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NONDESTRUCTIVE TESTING OF ROLLING BEARINGS

Engineering

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ABSTRACT

This paper presents the investigation results of lubricant ability of the materials and kinetics of the physical and chemical processes proceeding in boundary lubrication layers (BLL). The models of contacts at boundary friction are shown. The theoretic estimation of value nanometer thickness range of BLL at tunneling conductivity has been made. The electrical circuits for nondestructive testing of the rolling bearings are presented. The criteria for estimating the lubricity of grease lubricants at boundary friction are developed. The operating modes of the rolling and sliding bearings are determined.

KEYWORDS

rolling bearings, boundary lubrication layers, nanometer thickness, electrical circuits of nondestructive testing, criteria.

1. Introduction

The using of electrical probing method for diagnostic of the rolling bearings is considered in this paper. The main problems of diagnostic are: detection of rejects at the entrance control of the rolling bearings in the absence of lubricant in them; detection of a poor-quality greases; creation of the invariant criteria, which allow to gain the objective information about the state and kinetics of the physical and chemical processes proceeding in boundary lubrication layers (BLL) at dynamic loading of the bearings [1].

A contact electric conductivity of the rubbing metal pairs is extremely sensitive to different surface films (adsorbed, oxide, lubricating, etc.) found in the friction zone [2-6]. Therefore, various methods in the field of research are used to analyze the conditions of interfaces in terms of contact conductivity parameters, particularly the contact resistance Rc [7-11]. The quantum effect of the penetration of electrons through a barrier of nanometer thickness and the expression for the dependence of the tunneling conductivity on the thickness of the dielectric lubricating layer is described in these articles [11-17]. At low voltage (up to 0.1 V) the main mechanisms of contact conductivity within the temperature range typical of lubricated tribosystems are discussed in the articles [18, 19]. The analysis of the main types of contact conductivity at friction tests of lubricated point contacts show the feasibility of using the contact resistance method for thermal tests of BLL. The contact resistance method is especially effective for analyzing interfaces formed by metallic spot clusters inside the contour area or interfaces separated by a continuous lubricated film (up to 2 – 3 nm thickness) [18, 19]. In this case, at temperatures typical for real lubricated friction units, the thermoelectronic and intrinsic lubricant conductivites are negligible and the analysis of experimental data can be done using the theory of tunnel conductivity and constriction resistance theory, with account taken of the electrical properties of the oxides [18, 19].

Three types of layers (films) are known to be formed on the mating surfaces at friction under boundary lubrication regime [20–22]: a) physically adsorbed layer (A-layer) of lubricant molecules quite weakly bonded with the surface; b) more strongly bonded with the surface chemisorbed layer of organic deposits (D-layer) formed predominantly by lubricant destruction products; c) chemically modified layer (M-layer) on the base metal formed as a result of direct reactions between additives and metal. In general case, all three layers can exist in the friction zone, the role of each one can be integral depending on operation parameters, nature of lubricant and used metals. Model experiments which combine measurement of friction and electrical characteristics in static and dynamic nominally point contact, confirm that chemically active additives like, dithiophos phates can form chemisorbed layers of deposits (D-layers) on a moderately hot surface (T ~ 200 ºC) of noble metals [23, 24]. At contact pressures typical for contact spots, very thin residual D-layers are preserved in the contact clearance only. These layers, however, have quite high load bearing capacity and lubricating properties providing the friction coefficient decrease and metal surfaces protection from wear at room temperature [23, 24]. The electrical probing method was used for qualitative evaluation of physical and chemical process to the point contact and do not used for quantitative analysis of BLL with thickness up to ≈ 2 – 3 nm [18, 19].

2. Experimental details

Objects of the study were rolling bearings (Fig. 1) of different production: 1 – APP 6203RS (represented by the Russian trademark "APP groups"); 2 – 6-180203 C17 (represented by the Russian trademark "GPZ"); 3 – 6202-2RS d16 C3 (Perfect fit industries, inc. Florida, USA), 4 – ZVL 6302/16 (Slovakia).

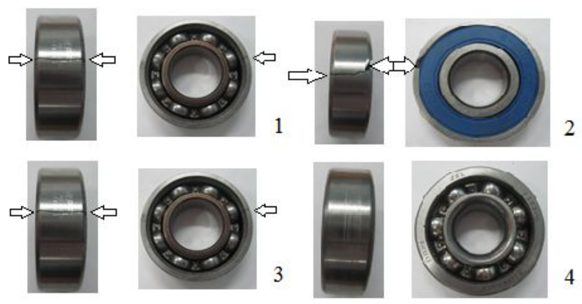


Figure 1. The bearings are: № 1 – APP 6203RS (RF); № 2 – 6-180203 C17 (RF); № 3 – 6202-2RS d16 C3 (Perfect fit industries, inc. Florida, USA); № 4 – ZVL 6302/16 (Slovakia).

The bearing inspection was carried out on the developed stand using the thrust-radial scheme of load. The block-scheme of stand is shown in figure 2. The measurement module controlled the rotation drive and records the friction coefficient, temperature, contact resistance (R_c) and acoustic signal. The four-wire circuit with voltage 50 mV in the open contact and current ≤ 1 mA through the closed contact was used for measurement R_c.

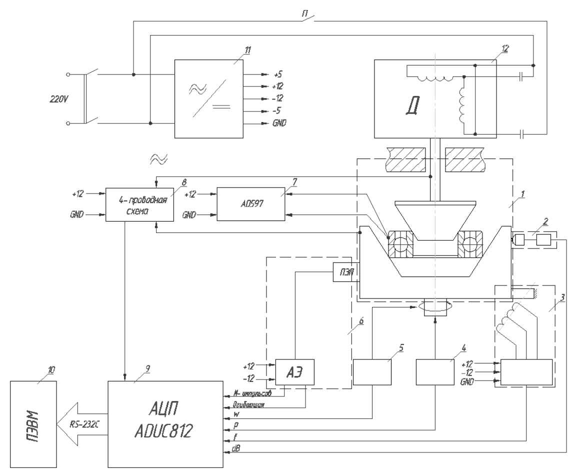


Figure 2. The block scheme (direct) of the stand: 1 – friction unit; 2 – vibration meter; 3 – friction force measurement system; 4 – load

mechanism; 5 – velocity unit; 6 – acoustic meter; 7 – temperature meter; 8 – contact resistance meter; 9 – analog-digital converter (ADC); 10 – PC; 11 – block of voltage; 12 – electric motor.

Resource testing of the rolling bearings were conducted with using of SMT-1 at load ≈ 2000 H and velocity bearing ≈ 0.5 m/s, where the bearing was fixed on the driving shaft. We prepared the new basic scheme (fig. 3) to define tribotechnical properties which allows to carry out voltage drop measurement in the bearing directly at its operation [1].

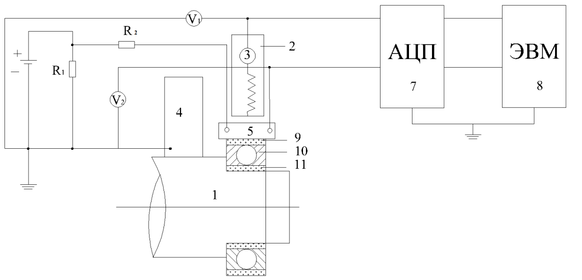


Figure 3. The block scheme (direct) of the device for rolling-contact bearing diagnostic: 1 - shaft; 2 - loading unit; 3 - load cell; 4 - first current collector; 5 - second current collector; 6 - constant-current source; 7 - analog-digital converter (ADC); 8 - personal computer; 9 - inner (outer) race; 10 - lubricant; 11 - inner race; R1 - resistance; R2 - calibrating resistance.

The parameter of contact resistance value (Rc) between racers using for diagnostic real bearing units is offered. The value of a contact resistance Rc was measured with using of the four-wire circuit [5].

3. RESULTS AND DISCUSSION

3.1The theoretical calculation is offered. When low voltage *(U<50 ... 100 mV)* is applied on the metal electrodes, the thin separating lubricant layer can be considered a potential barrier with the effective work function φ and the effective width being equal to the clearance d. The values of electrical conductivity per unit area σ and contact resistances Rt for the mating surfaces of rolling bearing at boundary friction and various thickness values of lubricant layer d, are calculated by the formulas (1) and (2) [25].

$$\sigma = \frac{e^2}{h^2 \cdot d}\sqrt{2 \cdot m \cdot \varphi}\ \exp\left(-\frac{4\pi d}{h}\sqrt{2 \cdot m\varphi}\right), \quad (1)$$

where e is a charge of electron, m is a mass of electron, h is a Planck's constant, φ is an effective work of electron, d is a distance between the electrodes.

The simplified expression for calculation of a tunnel contact resistance is given (2) [18, 19].

$$R_t = \left(\frac{10^{-14} d}{a^2 \varphi^{1/2}}\right) \exp\left(10{,}24\varphi^{1/2} d\right) \quad (2)$$

where φ is an effective work of electron, measured in eV, d is a boundary lubricant layer thickness (BLL), measured in nm.

An effective work of electron at BLL thicknesses less than 1.5 nm is 2.025 eV, and at 2.0–3.0 nm is 1.8 eV [18, 19].

For nondestructive testing of rolling bearings it is necessary to estimate the thickness BLL with using the expression (2). First it is necessary to count the actual contact spot (a) radius and the real contact area (S) proceeding from relationships of the classical Hertz theory (3).

The way consists in calculation of contact resistance value (Rc) between racers on the basis of Hertz theory relationships [11]. Here is an example of theoretical calculation. The object of research is rolling-contact bearing ZVL 6302/16 (Slovakia) with an external diameter of a race 42 mm and an inner race diameter 16 mm, width of races - 13 mm, diameter of a ball - 8 mm, quantity of balls - 7 pieces, the way width of an inner and outer race- 6 mm.

For methods of electrical probe the question on definition of the actual square of contact rubbing solids has a key value. Calculation of the nominal contact square of the conjugate solids is carried out from relationships of the classical Hertz theory. The contact ball square (S) with a racer makes an ellipse with semiaxises a* and b (figure 4) where the major semiaxis a* is directed perpendicularly to a rolling motion way (a rolling motion direction).

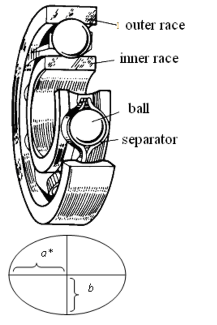


Figure 4. The rolling-contact bearing. The contact square in the form of an ellipse with semi axis a* and b.

The contact point radius of the ball with a plane a* is defined by value of load, mechanical properties of solids and their geometrical sizes and estimates from relationships for an elastic deformation of solids (3) [11]:

$$a^* = 1{,}11(NR/E)^{1/3}, \quad (3)$$

where N is a load, R, E is an effective radius and an elastic modulus, accordingly. An effective radius R is calculated by the formula (4) [26]:

$$\frac{1}{R} = \frac{1}{R_1} \pm \frac{1}{R_2}$$

where R_1 and R_2 are radii of contacting solids, a sign plus (+) is taken at the contact of convex solids, and a sign minus (-) is taken at the contact of the cylinder and a matching cylindrical groove. As races and balls are made of the same material (steel ШХ-15 or its analogue is most often used) the effective modulus is equal to the steel elastic modulus $2.6 \cdot 10^{11}$ Pa. The counted effective radius R for an outer and inner races makes accordingly $3.3 \cdot 10^{-3}$ and $2.8 \cdot 10^{-3}$ m. Calculated radii values of the contact point (a*) depending on loading (N) for the diagram ball-plane are given in the table 1, where P is a medium contact pressure [1].

Table 1. Calculated radius values of contact point (*a**), medium contact pressure (*P*), contraction resistance (R_s), oxide film (R_{ox}) and general (*R*).

N, H	a* , 10^{-6}, m	*S*, 10^{-12}, m^2	*P*, GPa	R^s, mOm	R^{ox}, mOm	*R*, mOm
20	74.90	17 615	1.1	2.0	56.8	58.8
100	128.10	51 526	1.9	1.2	19.4	19.6
200	161.30	81 696	2.5	0.9	12.2	13.1
400	203.30	129 779	3.1	0.74	7.7	8.4
600	232.70	170 029	3.5	0.64	5.9	6.5
800	256.10	205 944	3.9	0.58	4.9	5.5
1000	275.80	238 846	4.2	0.54	4.2	4.7
1200	293.10	270 118	4.4	0.51	3.7	4.2
1400	308.50	298 841	4.7	0.49	3.3	3.8
1600	322.60	326 782	4.9	0.47	3.1	3.6
1800	335.45	353 387	5.1	0.45	2.8	3.3
2000	347.40	378 956	5.3	0.43	2.6	3.0

It should be noted, that the results given in the table 2, have an approximate character, that is connected on one side with an experimental estimation of imprint lengths, and on another side it is connected with using of Hertz theory relationships where ideal smooth surfaces are observed, without the account of conjugate solids roughness, in our case of races and bearing balls [1].

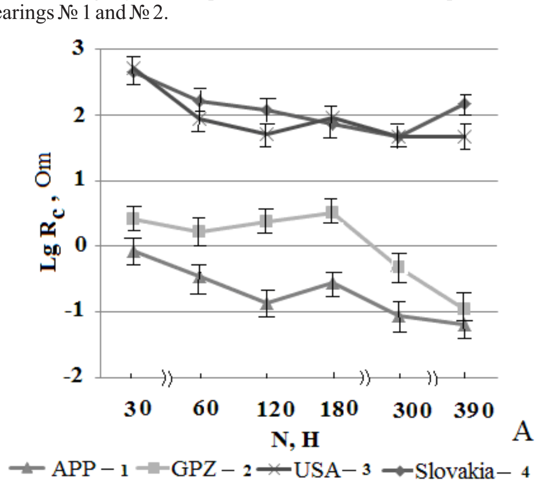
Table 2. Calculated values of parameters for rolling-contact bearings.

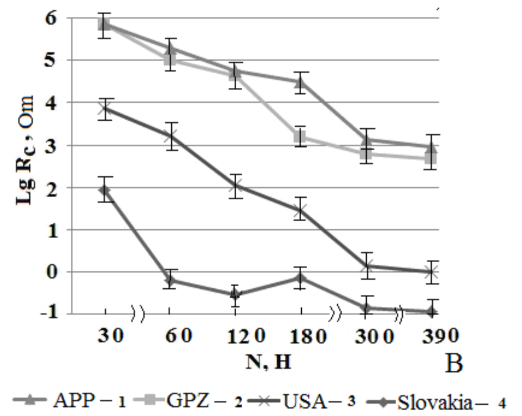
N, H	a, 10^{-6}, m	a*, 10^{-6}, m	b^{inner} 10^{-6}, m	b^{outer} 10^{-6}, m	S^{inner} 10^{-12}, m^2	S^{outer} 10^{-12}, m^2	Pinner, ГPa	Pouter, ГPa	Rs, mOm	Rox, mOm	R, mOm
20	74,90	299,6	69,4	70,0	65288	65852	0,31	0,30	1,0	30,5	31,5
100	128,10	512,4	113,8	120,2	183097	193394	0,55	0,50	0,6	10,70	10,3
200	161,30	645,2	143,3	151,4	290316	306726	0,69	0,65	0,4	6,70	7,1
400	203,30	813,2	180,5	190,7	460897	486943	0,90	0,80	0,36	4,30	4,7
600	232,70	930,8	206,6	218,2	603832	637736	1,00	0,94	0,32	2,27	3,6
800	256,10	1024,4	227,4	240,2	731459	772631	1,10	1,00	0,30	2,69	2,95
1000	275,80	1103,2	244,9	258,7	848345	896149	1,20	1,10	0,28	1,32	2,64
1200	293,10	1172,4	260,3	274,9	958252	1011999	1,25	1,20	0,26	2,00	2,2
1400	308,50	1234	274	289,4	1061684	1121355	1,30	1,25	0,24	1,84	2,1
1600	322,60	1290,4	286,4	302,5	1160452	1225686	1,40	1,30	0,24	1,66	1,9
1800	335,45	1341,8	298	314,6	1255549	1325489	1,43	1,36	0,22	1,55	1,8
2000	347,4	1389,6	308,5	325,9	1346092	1422014	1,5	1,4	0,22	1,44	1,65
Indexes «inner». «outer» are matched to the values, received for internal and outer races accordingly.											

Registered contact resistance value (Rc) achievement to some critical value Rcr, means BLL destruction and decreasing Rc to value, characteristic for the "dry" bearing, measured in the version one by experimental way and calculated in the version two (see table 2).

3.2. The research of "dry" bearings. It has been established that the values of average contact resistance for the bearings № 3 and № 4 are one or two orders of magnitude higher than for the bearings № 1 and № 2 (fig. 5) at a stepped radial-thrust loading of rotating bearings. The values of the contact resistance are determined by the area of the actual contact of the conjugated bodies, which in turn depends on their hardness and roughness, i.e. on the surface treatment method (cementing, nitration, etc.), surface finishing technology and quality of bearing assembly [5, 10, 11].

The defect in form of the crack on the external ring (fig. 1) of each bearing was created by means of mechanical blow. These bearings were under study by electrical probing, acoustics and other methods. It has been established that the average values of contact resistance for bearings № 1 and № 2 with defects is four or five orders of magnitude higher than for the bearings № 1 and № 2 without cracks (fig. 5). It is evidence of increase of the degrees of freedom and loss of stability of the rolling elements. It should be noted that a separator of bearing № 3 fixes more rigidly and keeps the balls in its nests compared with the bearings № 1 and № 2.





Fugure 5. Dependent of contact resistance on load for bearings № 1 - № 4 without defects (A) and with defects in form the crack on the external ring (B).

The use of a broadband filter in the measuring channel of the AE signal in the frequency range of 100 kHz –1.5 MHz makes it possible to register the kinetics of the formation and evolution of the development of cracks in the dynamic loading of a rotating rolling element bearing. It should be noted that the average values of intensity of acoustic emission (AE) for bearing № 3 are in 2–3 times lower in comparison with other bearings in the region of small loads up to 18 H, which indicates its higher technological quality of production. A split bearing generated a signal of AE in loaded condition. The average value of a count rate of AE increased in 2 times. The fluctuation of amplitude of AE increased in five to six times compared to a bearing without defect (fig. 6).

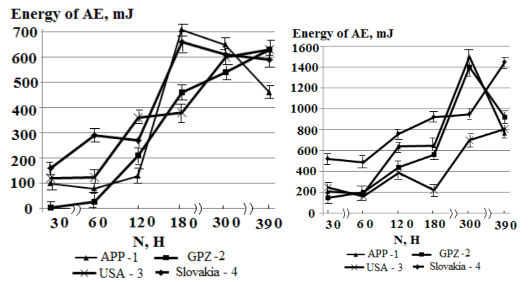


Figure 6. Dependent of energy of AE on load for bearings: № 1 – № 4 without defects (A) and with defects (B).

Dependences of contact resistance (R_c) from time (fig. 7) for two bearings at loading 2000 N are various. The surface of races, manufactured by Slovakia, passes following stages: steams adsorption of solvent elements moisture accompanied by insignificant increasing of R_c level; destruction of adsorbed steams and oxide film to level, characteristic for constriction resistance; intensive surface oxidation with change of chemical compound and structure of oxide film with γ-Fe_2O_3 (white colour) to α-Fe_2O_3 and Fe_3O_4 [27]; elastic energy accumulation in the subsurface layer and formation developed dislocation structure, accompanied by an union of microcracks in macrocracks and sliding strips [28]; the selective mechanism of surface deterioration, proceeding by means of great material volumes separating in the form of petals and a juvenile surface revealing, that leads to level R_c decreasing to the constriction resistance level, wedging of the bearing [29].

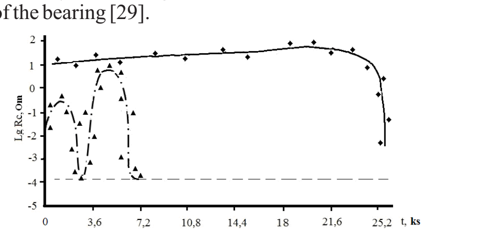


Figure 7. Dependent of contact resistance (Rc) on time for "dry" bearings at loading 2000 N: ▲ZVL 6302/16 and ◆6202-2RS d16 C3. The calculated contraction resistance value for loading 2000 N is shown by a dotted line (--).

We can assume the following bearing process technology 6202-2RS d16 C3. It is known, that the less grain size, the above steel strength and back-to-back endurance. The initial microstructure of bearing steel, characteristic for fine-grained pearlite is represented in fig. 8, arrow 3, reinforced layer (≈ 20 microns) arrow 1 and transitive structure, arrow 2.

High hardness on the surface provides low propensity to scuffing; high fatigue limit; high cavitations durability and good resistance to corrosion in atmosphere. Besides the reinforced layer is well grounded and polished, as evidenced by electronic microscopic picture of race surface (fig. 8,) and parameters analysis of surface roughness with using AFM (fig. 9) testifies.

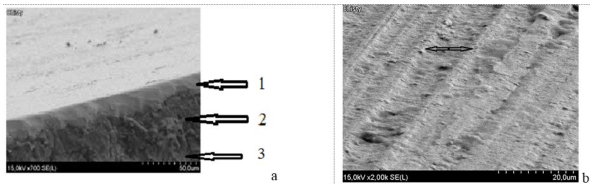


Figure 8, a and b. Electronic microscopic picture: a - race cleavage; b - tool marks on race surface 6202-2RS d16 C3.

On the electronic microscopic picture of the race surface we can observe clearly visible characteristic parallel each other tool marks along rolling paths on treated surface (fig. 8, b). The distance between them makes ≈ 8–12 microns (fig. 8, b, arrows).

It is known, that the higher a roughness class of inner race surfaces, the less is mechanical component of friction factor and therefore is more long a resource of bearing work [1]. Analysis AFM of the outer race surface image (fig. 9) shows, that the maximum heights spread (Rq) makes ≈ 2.8 microns.

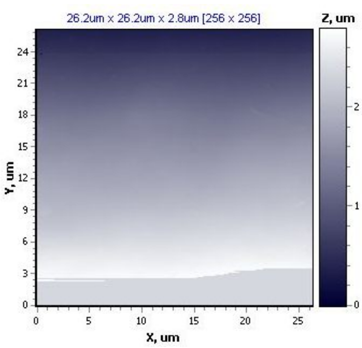


Figure 9. AFM the inner surface image of the outer race 6202-2RS d16 C3.

The multicyclic radial bearing loading (2000 N) 6202-2RS d16 C3 leads to microcracks formation on races surface which will increase in sizes, unit and form macrocracks. As a result of wear fragments separation pits, and hollows are formed on the surface, i.e. the pitting is observed [1]. The mechanical component of friction factor increases, that leads to an unimportant increasing of friction factor on a time section t = 11 – 16 ks (fig. 10).

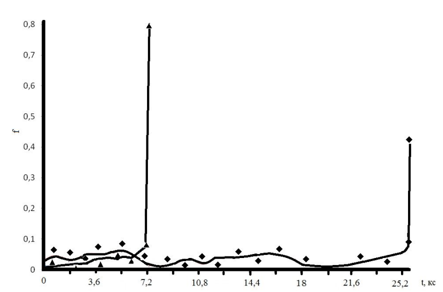


Figure 10. Dependence of friction factor (f) on time (t) at loading 2000 N for "dry" bearings: ▲ZVL 6302/16 and ◆6202-2RS d16 C3.

Sharp temperature drop (fig. 11) at time of order 20 ks is possible to explain by destruction of first mechanically strong coating layer.

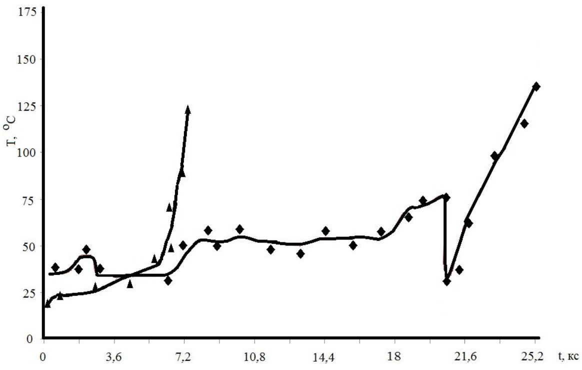


Figure 11. Dependence of temperature (T) on time (t) at loading 2000 N for "dry" bearings: ▲ZVL 6302/16 and ◆6202-2RS d16 C3.

It is obvious, that the heat conductivity of the second layer is higher than of the first layer that has led to substantial growth of the heat removal and as consequence to temperature decreasing ≈ 50° C. This layer does not possess high strength properties that lead to its destruction and increasing of friction factor and temperature. The adhesive and mechanical component of friction factor monotonously increases. Losses for displacement between molecules of a lubricant layer increase that leads to monotonous increasing of temperature. Bearing wedging can be observed at t = 25.2 ks, accompanied by sharp increasing of friction factor. It is necessary to note, that to reduce bearing 6202-2RS d16 C3 test time the speed of its turning (in terms of linear speed from 0.5 m/s to 1.5 m/s) has been increased three times.

The bearing 6202-2RS d16 C3 operating modes differ from operating modes of the bearing ZVL 6302/16. The first stage is characterized by elastic energy accumulation in the subsurface layer and formation of developed dislocation structure, accompanied by a union of microcracks in macrocracks and a sliding strip, at that contact resistance level increases monotonously, that can be caused of simultaneously proceeding surface oxidation process (fig. 7). The decreasing of level R_c, but not up to contraction resistance level (fig. 7) with simultaneous friction factor increasing at bearing wedging to 0.45, instead of to 0.8 (fig. 10) testifies that steel surface destruction (the second stage) proceeds, but not so intensively, as at the selective wearing mechanism as the metal juvenile surface is not revealing (the contraction resistance level will not attain and the friction factor is well below, than for the bearing ZVL 6302/16). At the juvenile surface revealing the adhesive component of friction factor is considerably higher for account of conjugate surfaces. The third stage is the bearing wedging.

Thus, the bearing 6202-2RS d16 C3 work resource is six times higher in comparison with the bearing ZVL 6302/16, that testifies about dominant role of method and thermal treatment of friction surfaces taking into account constructional features.

It has been established that the sensibility of the probing electrical method is higher in comparison with the AE method. This circumstance can be explained by the higher sensitivity of the probing electrical method to the change of the state of metal surface. By increasing the degree of sensitivity to changes of the state of metal surface of a bearing, the using methods can be defined to range: the temperature method, the registration of a coefficient of friction, the AE method, the electrical probing method. Timely culling of bearings by physical methods allows to make input control and to prevent a damage of equipment.

3.3. The study of the bearings at a boundary friction.

For an estimation of tribotechnical properties of boundary lubrication layers (BLL) researched the complex sulfonate calcium greases: 1) ITMOL LC HD - (manufactured by Belarus, the technical condition (ТУ BY 100029077/036-2010)); 2) OIMOL KL EP 2 (manufactured by Belarus); 3) OIMOL KSC WR 2 (manufactured by Belarus, ТУ BY 190410065/017-2014); 4) LGBH-2 (manufactured by Total, Holland) and 5) Prolong (manufactured by USA); 6) Litol-24 (manufactured by Russia). Contact resistance and load relation illustrated in Fig. 12. The thickness of BLL calculated with using the formula 2 and according to the data (table 1 and table 2). The thickness of BLL is ≈ 2 nm for each grease (Fig. 12).

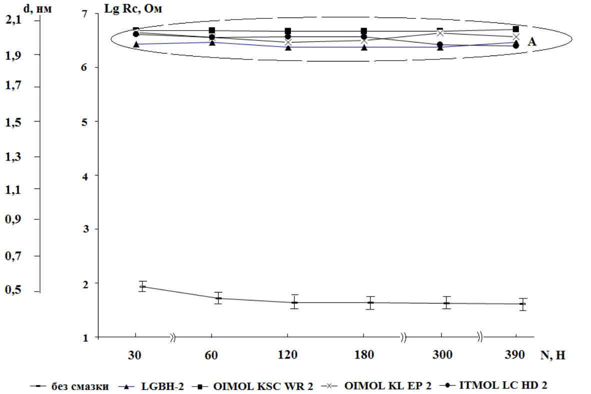


Figure 12. Dependent of contact resistance on load for the greases: LGBH-2; OIMOL KSC WR 2; OIMOL KL EP 2; ITMOL LC HD 2.

The experiments on measuring the friction and electrical characteristics have shown that the BLL produced by the grease LGBH-2 (D-layer) retain a sufficiently high load-carrying capacity and lubricity up to 2000 N (fig. 13).

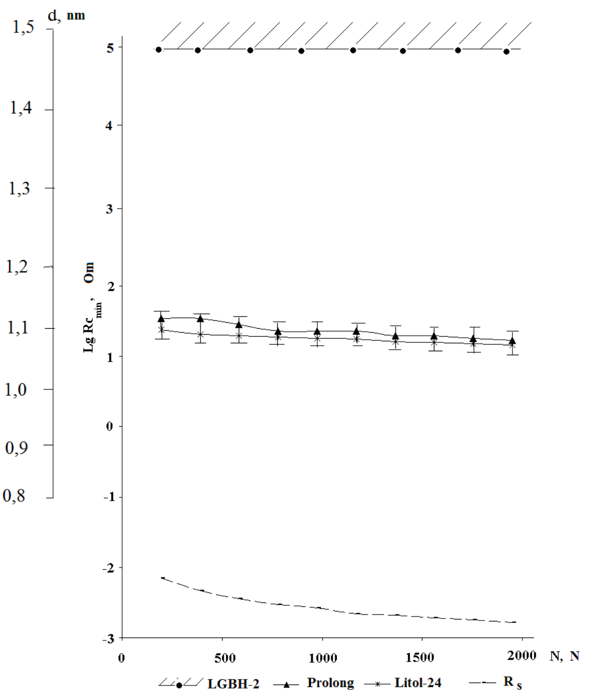


Figure 13. Dependent of contact resistance on load for the greases: LGBH-2; Prolong; Litol-24.

The values of constriction resistance (Rs) are calculated on the basis of Hertz theory (table 1 and table 2). The formation of D-layers reduces the friction coefficient and protects metallic surfaces against direct contact and wear.

The analysis of the experimental data indicates that formation of D-layers produced by chemically active additives may exert a governing effect on behavior of the friction contact under service conditions preventing the generation of the chemically modified layers on the friction surface by direct reactions with additives [8, 30].

It is necessary to calculate the module Young for the BLL formatted by the grease LGBH-2 to inner race surface of the bearing 6202-2RS d16 C3 at load of 2000 N and t = 22 ks. It is noted that module Young may be calculated by formula [31]:

$$E = \sigma \frac{l}{\Delta l} \qquad (5)$$

where σ is normal stress, Δl/l is relative elongation. It is known that a normal stress is ratio of strength to area. The load is 2000 N and the area of a contact of ball with race is ≈ $1422014 \cdot 10^{-12}$ $м^2$. The normal stress (σ) is ≈ 1.4 GPa.The thickness of D-layer formed with grease LGBH-2 was calculated by analyzing the parameters of surface roughness for the original ring of the bearing without grease and formed with D-layer. The average height of surface of ring without grease is 1.1 µm. The average height of surface of ring with D-layer is 1.7 µm (fig. 14). The thickness of D-layer formed with grease LGBH-2 is 0.6 µm.

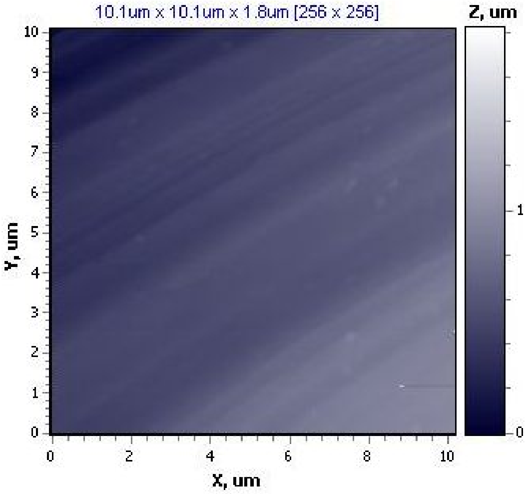


Figure 14. AFM image of topography of inner surface of ring the bearing 6202-2RS d16 C3 with formed D-layer.

The analysis of electron microscopic image of the ring of bearing has shown that the thickness of D-layer ≥ 278 nm (fig. 15).

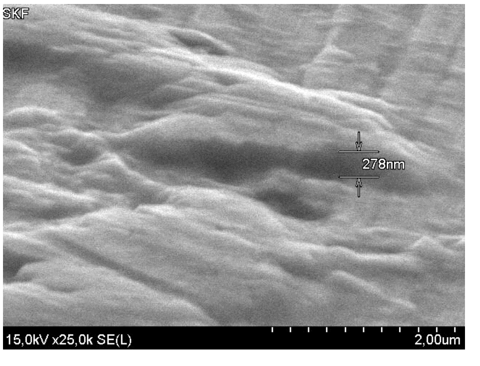


Figure 15. The electron microscopic image of the ring of bearing with formatted D-layer by the grease LGBH-2.

The registration values of contact resistance (Rc) > 105 Om at the load 2000 N for D-layer formatted by the grease LGBH-2 (fig. 13). The thickness of D-layer is ≈ 1.5 nm (fig. 13). The change of length (Δl) of D-layer is ≈ 598.5 nm. The ratio of the change of length of D-layer to the original length (Δl/l) is ≈ 1. The value of module Young for formatted D-layer by the grease LGBH-2 is ≈ 1.4 GPa, which is comparable to modulus of elasticity of rubber ≈ 5 GPa. The formed D-layer has a high load-carrying capacity and frictional properties.

It can be assumed that the high strength and friction properties of formed D-layers at comparatively low (room) temperature cause a significant increase in the time period (up to 4 times) of the cycle between hardening and destructing [32]. This fact explains the wear reduction. In the course of the friction loading, the microstructure is transformed, first into texturized elements shaped as thin dislocation lines, and subsequently into slide lines and a lamellar mesoscopic structure. Microcracks are generated along the boundaries of these lines that coalesce into main cracks, accompanied by the formation of material wear blades [33]. A mutual relationship has been established between the dislocation structure kinetic and wear intensity. It has been shown that the recurrent peaks of wear intensity are synchronous with the low points in the dislocation density curve [34].

The formation of the chemisorbed layer can facilitate the plasticization of metal subsurface layer and reduce the dislocation density and wear [35, 36].

4. CONCLUSION

The substantiation of using the electro physical probing methods for estimating of the operational properties of rolling bearings on a state of BLL and the surface of bearing steel is given. The electrical circuits and the techniques have been developed that make it possible to assess the tribological properties of BLL. The method makes it possible to investigate the kinetics of formation and destruction of BLL directly in real bearing assemblies during their operation. The values of contact pressures in the ball bearing ring system were calculated with relations of the Hertz theory. The dependences of constriction and contact resistance on the average contact pressure are established. The estimate of thickness of D-layers formed on inner and outer rings of the bearing is made.

The operating regimes of rolling bearings are determined. The following regimes of rolling bearings state are established: formation of monomolecular and polymolecular chemisorbed lubricating layers (D-layers) on bearing rings; regime of dynamic equilibrium between the formation and wear of lubricating layers; destruction of D-layers and the predominance of a "dry" non-lubricated contacting regime; regime of intensive oxidation of contacting surfaces and an accumulation of elastic energy of friction loading; regime of a wear of surfaces; regime of intensive selective wear; wedging of an bearing. Each operating regime of bearing corresponds to the certain type of dependence of contact resistance, friction coefficient and temperature. For example, reduce of the values of contact resistance to level ≈ 0.2 – 0.5 mOm characteristic for the bearing ZVL 6302/16 without grease mean the beginning of destruction of a monomolecular component of BLL. A reduce of the values of contact resistance to level ≈ 1mOm mean the beginning of oxidation, formation of a dislocation structure, it dispersion and increase of dislocation density. The result of these processes is selective wear of surface of and destruction of a bearing. The establishment of these criteria values allows spending the testing of rolling bearings during its operation. The result of the diagnosis can be the recommendation about replace of a grease or restrict the operating regime of machine or mechanism before begin it destruction. It has been established experimentally that the level of values of contact resistance for the bearing 6202-2RS d16 C3 production of USA (Perfect fit industries, inc. Florida) and for the bearing ZVL 6302/16 production of Slovakia are an order of magnitude higher than the values of contact resistance for the bearing APP 6203RS (manufactured by the People's Republic of China and represented by the Russian trademark "APP groups") and the bearing 6 180203 C17 (manufactured by KNR and represented by the Russian trademark "GPZ"). Level of the average values of intensity of acoustic emission (AE) for the bearing 6202-2RS d16 C3 is the lowest. This fact points to the high technology production of this bearing. It is established that the service life of the bearing 6202-2RS d16 C3 is five to six times higher compared to the service life of the bearing ZVL 6302/16 at load 2000 N. This fact is determined by: 1) the technology of surface treatment of rings (the nitriding); 2) homogeneous structure of the surface layer of rings; 3) the maximum height (≈ 2.8 μm) of the irregularities of a treatment traces; 4) quality of bearing assembly.

It has been established that with defect of ring bearing the level average values of contact resistance increase to two orders with compare of the level average values of contact resistance without defect. The level of average values of intensity of acoustic emission (AE) increase in 2 times in this case. It is shown that the sensitivity of the electrical probing method is higher with compare of the AE method. This circumstance can be explained by the higher sensitivity of the probing electrical method to the change of the metal surface state. By increasing the degree of sensitivity to changes of the state of metal surface of a bearing, the using methods can be defined to range: the temperature method, the registration of a coefficient of friction, the AE method, the electrical probing method. Timely culling of bearings by physical methods with using of developed the stand allows to make input control and to prevent a damage of an equipment.

The formation of chemisorbed layer (D-layer) most clearly observed for the grease LGBH-2. The estimation of thickness of D-layer (≈ 600 nm) was carried out by AFM method and electron microscopic without loading. The thickness of D-layer was ≈ 1.5 nm at the friction load ≈ 2000 H. The value of module Young for formatted D-layer by the grease LGBH-2 is ≈ 1.4 GPa, which is comparable to the modulus of elasticity of a rubber ≈ 5 GPa. The formed D-layer has high load-carrying capacity and frictional properties. The polymolecular component of D-layer was not destroyed as evidenced by the high level of values of contact resistance ≈ 105 Om. The chemical composition of this D-layer was determined by Raman spectroscopy. It is found that it contains the complex of sulfonate-calcium compounds. An operational properties of the greases Prolong, Litol-24 and LGBH-2 was investigated. It was established that in order to increase the strength, friction properties they can be aligned: Prolong and Lithol-24 (GOST 21150-75) and LGHB-2. It has been experimentally established that the complex sulfonate-calcium greases ITMOL LC HD (ТУ BY 100029077/036-2010), OIMOLKL EP 2, OIMOL KSC WR 2 (ТУ BY 190410065/017-2014) developed in the Joint Institute of Mechanical Engineering, Minsk, Belarus, are not inferior by tribotechnical properties to the known world analogue LGBH-2. The grease ITMOL KSC WR 2 used for high-loaded rolling bearings forms the chemisorbed layer with the thickness ≈ 2.1 nm on the rolling bearing rings, which indicates its high strength properties. The use of developed greases allows to increase at least twice the service life of rolling bearings, which will significantly reduce the number of equipment failures and costs for its repair. In addition, the use of developed greases helps to reduce energy consumption and, consequently, to solve environmental problems.

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