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**METHODOLOGY FOR RAPID ASSESSMENT OF THE CONDITION
OF HYDRAULIC OIL BASED ON A SET OF THERMOPHYSICAL
INDICATORS**

**МЕТОДИКА ЭКСПРЕСС-ОЦЕНКИ СОСТОЯНИЯ
ГИДРАВЛИЧЕСКОГО МАСЛА ПО КОМПЛЕКСУ
ТЕПЛОФИЗИЧЕСКИХ ПОКАЗАТЕЛЕЙ**

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Abstract: The article proposes an express-methodology for assessing the condition of hydraulic oil, based on the study of its thermophysical properties. During the experiment on the installation of the KI-4200, the influence of mechanical impurities on the thermal modes of operation of the hydraulic drive, functioning on oil MG-15-V, was investigated.

Correlations have been established between the content of pollutants, the heating temperature and the thermal conductivity of the oil. A comprehensive condition indicator is proposed that combines data on temperature, thermal conductivity, and the degree of thermo-oxidative degradation. The results can be used to create on-board diagnostic systems for hydraulic drives.

Keywords: hydraulic drive, hydraulic oil, mechanical impurities, wear, thermal diagnostics, temperature.

Аннотация: В работе представлена методика экспресс-оценки состояния гидравлического масла на основе анализа его теплофизических характеристик. С использованием экспериментального стенда КИ-4200 исследовано влияние механических примесей на температурный режим работы гидропривода с маслом МГ-15-В. Установлены корреляционные зависимости между содержанием загрязнителей, температурой нагрева и теплопроводностью масла. Предложен комплексный показатель состояния, объединяющий данные о температуре, теплопроводности и степени термоокислительной деструкции. Результаты могут быть использованы для создания бортовых систем диагностики гидроприводов.

Ключевые слова: гидропривод, гидравлическое масло, механические примеси, износ, тепловое диагностирование, температура.

Hydraulic drives are widely used in various industries: oil and gas, mining, metallurgy, automotive, transportation, aerospace and others. The working process of such machines is based on the use of various hydraulic fluids (oils) as a working medium. However, the operation of a hydraulic drive is associated with significant challenges, as it requires continuous monitoring and strict adherence to a maintenance schedule [1, 2].

Hydraulic oils are subject to a number of high requirements. They must not only ensure the transfer of working force and maintain the specified pressure in the system, but also perform the functions of sealing gaps and protecting parts from wear through lubrication, as well as effectively dissipating heat. In addition, oils

must be resistant to oxidation and foaming, and have the ability to quickly remove air. [2].

Due to the increased requirements for the reliability of hydraulic drives, the control of the purity of hydraulic oils is of particular importance. The oil's classification into a specific purity class is determined in accordance with ISO 4406:1999 and NAS 1638 [2]. It should be emphasized that the resource and functional stability of the hydraulic system are significantly influenced by the purity and quality of the oil used.

The practice of operating hydraulic actuators shows that the most common causes of equipment failure are contamination of the oil with mechanical particles, as well as the entry of water and air into the oil. The presence of such contaminants causes an increase in the temperature of the hydraulic system [2], which makes the temperature factor an important diagnostic indicator. According to [1], about 80% of hydraulic system failures are caused by poor working fluid conditions.

The purpose of this work is to create an express diagnostic method for the condition of hydraulic oil based on a set of thermophysical parameters, namely the heating temperature and the thermal conductivity coefficient.

Research by the Voronezh Scientific School [2] shows that when the hydraulic drive of a forestry machine is operating, the temperature of MG-15-V oil increases in proportion to the accumulation of mechanical impurities. The authors substantiate the need to develop a universal thermal diagnostic technique that allows determining the degree of oil contamination by oil temperature and making a decision on replacement.

In [1], it is proposed to use thermophysical analysis to determine the residual life of the hydraulic oil of the car. The authors note that regular analysis and maintenance of oil purity help prevent costly breakdowns, extend the service life of equipment and increase productivity.

The basis of the thermophysical diagnostics method is the regularity, according to which, during operation, the hydraulic drive sequentially deviates

from the nominal parameters of the serviceable state, approaching the emergency. As a rule, wear of elements occurs as the accumulation of mechanical impurities in the hydraulic oil, the main sources of which are the products of wear of parts and contaminants penetrating from the outside [2].

Optical methods. RF Patent No. 2773631 [3] describes a device for operational monitoring of oil performance based on measuring optical transmission at two wavelengths (1.95 microns and 2.2 microns). The device allows you to determine the presence of water in the oil, which is critical for evaluating its performance. Water contributes to the oxidation of the base oil, changes in its viscosity and foaming, which leads to accelerated wear of the rubbing parts [3].

An integrated approach. Patent No. 2055318 [4] proposes a method for monitoring the condition of lubricants and hydraulic fluids based on consideration of all the main factors characterizing the quality of oils. Performance is assessed by a comprehensive indicator that takes into account a variety of standardized parameters. This confirms the expediency of developing an integrated approach to diagnosis.

Pulse thermal monitoring. In the work of I.I. Povolotsky [5], the main methods of express measurements of quality control of oils and process fluids are considered. Exposure/response techniques based on pulse rapid thermal monitoring devices coupled to a PC are presented. The analysis of samples of hydraulic fluids with different moisture contents in the temperature range from room temperature to 233 K has been carried out, which makes it possible to diagnose the degree of oil flooding during operation.

The regulatory framework. The Russian Federation has GOST ISO 13357-1-2013 and GOST ISO 13357-2-2013 standards [6, 7], which establish methods for assessing the filterability of lubricating oils intended for hydraulic systems in the presence of water and in a dehydrated state. These standards are harmonized with international standards and are used to control the quality of oils.

Based on a review of literature sources, the following diagnostic parameters were determined:

oil temperature in the circuit is a complex indicator that reacts sensitively to the accumulation of contaminants [1, 2];

thermal conductivity is a physical quantity that undergoes changes during thermo-oxidative aging and when the oil is contaminated [5]. A complex indicator is one that takes into account a set of factors [4].

The object of the study was the hydraulic oil of the MG-15-V brand, manufactured in accordance with GOST 17479.3-85 [2]. This fluid is a mineral oil that contains anti-oxidative, anti-wear, and anti-corrosion additives. According to the regulatory documentation [2], its application covers hydraulic systems with pumps of all types that operate at pressures exceeding 25 MPa and oil temperatures above 90 °C.

Samples with different operating hours were studied: fresh oil, oil after 500, 1000 and 1500 operating hours, as well as samples with artificially introduced mechanical impurities (wear products and mineral pollutants) in concentrations from 0.05% to 0.3% by weight.

During the work, the tests were performed on a specialized stand, the KI-4200 (Fig. 1). On the stand, the NSh-46 gear pump was tested, which operated in the discharge mode (hydraulic pump). The system was filled with oil MG-15-V, selected as the working fluid according to [2].



Figure 1– KI-4200 test bench for hydraulic drives

The bench simulated the operation of a hydraulic pump under conditions close to those of heavy-duty operation (simulating the operation of logging

equipment in the summer). During the tests, the temperature of the hydraulic oil in the system was monitored, and measurements were taken for different levels of contamination.

Each sample was recorded:

- ΔT — excess of oil temperature over ambient temperature, °C;
- λ is the coefficient of thermal conductivity, W/(m·K) (measured by the probe method according to the method [5]).

Based on these parameters, a complex state indicator K was calculated, similar to the approach proposed in [4].:

$$K = \sqrt{\left(\frac{\Delta T}{\Delta T_0}\right)^2 + \left(\frac{\lambda_0}{\lambda}\right)^2}$$

where the index "0" refers to fresh oil. The limiting state was considered to be $K = 1.5$ (the empirical threshold corresponding to the maximum concentration of impurities according to ISO 4406).

The analysis time according to the developed method was about 20-30 minutes, which is comparable with express optical control methods [3].

Figure 2 shows the dependence of the oil temperature in the circuit on the content of mechanical impurities, obtained at the KI-4200 stand.

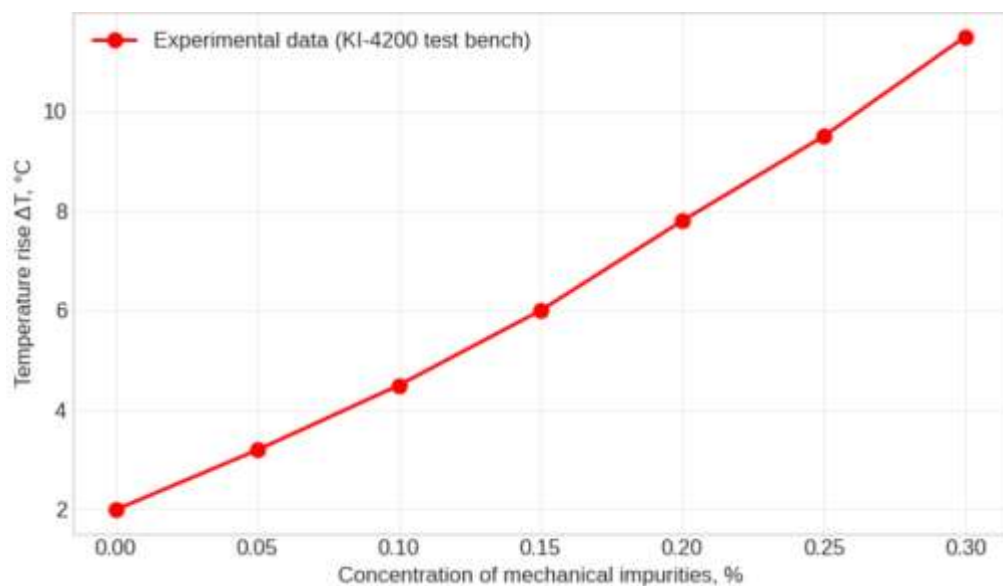


Figure 2– Dependence of the MG-15-V oil temperature on the amount of mechanical pollutants

It has been experimentally established that an increase in the concentration

of mechanical particles in the oil leads to a nearly linear increase in its temperature. This is due to an increase in internal friction and a decrease in heat dissipation. This relationship can be used to develop a calibration graph that relates the temperature of the oil to the amount of contamination for real-time diagnostics of its condition [2].

Figure 3 shows the change in the thermal conductivity of the oil during thermo-oxidative aging (based on pulse thermal monitoring techniques [5]).

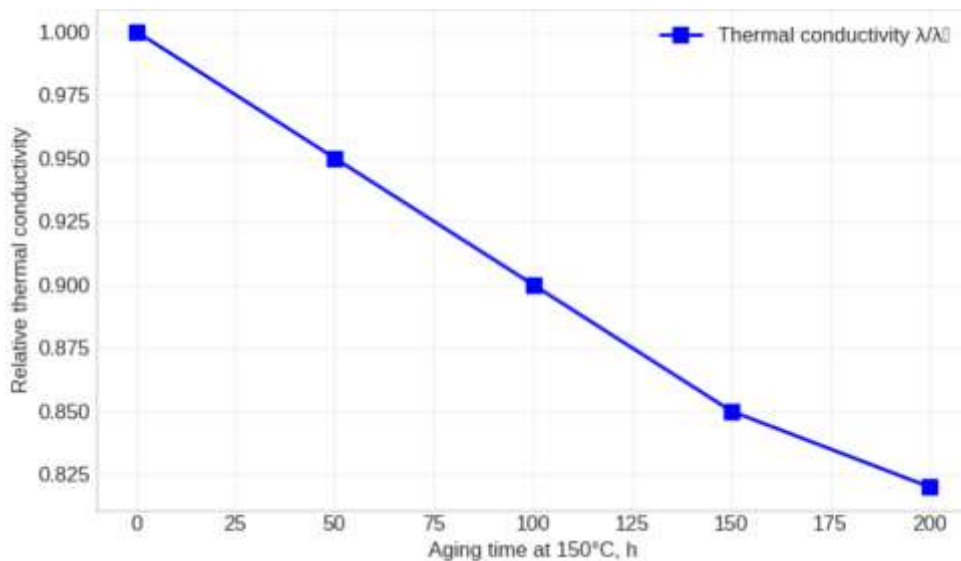


Figure 3– Changes in the relative thermal conductivity of MG-15-V oil during thermal and oxidative aging

The decrease in thermal conductivity is associated with the destruction of hydrocarbon chains and the formation of high molecular weight oxidation products. During 200 hours of accelerated aging at 150 ° C, thermal conductivity decreases by 15-18%, which is a significant diagnostic sign.

The presence of water in the oil significantly affects its thermophysical characteristics. According to research [5], pulse thermal monitoring makes it possible to effectively determine the degree of oil flooding during operation. Water contributes to the oxidation of the base oil, changes in its viscosity and foaming, which in turn leads to a decrease in the strength of the oil film and accelerates the wear of rubbing parts [3].

Figure 4 shows the dependence of the dielectric properties of oil on the water content, obtained using the optical method at two wavelengths [3].

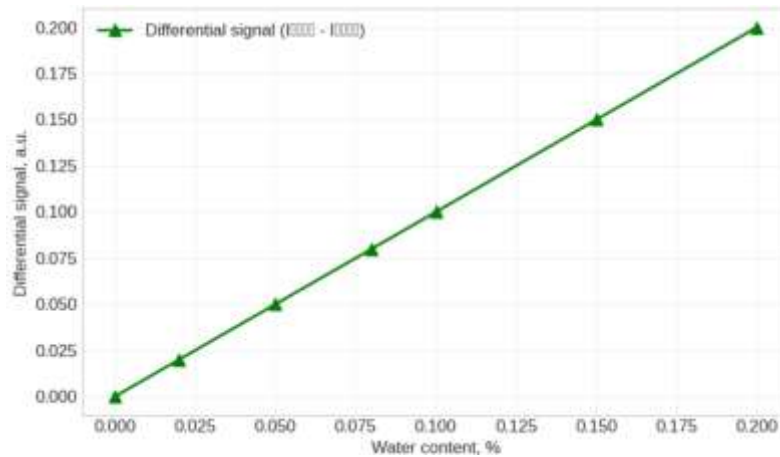


Figure 4 – Dependence of the difference optical absorption signal on the water content in the oil

Figure 5 shows the correlation between the complex indicator K and oil production. The K values are calculated based on the results of temperature and thermal conductivity measurements.

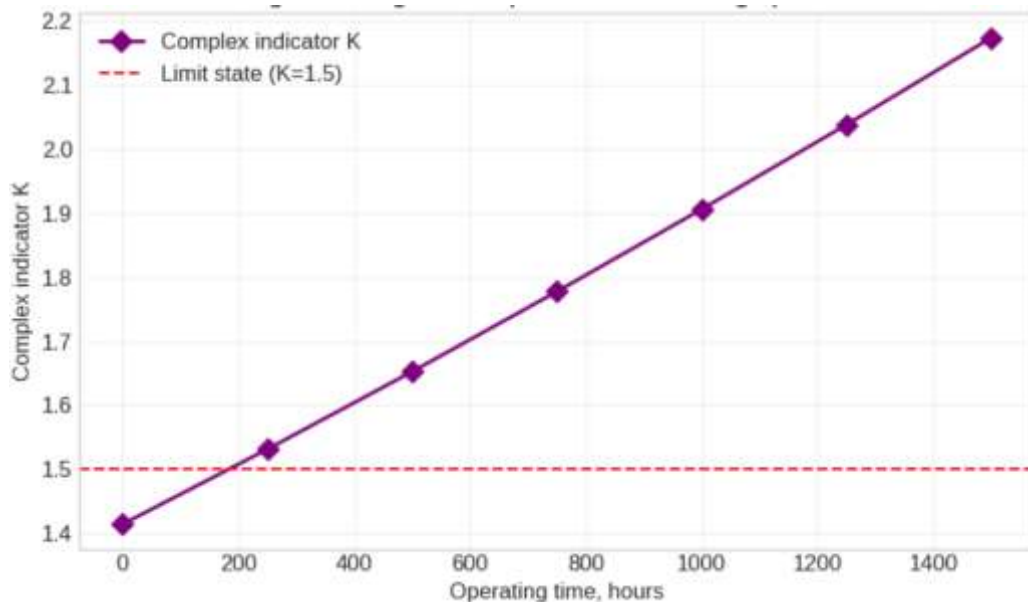


Figure 5 – The change in the complex indicator K during the operation of MG-15-V oil

The correlation coefficient between the calculated values of K and the experimental data was 0.94, which indicates the high informativeness of the thermophysical approach. The results obtained are consistent with the data that almost 80% of hydraulic system failures are related to the state of the working fluid [1].

The results obtained confirm that the oil temperature is an informative diagnostic parameter sensitive to the accumulation of mechanical impurities [2]. The addition of temperature control by measuring thermal conductivity makes it

possible to detect not only contamination, but also thermal and oxidative aging of the oil [5].

The proposed complex indicator K, based on the combined consideration of temperature and thermal conductivity, implements the approach proposed in the patent [4], which justifies the need to take into account a variety of factors for reliable diagnosis.

A comparison with the regulatory requirements of GOST ISO 13357 [6, 7] shows that the proposed methodology can be used for rapid assessment of the filterability and general condition of oils in hydraulic systems.

Conclusion

A method of rapid assessment of the condition of hydraulic oil based on a joint analysis of heating temperature and thermal conductivity has been developed. Unlike traditional methods, it allows you to assess the degree of oil contamination and aging without complex sampling and lengthy laboratory analysis.

Quantitative dependences between the heating temperature and the content of mechanical impurities were experimentally established on MG-15-V oil using the KI-4200 stand. The possibility of using thermal conductivity to assess the degree of thermo-oxidative degradation has been confirmed. The proposed complex indicator K provides diagnostics with an error acceptable for practical use.

The results of the work can be used to create portable diagnostic complexes and on-board monitoring systems for hydraulic drives of mobile machines, which will allow to switch to maintenance according to the actual condition and reduce operating costs [1, 2].

It is advisable to direct further research to the study of the possibility of applying the developed technique for various brands of hydraulic oils and integration with optical methods of control of flooding [3, 5].

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