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THE USE OF TWO-PHASE OIL-VAPOR-GAS MIXTURES TO IMPROVE THE PERFORMANCE OF TRIBOSYSTEMS

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Abstract: the article investigates the viscosity-temperature and anti-wear properties of mineral and synthetic oils of the motor-transmission group under normal conditions and when giving these lubricants the properties of two-phase. Such properties are acquired by circulating selected lubricants through a tribomolecular generator, resulting in their physical-phase state becoming similar to such unstable media as oil-vapor-gas mixtures.

Keywords: viscosity-temperature characteristics, two-phase, aggregate-phase state, oil-vapor-gas mixtures, wear resistance, tribosystems.

1. INTRODUCTION

The efficiency of tribosystems, reliability, and durability of modern equipment in general significantly depends on the used lubrication systems, quality, and properties of lubricants and media.

The main performance characteristics regulated by well-known world manufacturers and reflecting the properties of lubricating media in relation to their use in certain friction units under certain conditions are their density, kinematic and dynamic viscosity, as well as the viscosity index. The world's most widely used single viscosity standard is SAE J300, which characterizes the flow resistance of lubricants at high and low temperatures.

A large number of manufacturers of commercial lubricants and technical fluids on the world market of these products put forward their own, relevant requirements for their performance and purpose, the possibility of use in certain friction units of modern equipment, and compliance with standards, specifications, and environmental standards. For example, for well-known global car brands as lubricants, according to the ACEA (Association des Constructeurs Européens d'Automobiles) classification, it is recommended to use only specific lubricants from a particular approved manufacturer for a specific engine.

Despite the existence of the necessary standards and methods that classify lubricants, today the main generally accepted criteria that recommend the possibility of using these materials under certain conditions are viscosity-temperature characteristics. But the tribological properties of lubricants, in particular anti-wear, which affect the wear resistance of friction pairs, depend not only on the viscosity.

2. LITERATURE REVIEW

One of the most widely accepted theories of friction and wear, molecular-mechanical or adhesive-deformation, considers the process of friction as contacting metal surfaces, with their relative sliding,

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considering the multiple deformations of the surface layers of contact surfaces, the formation, and rupture of actual molecular forces [1]. However, this theory does not consider the influence of friction, wear, and features of mutual contact on the surfaces of tribosystems and lubricants. What is important when conducting laboratory tribological studies of lubricants for various functional purposes in conditions of extreme lubrication.

Therefore, for the theoretical substantiation of the obtained experimental results, the main provisions of the adhesive-hydrodynamic model of friction and wear were used [2-3].

According to the adhesion-hydrodynamic model, from the beginning of the movement to the exit to a stable mode of operation, in the tribosystem, there is a transition through the region of low sliding speeds, ie through the region of realization of guaranteed limit friction. It is during this period of time that approximately 70…80% of parts of friction units of ground and aircraft engines are worn out [4-5].

In transient modes, when epitropic liquid crystal boundary layers with dense packing are formed on the friction surfaces after settling, and the oil is in a homogeneous single-phase state, comprehensive stretching of these liquid crystal structures is carried out in diffuser regions and conditions for quasi-dry friction arise. Under such conditions, there is an adhesive interaction and wear of the friction surfaces [2, 6].

One of the promising areas to reduce the wear of friction pairs is the use of highly effective lubricants with a set of anti-wear additives, which in many cases implements the effect of friction without wear [7-9] and creates optimal microrelief of surfaces [10-15].

The results of laboratory studies have shown that the use of two-phase oil and gas lubricants for lubrication of friction surfaces is a promising direction to improve the operational and tribological properties of tribosystems, and improve the serviceability of friction surfaces and optimize the microrelief of work surfaces. The method requires the continuation of thorough research and development of criteria and means of control of the current aggregate-phase state of these fluids in circulating lubrication systems in order to determine and improve their initial parameters [16]. Therefore, equipment and relevant research methods were designed, developed, and manufactured.

RESEARCH METHODOLOGY

The method of research on friction and wear at constant linear contact of polished surfaces from steel 100Cr6, with the stabilized contact stresses, in the mode of limiting friction which is realized on the laboratory device of friction ASK-01 (Figure 1) was used for carrying out tests. The ultimate friction is realized due to the correctly selected contact load and ensuring the speed of rotation of the counter-sample at the level of 0.3 m/s.

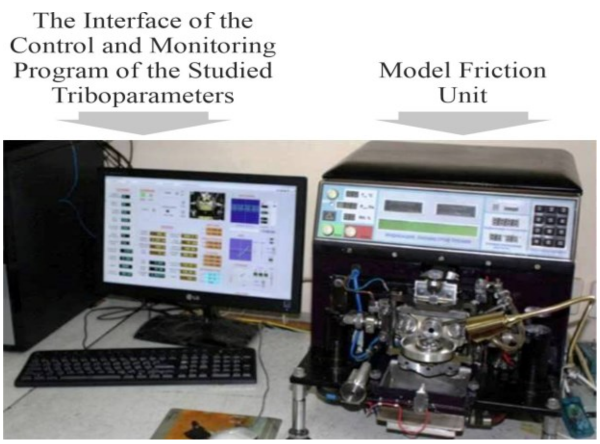

Figure 1. General view of the laboratory automated friction device ASK-01

The test method included initial stages (500 m of friction path - for the development of secondary structures), the number of which depends on the type of lubricant, and a long stage (3000 m of the path), designed to study the anti-wear properties of lubricants and wear resistance of model tribosystem surfaces structures. For testing engine and transmission oils, the number of start-up stages was four. That is, it is for 2000 m of the friction path on the studied tribosurfaces that stable secondary structures are developed (there is an adaptation to the friction conditions).

The viscosity of the investigated lubricants was performed on a GRADIENT-1 device using viscometers placed in moving glycerin with a stable controlled temperature (Figure 2).

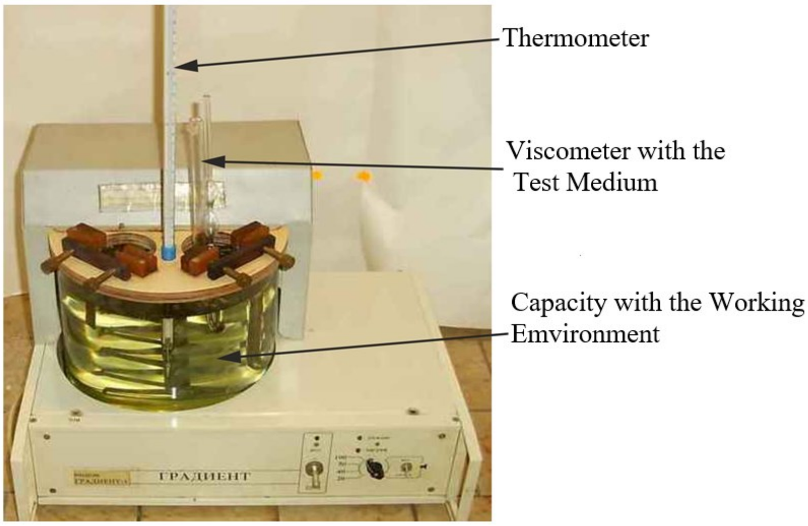

Figure 2. GRADIENT-1 device for studying the viscosity of lubricating media

The friction surfaces were gradually polished with diamond pastes of different grain sizes to achieve a roughness of 0.02 μm, which was monitored by a laser scanning differential-phase microscope profilometer (LSDPMP) [17].

TASKS OF THE RESEARCH

To develop principles of control of the current aggregate-phase state of lubricating media in the set test modes for an increase of tribocharacteristics and resource of friction knots.

RESULTS

Today, the development and serial production of lubricants that would have the properties of two-phase, ie their physical-phase state would be similar to such unstable media as oil-vapor-gas mixtures, is a very important problem of scientific and applied nature. Lubricants in this state have excellent anti-wear properties, which provide good wear resistance of friction working surfaces, are more economically efficient, and do not require the additional introduction of highly effective anti-wear additives.

If we compare two-phase lubricants with others, it should be noted that they effectively begin to protect the surfaces of the tribosystem from wear at the initial time, when the surfaces only begin to contact each other (for example, after stopping). When friction after stopping, it is traditionally believed that the friction surface at the starting point of friction is the wear of the working surfaces and, accordingly, the development of secondary structures.

The explanation of the process of lubrication of surfaces during friction from the standpoint of the elastohydrodynamic approach was based on the assumption, that the lubricating film is considered continuous, and therefore, in this case, it is difficult to explain the formation of microbubbles around the contact zone. However, a number of domestic and foreign scientists [2, 18-19], as well as the authors of this work, confirm the presence of a two-phase physical state of the lubricating medium in the contact zone caused by the transition of the boundary lubricating film containing air dissolved in oil and other gases. zones of excess pressure (at the inlet of the contact) to the diffuser zone, characterized by the formation of a vacuum at the outlet of the contact (Figure 3).

Japanese scientists Nakano, T. Takahashi, and M. Zimmerman W.B., who carefully study the properties, composition, and mechanisms of microbubble formation in oil liquids in order to improve the performance of tribosystems, also see prospects in such studies [20-21].

We studied the performance properties of oils of the engine-transmission group. For this purpose, oils of the motor-transmission group were taken, and their viscosity-temperature and anti-wear properties were studied.

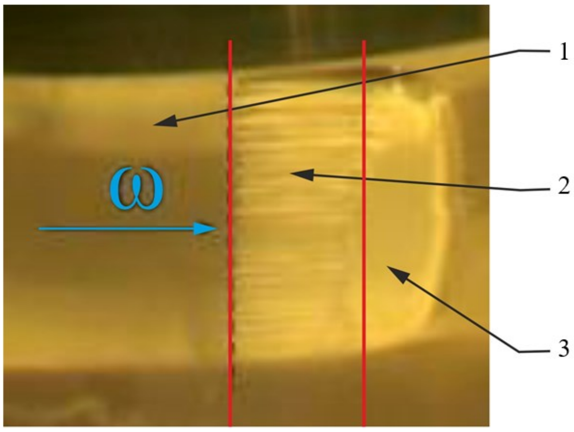

Figure 3. General view of the oil film in the contact zone: 1 - rarefaction zone (confusing zone); 2 - zone of formation of excess pressures (diffuser zone); 3 - the formation of an air bubble in the oil under the influence of excess pressure

The study of viscosity at temperatures of 50 and 100 °C was performed on the device GRADIENT - 1. The research results are presented in Table 1.

Table 1. The results of the study of the viscosity of oils of the engine-transmission group

Types of oils		№ sample	Viscosity value *υ, cCt* at temperature t,°C	
			50	100
Motor	Mineral	№ 1	70	34
		№ 2	75	34
	Synthetic	№ 3	14	10
Transmission	Mineral	№ 4	70	32
		№ 5	85	34
	Synthetic	№ 6	28	16

Studies show that the viscosity of synthetic oils (regardless of whether they are motor or transmission oils) depends on the least.

Further studies of selected oils were performed using LSDPMP [16-17] to determine the contact area and the presence of gases in them.

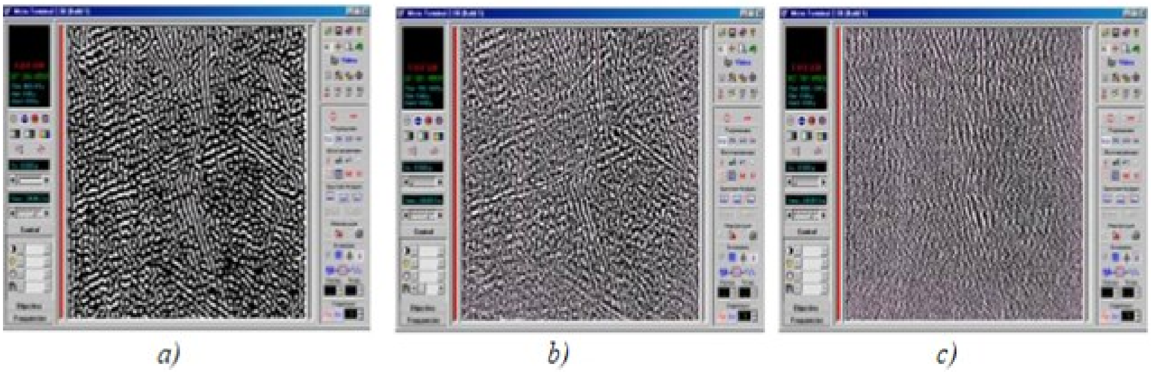

Figure 4. The results of the study of the contact area on the polished surfaces of the friction pair quartz – 100Cr6 on LSDPMP with boundary layers of opaque lubricating medium: a) compressed surfaces with a force of 10.0 MPa; b) the surface 10 minutes after stress relief; c) the surface 24 hours after removal of the load

The test surfaces were gradually compressed, applying a pressure of 1 to 10 MPa (Figure 4). There was an increase in the contour area of contact from 40% (at a pressure of 1…5 MPa) to 60% at a pressure of 10 MPa. After removal of the load, there was a slow increase in the volume of lubricating media, which we explain as the return of compressed gases in the oil to the initial conditions. This study allows us to explain the contact interaction of precision friction surfaces and to make new assumptions about improving their wear resistance.

Studies on friction and wear of selected samples of oils of the engine-transmission group were performed according to the above method on a friction machine ASK-01 at a contact load P = 1100 N for all oil samples except sample № 3. Motor synthetic oil was tested at a contact load P = 1500 N. The test results are shown in Figure 5 and Figure 6.

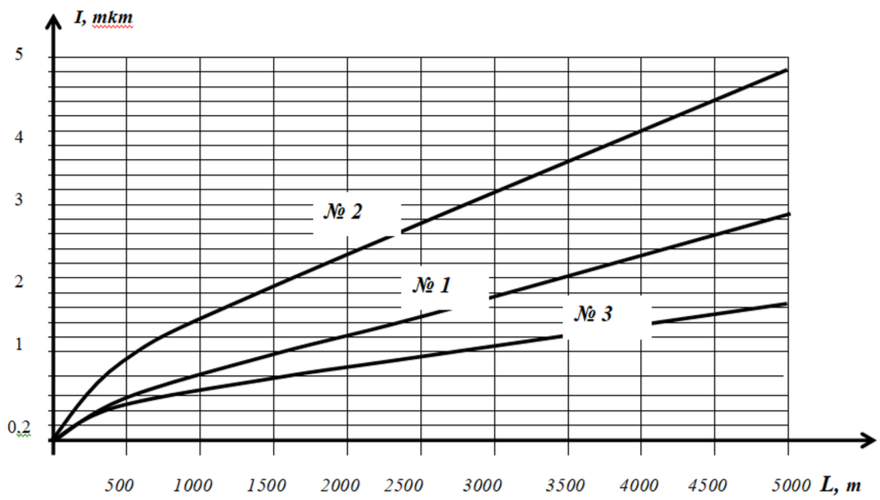

Figure 5. Dependences of the amount of wear on the path of friction in the study of anti-wear properties of selected samples of motor oils

If we compare the anti-wear properties of oil samples № 1 and № 3 by the criterion of wear intensity, they are usually similar (Figure 5). However, the wear of the friction surfaces when used as a lubricant of the sample № 3 is almost twice lower compared to the sample № 1. It should also be noted that the load when testing the sample № 3 was 400 N higher compared to the load at which other test samples were tested oil.

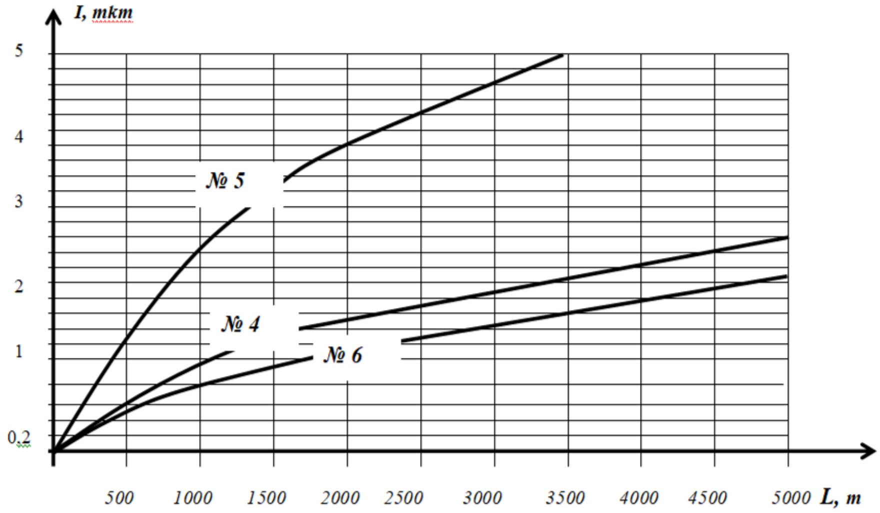

Figure 6. Dependences of the amount of wear on the path of friction in the study of anti-wear properties of selected samples of transmission oils

The anti-wear properties of oil samples № 4 and № 6 are similar, and sample № 6 is significantly (several orders of magnitude) worse (Figure 6). Usually, the wear resistance of friction surfaces when lubricated with synthetic oil № 6 is higher (approximately 20%), compared to conditions when the lubricating medium is mineral oil (sample № 4).

Given the results and objectives of the study to develop principles for controlling the current aggregate-phase state of lubricating media to improve the tribocharacteristics of friction units, the study was conducted on special equipment consisting of the device for monitoring the current aggregate-phase state of the working fluid with control unit, layout crankcase and friction device ASK-01 with a personal computer and specialized software.

Device for circulation and control of the current aggregate-phase state of the working fluid with a tribomolecular generator for generating oil-vapor bubbles to saturate the lubricating medium to the required two-phase state in the crankcase layout and circulation and supply it to the contact zone of the friction device ASK-01 (Figure 7).

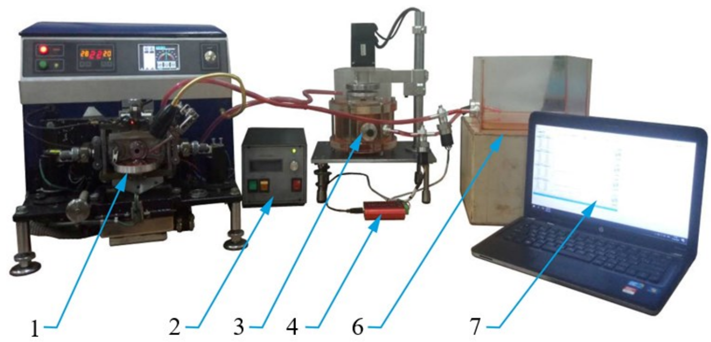

Figure 7. Device for circulation and control of the current aggregate-phase state of the working fluid with a tribomolecular generator: 1 – model friction node; 2 – amplifier; 3 – the tribomolecular generator; 4 – USB converter; 5 – container for working fluid; 6 – control system

The principles of controlling the current aggregate-phase state of lubricating media are to create a two-phase oil-vapor-air mixture of the required concentration, using special tribomolecular generators, to use the effects of micro- and nanobubbles with reduced pressure in diffuser areas and their injection through special receiving devices. in order to improve the performance of tribosystems. In real tribosystems, such a device is proposed to be installed at the inlet to the oil pump and with the help of a special microcontroller can be controlled as an on-off tribomolecular generator and regulation the current physical and phase state of the lubricant used.

The device was used to create a two-phase oil-vapor-air mixture from selected test materials of the engine-transmission group, to study their tribological properties on a laboratory automated friction device ASK-01. These properties were compared with tribological properties under normal conditions (Figure 8 and Figure 9). Samples №1 and №3 of motor oils and samples №4 and №6 of transmission oils were used. In the case of studies of these samples in the state of oil-air mixtures, we added to the sample number marking D (two-phase).

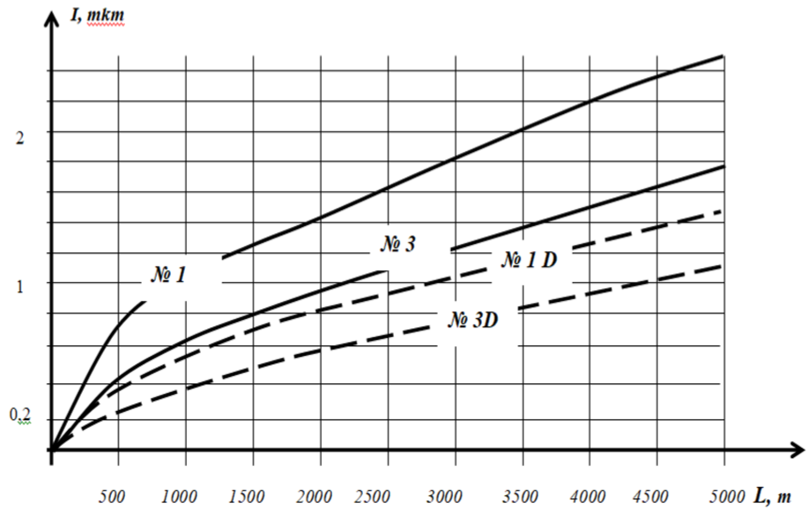

Figure 8. Dependences of the amount of wear on the friction path in the study of anti-wear properties of selected samples of motor oils under normal conditions (№1, №3) and in the state of oil-vapor-air mixtures (№1D, №3D)

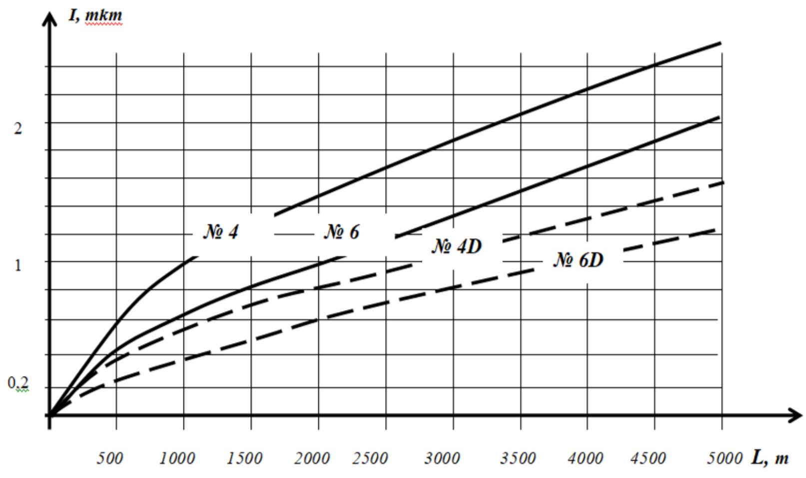

Figure 9. Dependences of the amount of wear on the friction path in the study of anti-wear properties of selected samples of transmission oils under normal conditions (№ 4, № 6) and in the state of oil-vapor-air mixtures (№ 4D, № 6D)

Analysis of the research results shows that the use of two-phase oil-vapor-air mixtures as lubricants allows reducing the wear intensity by 30% and friction forces by 15%. These figures may be higher depending on the operating conditions of the tribosystems. At the same time, the resistance to the setting of surfaces increases by almost 20%, and energy consumption decreases significantly.

CONCLUSIONS

The results of the study indicate the prospects for the use of two-phase oil-steam mixtures as lubricants for lubrication of tribosystems, in particular friction pairs of the engine-transmission group. The use of two-phase oil-steam-air mixtures allows to reduce energy consumption in various machines and the intensity of wear of tribosystems by 30%, friction force by 15%, as well as increase the resistance to setting surfaces by almost 20%.

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