The use of greases with ultrafine diamond-graphite powder to reduce a fatigue wear of rolling bearings

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Abstract. The present paper shows the results of studies on the use of the plastic lubricants with ultrafine diamond-graphite powder in rolling bearings. Even with a short-term tightening of the operating mode, it is possible to establish a friction boundary mode by squeezing the lubricant out of the rolling parts contact zone with the ring tracks, which leads to an increase in the friction torque and temperature. Reducing slippage, lowering the working temperature, limiting the friction torque can be achieved by improving the antiwear and anti-friction properties of the lubricants used. Tribological studies have established that the introduction of the ultrafine diamond-graphite powder into the composition of basic industrial lubricants significantly improves their performance. The introduction of ultrafine diamond-graphite powder into a lubricant reduces the amount of rolling bearings wear up to 1.6–1.8 times, reduces the amount of friction torque to 23–25%. The presence of a lubricant that can significantly reduce friction forces, reduces the amount of internal stresses and delays the fatigue cracks progress, which allows to increase the service life of rolling bearings by 1.5–2 times.

1. Introduction

The service life of rolling bearings is highly associated with reduced wear of rolling elements, cage and rings. During operation, parts of the bearing are subjected, to varying degrees, to all sorts of wear, causing the bearing to fail. A variety of factors related to the bearing assembly operation can lead to abrasive wear, fatigue wear of the rolling bodies and rings, scuffing and hardening of the surfaces, which are caused by heating in the event of a lubricant lack, wear of the rolling bodies and rings during slippage, wear and destruction of sockets and guides separator sides, fretting corrosion. [1]

Rolling bearings under normal conditions and operation modes most often fail due to fatigue damage to the contacting surfaces [2]. Here, lubricants and their proper selection are represented by separate factors that affect the life of rolling bearings. In most cases, the fatigue failure of bearing components begins on the surface of the rings. By reducing the friction force in the contact zone, the process of the fatigue cracks formation is modified from surface to deep, which increases the operation time of the bearing supports before the start of fatigue failure [3].

One of the methods for improving the lubricating properties of plastic lubricants remains the introduction of various kinds of additives. In recent years, considerable attention has been given to nanophase materials powder with special properties. Ultrafine materials with 10–60 nm particle sizes, such as diamond-graphite powders (UDD-G), capable of creating a screening layer in the contact area, reducing the value of the friction coefficient, changing the surface microgeometry and reducing the contact pressure, have been widely used [4-6]. These substances have been used as functional additives in lubricant compositions used in various friction units [7-10].

In the present paper, the individual results of experimental studies carried out in the framework of studying the UDD-G tribological properties and the possibility of its use for lubricating compositions based on plastic lubricants used in rolling bearings are presented.

The purpose of the research is to study the effect of ultrafine diamond-graphite powder on the antiwear and antifriction properties of grease lubricants.

2. Experimental study

Comparative evaluation of the tribological properties of lubricants was carried out on the laboratory installations which simulate the operation of the assembly with rolling bearings (Figure 1). Samples were angular contact bearings of type 7206A with tapered rollers that were loaded with an axial load from 1 kN to 2.5 kN. The inner ring of the bearing rotates unidirectionally with a frequency of 960 rpm.

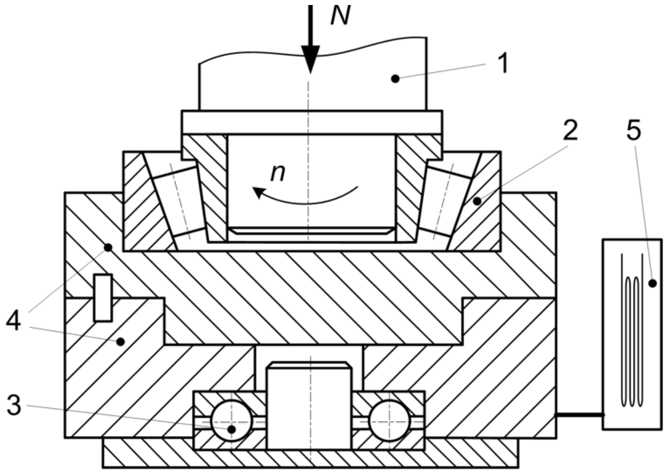


Figure 1. Test pattern for rolling bearings: 1 – drive shaft, 2 – test bearing, 3 – thrust bearing, 4 – body, 5 – tensiometer.

To create a lubricant composition was selected lithium grease TSIATIM-201 (similar to US product NLGI-2).

Ultrafine diamond-graphite powder used as a filler is a carbon-containing condensed product obtained by the method of detonation synthesis in carbon dioxide (TU 40-2067910-01-91). The powder used to introduce the lubricant is a carbon mixture with a particle size from 7 to 60 nm. The share of graphite was up to 80% of the explosion product, the rest is in the form of a highly-dispersed diamond-like phase. The concentration of the powder in the lubricant compositions was 1 mass %, as the most optimal for lubricants [6, 11].

The effectiveness of the solid additives use in lubricants was evaluated by the amount of rolling bearings wear and the magnitude of friction moments. Wear was determined by the gravimetric method every 3 hours of testing. Before testing, the weight of the bearing was measured, then the bearing was packed with a test lubricant. The friction forces at the contact area were determined by a strain gauge.

Studies of the stress state of the bearing contacting parts were performed using a computer model of the cylindrical roller contact with a slip area in the presence of friction forces developed using the ELCUT software package. Tangential and normal stresses along the contact area, as well as their distribution over the track depth, were evaluated. A contact model was considered for roller moving on the elastic base with slippage taking into account tangential loads acting at the contact area, the conditions for deforming the surface layer satisfy the hypothesis about the elastic properties of the material (Figure 2).

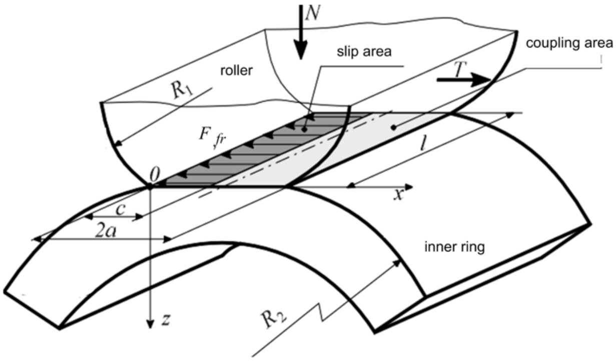


Figure 2. Calculation diagram of the roller-ring contact model.

The proposed model of contact is based on the provisions of the Hertz and elastic-hydrodynamic theory of contact, and also takes into account the operating conditions of roller bearings for boundary friction mode [2, 11]. The contact surfaces were set between the roller and the rolling surface of the inner ring. In the contact zone there is a Hertz platform of rectangular shape of width 2*a* and length *l*, equal to the length of the roller, formed by elastic deformations.

The contact area consisted of two areas:

- clutch located on the side of the cylinder crowding
- slipping, where friction forces take place.

The coordinate of the point *c* separating these two areas was determined from the formula [11]:

$$c = a \cdot \left(1 - \frac{1}{\pi} arctg \frac{1-2\nu}{\mu(2-2\nu)}\right) \tag{1}$$

where:

- a - half width of the contact area, defined by the Hertz formulas;
- μ - coefficient of sliding friction;
- v - Poisson's ratio.

The size of the platform width at static contact of the cylinder with the plane was calculated by the formula [4]:

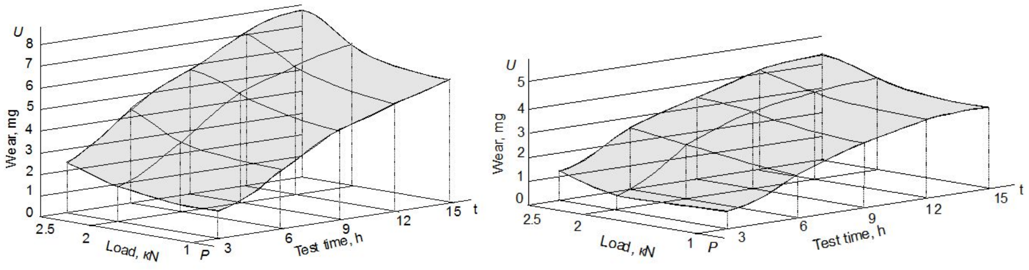
$$a = 0{,}798\sqrt{2pR(\Theta_1 + \Theta_2)} \tag{2}$$

where:

- R - the cylinder radius;
- $\Theta_i = \frac{1-\nu_i^2}{E_i}$ - elastic coefficient;
- E_i - material elastic modulus;
- v_i - Poisson's ratio.

3. Results

Studies have shown that the introduction of additives UDD-G significantly improves the quality of commercially available lubricants TSIATIM-201. Figure 3 shows the results of experiments on the wear of a rolling bearing using standard and modified lubricants.

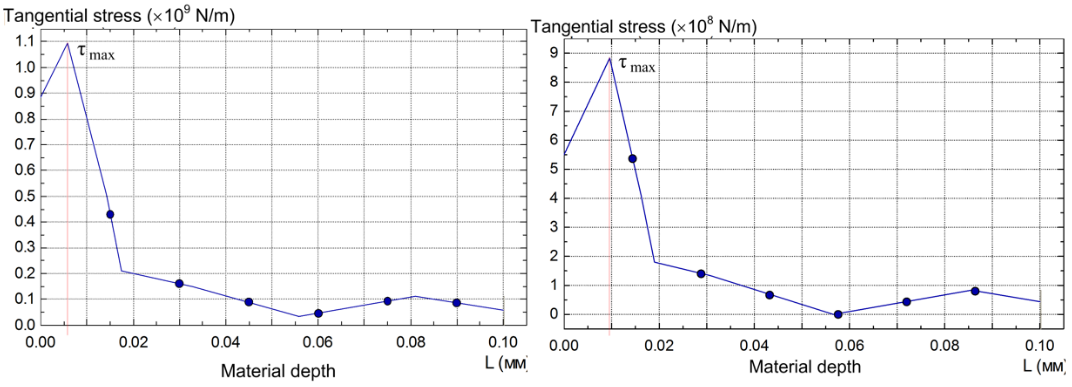


a) b)

Figure 3. Dependence of bearing wear on operating time for TSIATIM-201: a) without additive; b) with the addition of UDD-G.

According to the graphs it can be noted that the best anti-wear properties were observed in greases with UDD-G. Here, the reduction in wear for TSIATIM-201 grease was 1.7–1.8 times as compared to the base.

The dependences of the change in tangential stresses τ over depth l at the contact area shown in Figure 4 are obtained from computer simulation of the contact between the roller and the rollway surface.



a) b)

Figure 4. The distribution of tangential stresses over the depth of the inner ring with friction coefficients: a) $\mu = 0.13$; b) $\mu = 0.09$.

The values of friction forces corresponding to the tangential loads on surfaces are taken on the basis of experimental data. It is noted that in the case of the plastic lubricants use with UDD-G, shear stresses are reduced to 13%.

4. Discussion

For rolling bearings, which use plastic lubricants, the most usual is the mode of boundary friction. As the load increases and the relative sliding speed decreases, the thickness of the lubricant film between the sliding surfaces decreases. In such conditions, the distribution of contact pressure is close to the case of contact without a lubricant. The results of modeling the contact of the roller with the rollway at different values of friction forces presented in the graphs (Figure 4) show that an increase in friction forces in the sliding section causes the maximum tangential stresses to move to the surface in the direction of the friction force, with the maximum shear stresses will be located at a shallow depth or directly on the surface. Under conditions of rolling with slipping and with free slip (at $f > 0.05$), the crack grows closer to the surface or on the surface itself [3].

A noticeable improvement in the performance properties of plastic lubricants with the introduction of UDD-G into them is observed precisely for the friction boundary modes. Under fluid friction conditions, the insoluble and chemically inert powder UDD-G does not affect the change in the composition of the lubricant. In volumes of lubricant, the powder weakly expresses its properties. But with a decrease in the lubricating layer thickness, when a transition to boundary friction is possible, the adhesive abilities to metal surfaces begin to show themselves due to the increased surface energy that the powder particles possess due to the production method. The rather small particle size of the UDD-G allows them to penetrate into the structural framework of the plastic lubricant, which leads to a hardening of the boundary film and an increase in resistance to fracture.

As the simulation results show, the presence of a lubricant with good antifriction properties in the contact area reduces the magnitude of tangential stresses to 18–20%, the maximum tangential stresses under the contact area are shifted inwards, pushing off the beginning of fatigue crack formation on the contacting surfaces, thereby increasing the node operation time.

5. Conclusion

An analysis of the results obtained from laboratory studies led to the conclusion that the introduction of ultrafine diamond-graphite powder into TSIATIM-201 plastic lubricants as a filler increases their antiwear and antifriction properties. The results of computer simulation of the roller contact with the rollway in the presence of friction confirm the theoretical propositions about the effect of ultradispersed diamond-graphite powder on improving the quality of plastic lubricants.

Based on the research results, it can be concluded that greases with UDD-G can increase the service life of the bearing assembly by 1.5–2 times.

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