is 4250 min^{-1}.

Figure 4. Deep groove ball bearing 6306 2RSR C3

The load of tested bearings was pure radial (F = 0.12C and 1.5F = 0.18C, where C is dynamic load rating of tested bearing).

Deep groove ball bearing **6306 2RSR C3** (internal radial clearance *e* = 8...23 μm) was used as specimen. Tested bearings were lubricated by grease based on mineral oil.

Abrasive particles of synthetic diamond were mixed with lubricant. Sizes of abrasive particles were $a \leq 2$ μm and $a \leq (10...14)$ μm. Concentrations of abrasive particles in the lubricant were 1.25 g/l (5 mg/bearing), 2.5 g/l (10 mg/bearing) and 17.5 g/l. These concentrations are few times higher than values defined by ISO 4406 standard. This was the way to achieve the effect of intensive abrasive wear in a very short time of bearing operating. Bearings testing lasted 10^5 load cycles (number of revolutions of inner rings) and after that, tested samples of bearings were washed in ultrasound bath.

5. EXPERIMENTAL RESULTS

5.1. Micro geometry

Even visual control of tested bearings parts (Fig.5) has shown that there are damages of both ball and raceways surfaces (Fig.6).

Figure 5. Parts of tested bearing

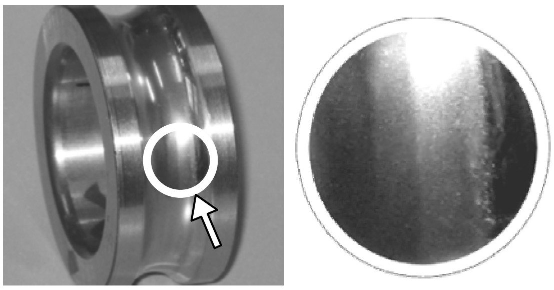
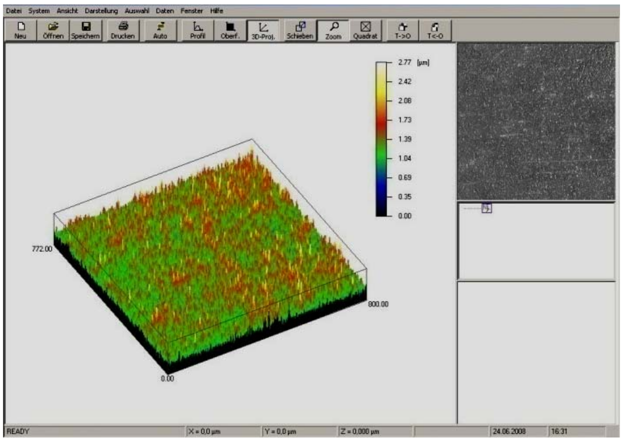


Figure 6. Raceway of inner bearing ring

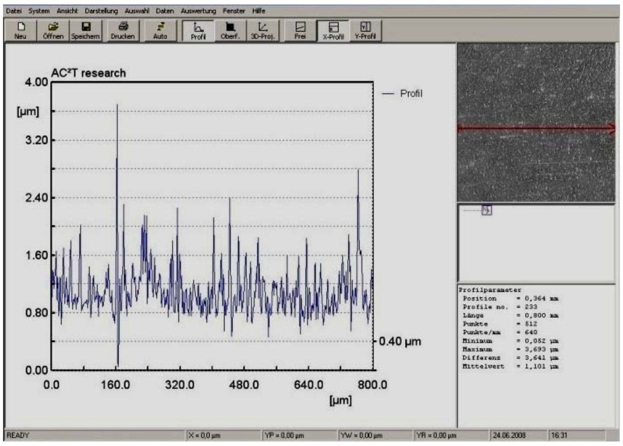
Measuring of worn surfaces micro geometry has realized in AC^{2}T in W.Neustadt on the NanoFocus device with appropriate software μProfile [2].

Micro profile and all measured roughness numerical characteristics of worn out surface of inner ring raceway are shown in the Fig.7.

There are different surface damages due to abrasive wear of raceway surface depending on type of contact between balls and raceway (rolling or rolling with micro slip). The surface worn by micro cutting caused by abrasive particles entrained in sliding contact between ball and raceway is presented in the Fig.8a. The areas of contact surfaces being in pure relative rolling are areas of particles tumbling. In these areas of contact surfaces, abrasive particles have made micro dents more than micro cuts (Fig.8c). Both of mentioned above wear mechanisms and phenomena of surface damage are present simultaneously on the areas between pure rolling and pure sliding (Fig.8b).



a)



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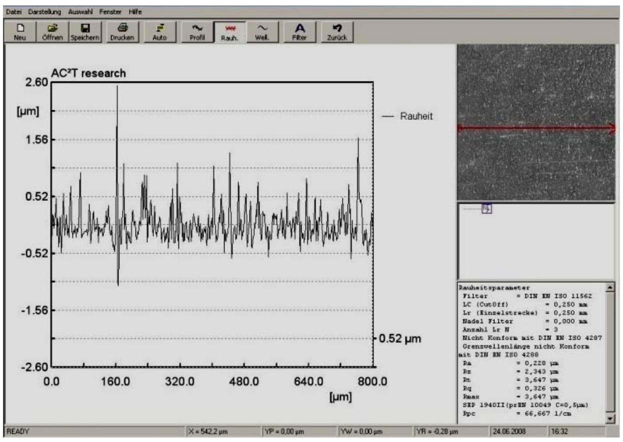
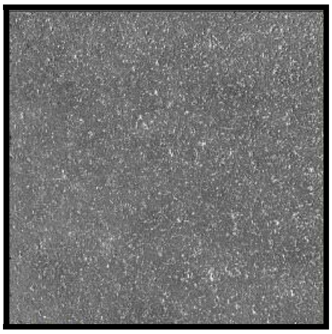
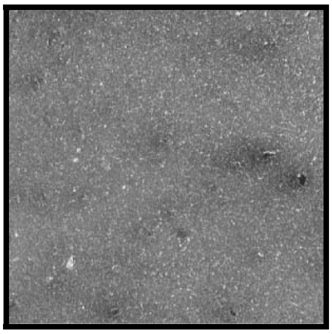


c)

Figure 7. Surface (a), profile (b) and roughness (c) of worn out inner ring raceway



a)



b)

c)

Figure 8. Worn out surface of the inner ring raceway

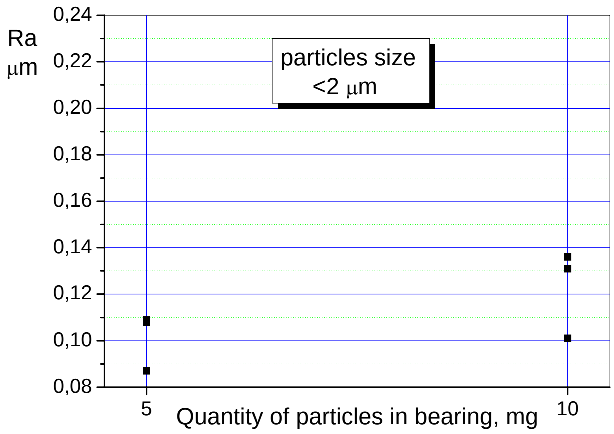
Dependence of arithmetic average deviation of considered contact surface profile R_a on both size and concentration of debris particles in the bearing lubricant is shown on the Fig.9.

Based on shown diagrams, following conclusions could be made:

- roughness of worn surfaces increases with size of abrasive particles;
- roughness of worn surfaces increases with concentration of abrasive particles in bearing lubricant;
- Influence of abrasive particles concentration in bearing lubricant on the contact surfaces roughness is higher when wear is caused by larger abrasive particles.

5.2. Macro geometry

During the abrasive wear, internal dimensions of tested bearings were changed. Diameter of outer ring raceway D_e has become larger and diameter of inner ring raceway D_i and diameter of balls D_w have become smaller due to intensive abrasive wear. Consequently, internal radial clearance was increased and tested bearings have been generating high vibrations and noise during testing.



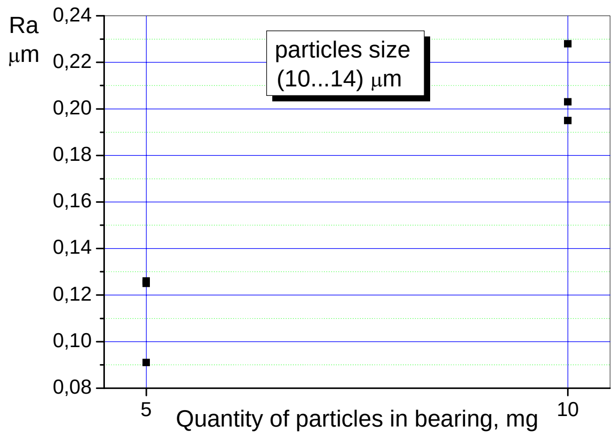


Figure 9. Roughness vs. abrasive particles concentration in the bearing lubricant

Relative changes of both raceways and balls diameters (D_e, D_i and D_w) named as relative wear rate (h_e, h_i and h_w, respectively) are presented in Table 1. Conclusions based on obtained data are:

- with increasing of abrasive particles concentration in the lubricant, wear rates of all worn out bearing parts are increased;
- balls are worn out much more than raceways and this is in accordance to results presented in [3].

Table 1. Relative change of bearing internal dimensions

Abrasive particles size, μm	Relative wear rate, %	Abrasive particles concentration, g/l	
		1.25	2.50
≤ 2 μm	h_e	0.010	0.020
	h_i	0.003	0.008
	h_w	0.400	0.100
(10...14) μm	h_e	0.003	0.008
	h_i	0.005	0.006
	h_w	0.500	0.960

Measured values of internal radial clearance of tested bearings worn out with different concentrations of abrasive particles in the lubricant are presented by diagram in Fig.10 [4].

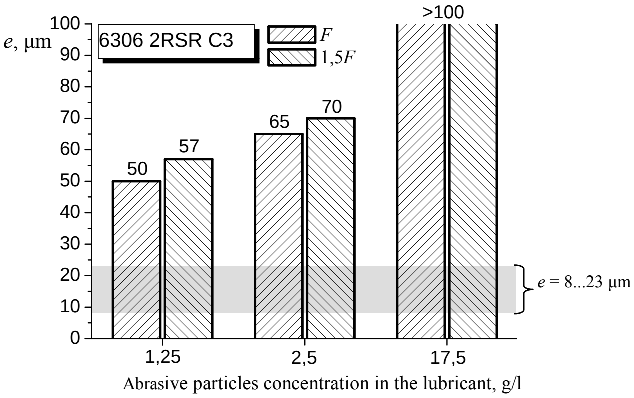


Figure 10. Internal radial clearance vs. abrasive particles concentration in the lubricant and external radial load

In this diagram, wear by particles with size ≤ 2 μm is considered. In the case of wear by particles with size (10...14) μm, internal radial clearance in all tested bearings was larger than 100 μm. Based on shown diagram, the following conclusions can be made:

- with increasing of abrasive particles concentration in the lubricant, internal radial clearance is increased;
- with increasing of external radial load of the bearing, gradient of internal radial clearance increasing is larger.

6. CONCLUSION

This paper is focused on analysis of ball bearing internal geometry change caused by abrasive particles present in lubricant. Carried out analysis shows that roughness of worn surfaces depends on size and concentration of lubricant debris, as well as on change of internal radial clearance. A cause of this phenomena is mechanical acting of abrasive particles on the contact surfaces - micro cutting. The roughness of bearing parts contact surfaces is increased with both particles size and particle concentration increasing. Micro damages appeared on the contact surfaces could be stress concentration raisers and this could lead to rapid fatigue and decreasing of bearing service life. By abrasive acting of debris particles, diameters of raceways and balls are changed. The wear of balls is dominant. With increasing of abrasive particles concentration in the lubricant, the internal radial clearance of the bearing is increased. Consequently, the bearing is lost operational ability generating abnormal vibrations and noise.

7. REFERENCES

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