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Investigation of the tribological properties of ultrafine diamond-graphite powder as an additive to greases

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Abstract. The paper presents the results of studies on the use of plastic lubricants with ultrafine diamond-graphite powder in rolling bearings. Under operating conditions, even with a short-term toughening of the operation mode, it is possible to establish the boundary mode of friction due to the extrusion of lubricant from the zone of the rolling elements contact with the tracks of the rings. This leads to an increase in friction torque and an increase in temperature, which affects the performance of rolling bearings. Reducing slippage, lowering the working temperature, limiting the friction torque can be achieved due to the quality of the lubricants used with improved anti-wear and antifriction properties. Tribological studies have established that the introduction of 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 1.6–1.8 times, the friction torque - to 23–25 %. The temperature of the bearing assembly decreases by 16–20 %. The presence of a lubricant that can significantly reduce friction forces. It reduces the amount of internal stresses and retards the development of fatigue cracks, which can increase the service life of rolling bearings 1.5–2 times.

1. Introduction

The use of a lubricant in rolling units has the following objectives: reducing friction and wear on the surfaces of rolling bearings sliding parts, removing heat and protecting surfaces from corrosion.

But the reduction of friction forces in the contact zone is the most important of these. The emergence of these forces is facilitated by micro-slip of surfaces, as well as differential sliding in the contact zone, caused by design features or influence of external tangential loads. For these purposes, it is possible to use all types of lubricants that can reduce the magnitude of friction forces. However, the mechanism of lubricating action may be different and depends on the conditions of contact [1].

The issue of increasing the durability of bearing assemblies is closely related to the lubricants used in them. Created modern mechanisms require the use of higher quality lubricants, allowing operation of the bearings of the machinery and equipment under increased operating loads, temperatures and speeds without catastrophic consequences for friction units. Lubrication conditions for rolling bearings have a significant effect on fatigue chipping in the contact zone, which is a typical cause of bearing performance loss under normal operating conditions [2].

In most cases, the fatigue failure of bearing components begins on the surface as a result of the occurrence of significant shear stresses, but with a decrease in the friction force in the contact zone, the process of formation of fatigue cracks changes from surface to deep. This increases the time to fatigue failure of the tracks and rolling elements of bearings [2, 3], wherein the speed of the wear process depends on the lubricant properties and the lubricant film thickness.

In addition to the creation of absolutely new brands of lubricant, the method of modifying existing substances by introducing various agents that improve the tribological properties and their composition has been widely used recently. Plastic lubricants modify mainly due to the introduction of fillers, representing solid fine-dispersed materials, insoluble in the dispersion phase, which, when toughening of operating conditions, should provide the lubricant with high antifriction and anti-wear properties. The used materials are diselenides and molybdenum disulfides, graphite, talc, metal powders, polymeric materials and other substances capable of increasing lubricating properties [4-7]. However, the long-term use of such materials has revealed their shortcomings, which are determined by significant wear of the mating surfaces, the appearance of stresses in the surface layers. In addition there is a decrease in fatigue wear resistance when the actual contact area is changed, the formation of corrosion on the friction surface, and the softening of the plastic lubricant structure [8].

Since the increased performance requirements for lubricants cannot be met due to these shortcomings, it is necessary to find better materials that can be introduced into plastic lubricants as fillers. This allows us to raise the durability of friction units by increasing the carrying capacity of the lubricating layer, improving anti-friction and anti-wear properties, reducing the temperature in the contact zone. Ultrafine powders of diamond and diamond graphite (UDD-G) [9-12] can be attributed to such materials. Their good adhesion to metal surfaces due to increased surface energy contributes to a strong retention of a lubricant layer on the friction surface. Particles of ultrafine powder localize in the areas of rubbing surfaces, forming on them a strong film that prevents adhesion, reduces the coefficient of friction and is able to withstand considerable loads. These substances have been used as functional additives for lubricant compositions used in various friction units [11, 13-21].

This paper presents selected results of experimental studies on the tribological properties of UDD-G and the possibility of their use for lubricating compositions based on plastic lubricants used in rolling bearings. The goal of the research is to study the effect of ultrafine diamond-graphite powder on the antiwear and antifriction properties of grease lubricants.

2. Materials and methods

The efficiency of using UDD-G in lubricants was estimated by the intensity of rolling bearings wear, the magnitude of friction moments, the rheological characteristics of new lubricant compositions, the temperature of the assembly and other parameters. To create lubricating compositions with ultrafine diamond-graphite powder, a plastic lubricant brand TSIATIM-201 (similar to US product NLGI-2) was used. They are widely applied in support assemblies with rolling and plain bearings of all types, in hinges and other gears for lubrication of the rubbing surfaces of mechanisms for various purposes. It has a satisfactory mechanical stability and is operable in a wide range of temperatures.

Ultradispersed powder of diamond graphite, which is used in this work for the preparation of lubricant compositions 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 of 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 tests were performed in the laboratory facility that simulates the operation of a bearing assembly with unidirectional rotation of the bearing. Radial roller bearings of type 2308 with short cylindrical rollers were taken as samples. Figure 1 shows the scheme of the test unit. Studies of lubricating properties were carried out with radial loads from 0.5 to 2.5 kN, the rotational speed of the inner ring changed from 960 to 1800 rpm; the outer ring was fixed.

Bearing 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 the test lubricant. Friction forces corresponding to tangential loads on the contact area were determined experimentally by tensometry.

The volume of lubricant was 1/3 of the bearing' free space. Studies were conducted at a concentration of UDD-G in the lubricant compositions from 0.5 to 5 % by weight of the lubricant.

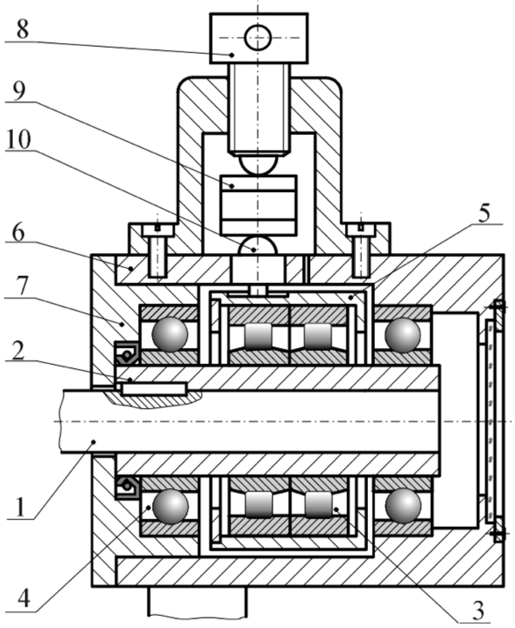

Figure 1. Test scheme for rolling bearings: 1- shaft; 2 - inner sleeve; 3 - tested bearings; 4 - thrust bearings; 5 - outer sleeve; 6 - case; 7 - case cover; 8 - screw; 9 - loading spring; 10 - cylinder.

3. Experimental study

The graphs of bearing wear variation depending on operating time are shown in figure 2 and figure 3. They were obtained with loads of 0.5 and 2 kN for lubricant compositions and base lubricants with a filler concentration of 1 % by mass at an internal ring rotation frequency of 960 rpm. Such concentration of UDD-G is most optimal when used in plastic lubricants [22].

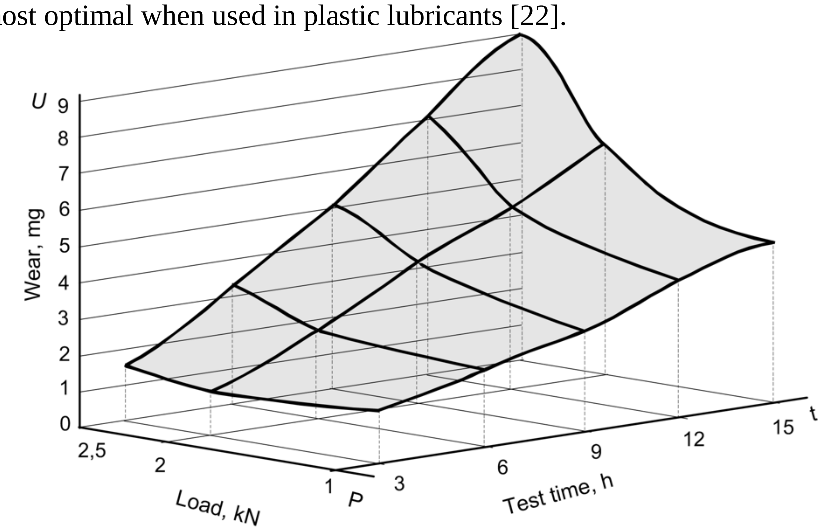

Figure 2. The dependence of the rolling bearing wear on the operating time under radial load for the grease TSIATIM-201 without addition of UDD-G.

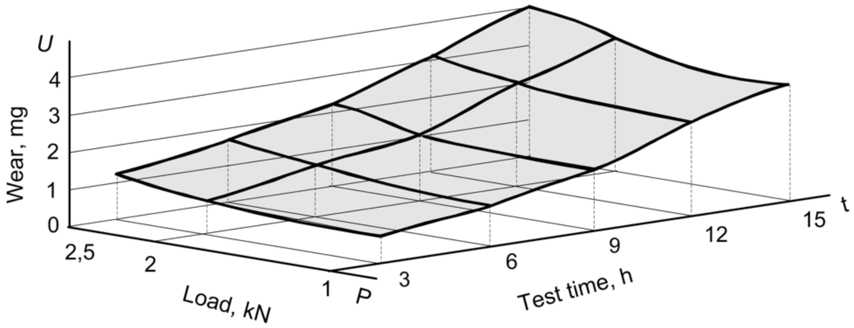

Figure 3. The dependence of the rolling bearing wear on the operating time under radial load for the grease TSIATIM-201 with addition of UDD-G.

According to the graphs, it can be noted that the introduction of UDD-G into basic lubricants reduces the amount of wear for TSIATIM-201 under all loads; similar dependences were obtained when the rotational speed of the bearing inner ring increased.

The effect of the filler on the change in antifriction properties was estimated by the magnitude of the friction torque in rolling bearings. So, presented in figure 4, dependences reflect changes in the friction torque in the bearing under the load of 2 kN. Measurements were taken at the beginning of the test before and after the load was applied, then at the end of the test before and after the load was removed.

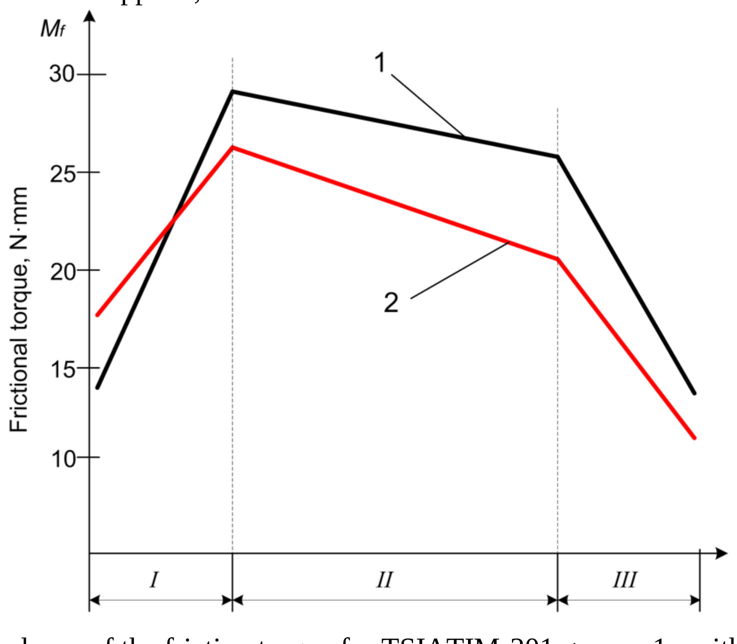

Figure 4. Dependence of the friction torque for TSIATIM-201 grease: 1 - without addition of UDD-G; 2 - with addition of UDD-G.

The graphs marked three areas that meet certain test conditions. Section I corresponds to the beginning of the tests, Section II - to the main test time after application of the load, and Section III - to the final stage of the tests after the load removal.

The positive effect of the introduction of UDD-G was observed for the TSIATIM-201 grease. So, there was a decrease in the friction torque in the bearing under various loads.

Also, the positive effect of UDD-G on the antiwear properties of all lubricants considered in operation should be mentioned. For a TSIATIM-201 based lubricant composition, the bearing wear value decreases 1.6–1.8 times, the friction torque decreases 24–26 %.

4. Discussion

The analysis of the obtained results suggested the reasons for demonstration of high tribotechnical characteristics of lubricants with the ultrafine diamond-graphite powder addition. Unlike other used powder additives, UDD-G is characterized by high adhesiveness to metal surfaces due to increased surface energy. The presence of own charge on the surface of the particles leads to the formation of an oriented layer on the contacting surfaces of the metal, which contributes to the durable holding of a thin film of lubricant on the friction surface. Such film can withstand considerable loads without destruction and localizes the areas of rubbing surfaces, preventing the setting of the contacting surfaces.

According to the measurement results of friction moments, it can be noted that a significant improvement in anti-friction properties was observed when using a lubricant composition with TSIATIM-201. Here, the friction torque value decreased in comparison with the base lubricant by 20–25 %. Similar results were observed for other loading modes.

Despite the fact that there is an increase in the friction torque at the run-in stage, which is associated with the abrasive properties of the ultrafine powder particles, this contributes to reducing the equilibrium roughness formation time and transition to the steady-state friction mode.

The nature of the obtained results can be explained by the initial processes of the running-in regime, associated with the formation of new roughness of friction surfaces during smoothing of the most prominent asperities. Having many edges due to their polycrystalline structure, diamond particles somewhat cut off the protrusions on the friction surface. This leads to an increase in the wear rate of the rolling bearing at the initial moment of operation, which may explain the increase in the friction coefficient during this period of operation.

For friction assemblies where plastic lubricants are used, friction boundary mode is the most common. As the load increases and the relative sliding speed decreases, the thickness of the lubricant film between the sliding surfaces decreases. With limited lubrication, the distribution of contact pressure is close to the case of contact without lubricant; there is no pressure peak resulting from elastohydrodynamic contact. The characteristics of contact and friction substantially depend on the loading conditions and mechanical properties of the surface layer [2, 3]. An increase in contact stresses leads to an increase in rolling resistance of approximately the same proportionality as with clean surfaces. The main purpose of the lubricant in this mode is to reduce the friction forces in the contact zone and to protect the rubbing surfaces from setting.

The properties of the lubricant will differ from the properties in the volume, the role of viscosity properties in this case becomes secondary. Thus, the particles will firmly hold the molecular lubricating layer on the friction surfaces, creating a kind of the protective screen [16, 22].

5. Conclusion

The 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.

Based on the results of the conducted research, it can be concluded that greases with the addition of ultrafine diamond-graphite powder can increase the service life of the bearing assembly 1.5–2 times.

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