Analysis of factors influencing tribological characteristics of lubricating oils and methods of their control

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Abstract. Methods and means of controlling the tribological characteristics of lubricants are presented. The advantages and disadvantages of four-ball and three-ball friction machines are considered. The analysis of factors influencing the intensity wear of the tribological conjugation of friction units is carried out. The research results of commercial and working motor oils are presented and their tribological properties are evaluated by the method of controlling the wear resistance of friction pairs.

1. Introduction
The lubricant is an essential part of the mechanical system. From its quality depend on such indicators of engines as: durability, reliability, environment, fuel efficiency, etc. Durability depends on the operating conditions, modes, as well as the quality of motor oils, the properties of which change during operation. In engines, engine oil is constantly mixed with mechanical impurities, oxidation products and can be heated to high temperatures, which also affects the performance of the oil.

The effectiveness of the use of motor oils depends on numerous factors that determine the nature of their influence on the surface of rubbing parts. The intensity and frequency of manifestation of these factors in most cases depends on: the properties of the oil, the condition of the surfaces being treated, the material of the parts, the nature of the interaction between the components of the oil and the surfaces of the parts, sliding speed, load, operating temperature, etc.

The operation of the used oil leads to wear of parts, and the use of better engine oil increases the cost of operating the equipment, therefore monitoring the condition of engine oils is one of the important tasks of increasing not only the economy of their use, but also the durability of the engines.

2. Factors influencing the wear process
Friction, as a process, is inherent in absolutely all technical devices that have contact parts. Intensive mechanical and thermal effects on the material and enhanced by the influence of the natural environment on the surface layers lead to the modification of the material. The classification of types of friction in tribological conjunctions of technical devices is presented in figure 1.

The main factors influencing the processes of friction and wear are: mechanical stresses, type and duration of friction, physical and mechanical properties and geometry of rubbing surfaces, the presence or absence of a lubricant, etc.

Under external mechanical influences understand the speed of the relative movement of the
rubbing surfaces and the load. The analysis takes into account not the absolute value of the applied load, but the specific load per unit surface area.

Load and speed are significant factors that determine the energy balance in tribological conjugations. An increase in these parameters usually leads to an increase in the surface temperature of the parts. The temperature should be divided into volume temperature, temperature at the contact, and temperature gradient [1].

Friction and wear are often associated with temperature and temperature gradient and depend on the geometric shape of the surfaces, their areas, the ratio of the areas of contacting surfaces to the total surface of friction, heat transfer, heat capacity, thermal conductivity, etc.

Physicomechanical parameters of tribological conjugations include: macro- and microhardness, elastic modulus and yield strength of the material of friction pairs, tensile, compression, shear, and other characteristics.

It should be borne in mind that some factors, their impact on the processes of friction and wear may increase depending on specific conditions.

The most favorable conditions for the operation of tribological conjugations are: friction during hydrodynamic, gasdynamic, hydrostatic, gasostatic and elastohydrodynamic lubrication, in which under complete conditions complete separation of the rubbing surfaces is achieved, however, in practice such conditions are difficult to achieve. Therefore, most of the friction units of machines are
operated in conditions of friction with boundary lubrication.

Figure 2. Factors influencing the intensity wear of the tribological conjugation of friction units.

From the whole variety of factors influencing the wear rate of tribological conjugations (it is believed that there are more than 40 of them), 12 factors of general influence and an additional 5-6 factors for friction units operating under extreme conditions can be distinguished (figure 2) [2].

3. Methods of tribological characteristics control
To determine the tribological characteristics, a four-ball friction machine (GOST 9490-75) is used. The machine is designed to test liquid and plastic lubricants used to lubricate friction surfaces in order to determine the basic tribological characteristics of lubricants.

A method for determining the lubricity of oils is known, which consists in operating a friction pair in the presence of a lubricant and an electric current passed through the pair. From the surface of the friction pair, the static voltage is removed by changing the polarity of the electric current and a constant current is measured at a stationary friction pair, and then at a steady-state friction mode. The measured current values for the period from the start of the test to stabilization are constructed in the form of a graphical dependence and the lubricity of the oil is estimated according to the parameters: adaptability, oil adaptability rate to these friction conditions and oil compatibility coefficient, while the lubricity of the oil is evaluated taking into account one of the electric current parameters.

However, this method has drawbacks: insufficient information, because it does not take into account changes in the lubricating properties of the used oils during their oxidation, as well as the influence of current on mechanical processes occurring on the friction contact area.

The material properties of the friction pair, the load, the oil temperature, and the sliding speed are significant. All these factors determine the speed of processes on the friction contact and the formation of a protective membrane on it. Therefore, the lubricity index of the tested oil cannot be compared with other materials of friction pairs, however, the availability of information on the effect of materials of friction pairs on the lubricity significantly increases the reliability of the results [3].

The task of increasing information content is achieved by the fact that in the method for determining the lubricating ability of oils, a friction pair is operated in the presence of the test oil, a low-frequency electric current is passed through it, a direct current is measured with a fixed friction pair and, in the established friction mode, a constant mass oil sample is heated with constant stirring at a certain temperature for a constant time, then part of the sample of oxidized oil is taken and tested twice on a friction machine with the same parameters friction.

According to the test results, wear parameters (wear spot diameter) are measured with and without direct current passing through a friction pair, the coefficient of the influence of current on the lubricity of the oxidized oil and the lubricity of the tested lubricating oil are determined by the values of the
coefficient of influence of the current, where a negative value means an increase in lubrication ability of oxidized oils, and a positive - decrease [4].

The solution to the lack of accurate installation of the transmission links at right angles to the guides was a three-ball friction machine [5].

The use of the electrometric method for monitoring the processes occurring at the frictional contact made it possible to justify the use of additional indicators of the tribological characteristics of oils, including the duration of plastic, elastic-plastic and elastic deformations, the electrical conductivity of the friction contact and its formation time, and the intensity factor of mechanochemical processes. This helps to assess the effect of mechanical and chemical components on wear [6].

Widely known are methods for increasing the wear resistance of friction pairs by introducing friction modifiers into the lubricant, for example, in the form of ultrafine powders of chemical elements, as well as various additives, both metal-containing and composite. The use of metal-containing additives containing ultrafine copper powder [7].

There is a method to improve tribological characteristics of lubricants by passing through a pair of friction direct current value of 100 µA.

Application of the considered methods allows controlling the quality of the produced lubricants. This caused an increase in adsorption processes and the formation of protective boundary layers on them [8].

It is known [9] that with boundary friction, layers of physically adsorbed lubricant molecules form on the friction surfaces due to the surface energy of a solid. These layers are loosely bonded to the surface of a solid. The chemisorption layer is firmly bound to the surface by organic compounds formed mainly by the products of oxidation and degradation of the lubricant.

Chemically modified layers are formed on friction surfaces during chemical reactions of a metal with additive molecules. The formation of these layers depends on the temperature on the friction surfaces.

When testing lubricants for temperature resistance in a volume (without friction), the processes occurring in it with increasing temperature are studied, the results of which are used to explain the mechanism of formation of chemisorption and modified layers during friction.

4. Method and results of the research

Let us consider a method of increasing the wear resistance of friction pairs by improving the performance properties of motor oils without interfering with its chemical composition. The test used commercial and used mineral oils: U-tech Navigator (mileage 15000 km) Lukoil Standard (mileage 9957 km) M-8G,k and (mileage 11950 km).

The tests were carried out on a three-ball friction machine with a "ball-cylinder" scheme, and a constant current from an external stabilized 3V voltage source of 100, 200 and 300 µA of positive and negative polarity, established with the static position of the friction pair, was passed through one friction pair. This will determine the optimal value of the current passed through the friction zone, exerting a maximum effect on wear. The results of the study are presented in table 1.

| Test oil                  | The average value of the diameter of the wear spot, mm |
|---------------------------|-------------------------------------------------------|
|                            | without passing direct current | With direct current of various polarity, µA |
|                            | 100       | 200       | 300       |
|                            | +         | -         | +         | -         |
| commercial oil             | 0.32      | 0.293     | 0.28      | 0.3       |
| used oil                   | 0.7       | 0.683     | 0.74      | 0.31      |
| Lukoil Standard            | 0.3       | 0.28      | 0.287     | 0.244     |
| commercial oil             | 0.38      | 0.338     | 0.303     | 0.28      |
| used oil                   | 0.38      | 0.338     | 0.303     | 0.28      |

Table 1. Research results for commercial and used oils.
According to the results of the study, it is clear that the antiwear properties of the studied oils with a positive potential are higher than the antiwear properties of the oils tested without passing current. Moreover, at a current of 200 μA and a positive polarity, the effect of its influence is most effective. The table shows that when passing a current from 100 to 300 μA, the wear of a friction pair decreases on average by 10-20%.

Application of the considered methods allows controlling the quality of the produced lubricants.

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