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Control of the process of wear of the tribosystems based on the optical density of the lubricating oil using neural network models

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Control of the process of wear of the tribosystems based on the optical density of the lubricating oil using neural network models

V G Shram[1], E D Agafonov[1], N F Orlovskaya[1], G V Vashchenko[1] and A V Egorov[2]

[1] Siberian Federal University, 82 Svobodny Avenue, Building 6, 660041, Krasnoyarsk, Russia
[2] Volga State University of Technology, 3, Lenin Square, 424000, Yoshkar–Ola, Russia

E-mail: Shram18rus@mail.ru

Abstract. The article considers the task of studying how the two processes relate - the destruction of lubricating oil and the wear of the elements of the tribosystem. The paper analyzes one of these indicators - the optical density of the oil, which characterizes the process of its destruction. The study includes the stage of constructing multifactor intelligent critical wear models depending on the optical density of the oil and the effort in the friction pair. The initial data for the construction of models are the results of measurements of the optical density of oils and the diameter of the wear spot. The obtained forecast models are indispensable for explaining the fundamental processes of wear that occur during the operation of lubricating oil. In addition to this, it should be noted that the results obtained make it possible to take the next step towards the creation of a new technique for the rapid assessment of the state of lubricating oil and the corresponding nature of the process of wear of the tribosystem.

1. Introduction

Today, the question of the proper operation of lubricating oils remains open, both from the point of view of a theoretical analysis of the processes occurring in them and from the standpoint of the practical use of oils [1-3]. After the oil is manufactured and shipped to the consumer, his work begins as a component of the machine or mechanism. The oil circulates inside the machine and creates a separating film between the rubbing surfaces, preventing their abrasion and destruction. Mechanisms wear out over time, and wear products enter the oil. At the same time, the oil itself also worsens its properties: products of its own oxidation appear in it, antiwear and antioxidant additives are consumed, long polymer chains of additive molecules are broken, providing the desired viscosity. In addition, in the absence of proper protection, water and dirt can enter the oil system from the outside. As a result, losing its original properties and accumulating solid impurities, the oil begins to work as an abrasive, causing even greater wear. Studies [1, 2] show that more than 80 % of machine failures are caused by oil pollution. The engineer operating the machine raises questions: how long will the machine starting to break down last longer, can it be predicted that it will fail, and how to ensure the maximum possible service life. It is a common practice to follow the operating recommendations given by the machine manufacturer – for example, change the oil regularly, observing the frequency of the time interval, mileage in kilometers or resource expressed in hours. When the machine loses its functionality, it is stopped for repairs.

However, it is possible to significantly extend the life of the machine and reduce unplanned downtime. For this purpose, diagnostic monitoring of the equipment by the state of the lubricating oil is used.

Currently, there are two areas of oil analysis procedures: oil analysis in production and analysis during its operation. These two areas are fundamentally different from each other. So in production, it is necessary that quality indicators fall within predetermined, predetermined limits defined by standards and specifications. During operational control, it is necessary to monitor not only the absolute values of various quality indicators, but also the change in these values over time. This approach is often called trend analysis.

During operation of the tribosystem, wear is uneven. This process is influenced by many factors, such as temperature, loading conditions, oxidation processes, mechanical impurities and others [4–6]. At the same time, some parameters of the lubricating oil can be used as an indicator that determines the nature of the process.

In this paper, we analyze one of these indicators – the optical density of the oil, which characterizes the process of its destruction. The task of the study is to study how these two processes relate – the destruction of lubricating oil and the wear of the elements of the tribosystem. The study includes the stage of constructing multifactor intelligent critical wear models depending on the optical density of the oil and the effort in the friction pair.

2. Materials and methods

The initial data for the construction of models are the results of measurements of the optical density of oils and the diameter of the wear spot. The studies were carried out on commercial partially synthetic TNK Super 5W-40 SL/CF and synthetic ESSO Ultron 5W-40 SL/CF.

A series of experiments was carried out, which was as follows: a sample of oil weighing 80 *g* for 8 hours was thermostated in the temperature range from 140 to 300 *°C* with an interval of 10 *°C* without air. At each temperature, a new oil sample was tested. Each oil sample was subjected to photometry, and the absorption coefficient of the light flux K_a, characterizing the optical density, was calculated by the formula:

$$K_a = \frac{300 - P}{300},$$

where P – is the readings of the photometer during photometry of the test oil, μA; 300 - photometer readings in the absence of oil in a photometric cell, μA.

Then a sample of thermostated oil was tested for two hours on a three-ball friction machine with a ball-cylinder friction scheme with parameters: load – 13, 23 and 33 N, sliding speed – 0.68 *m/s*, the temperature of the oil in the volume is 80 *°C*. The diameter of the wear spot was measured with an Altami MET 1M optical microscope, which was made with the ability to photograph the relief of wear spots. The antiwear properties of the oils were determined by the arithmetic mean of the diameter of the wear spot on three balls.

Since today there is no information on the analytical dependence of the parameters of optical density and wear, it was proposed to evaluate the dependences using models built on the basis of experimental data. For a quantitative and qualitative analysis of the relationship between optical density, wear, and load indicators, an approach based on the construction of a predictive regression model was used. As a method of obtaining regression dependence, a variety of artificial neural networks was used, the advantage of which is the ability to work in conditions of a lack of a priori information about the object of study. Correct adjustment of the structure and parameters of the network allows you to work with small amounts of data, obtaining smooth dependencies of variables. The data obtained as a result of experiments were approximated using a neural network model with Bayesian regularization (Levenberg-Marquardt learning algorithm) [7]. The structure of the model included two hidden layers with two neurons in each. The model building algorithm is also implemented using the MATLAB R2017b package.

3. Results and discussion

The results of applying the neural network approach to model building showing the dependence of optical density, wear, and load are shown in figure 1, 2.

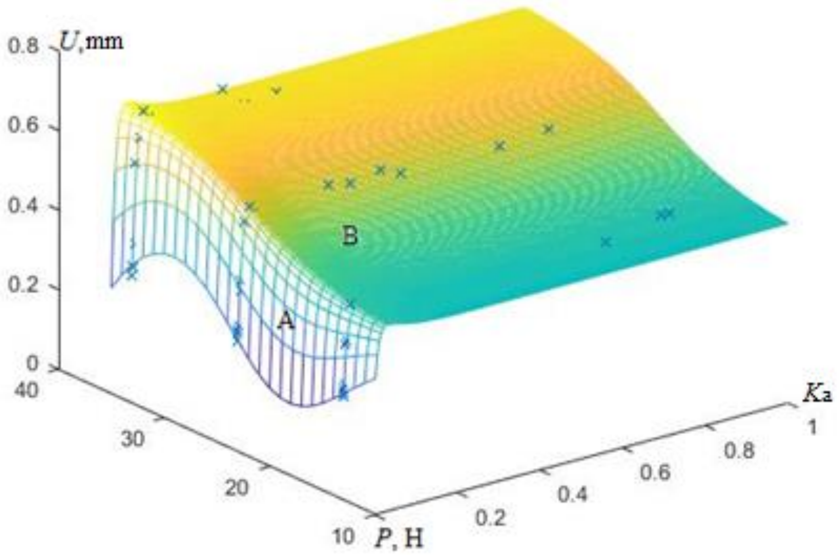

Figure 1. Dependence of the diameter of the wear spot on the optical density and load of the partially synthetic TNK Super 5W-40 SL/CF engine oil.

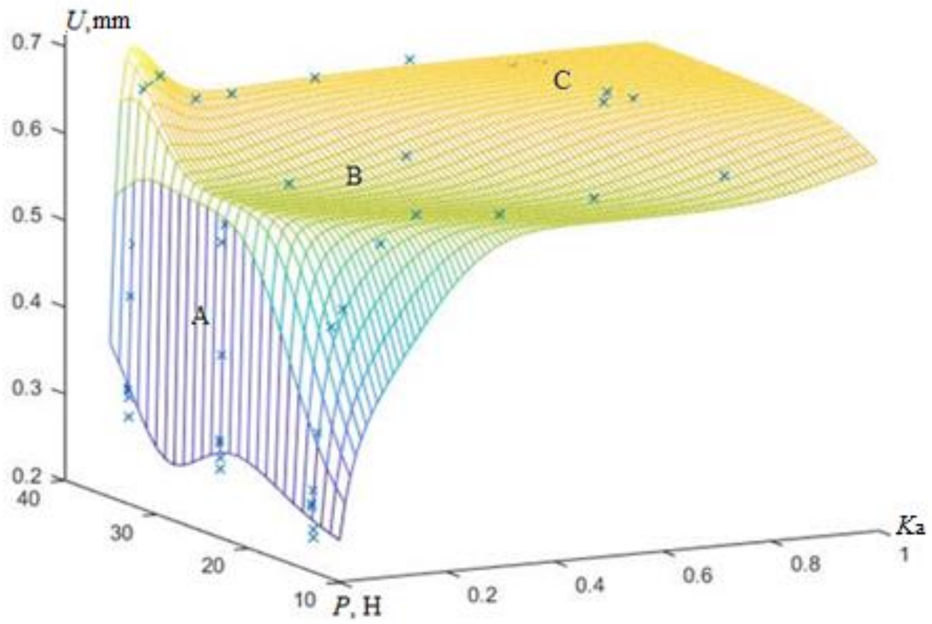

Figure 2. Dependence of the diameter of the wear spot on the optical density and load of the synthetic engine oil ESSO Ultron 5W-40 SL/CF.

In the presented figures, several stages of wear characteristic of different types of oils can be distinguished. In addition, a set of wear areas was noted within one relationship. For example, for synthetic oil there are three characteristic zones designated A, B and C. Zone A corresponds to the area of rapidly growing wear at the initial stage of the oil destruction process. Maximum wear occurs at low optical density values of 0.2-0.3. Also, this zone is the most sensitive to the magnitude of the applied load on the friction pair, which indicates the occurrence of intense transient destruction processes in the lubricating oil. At small load values up to 25–25 *N*, wear changes more smoothly, and with an increase in load due to structural transformations in the lubricating oil, its lubricity decreases, which leads to increased wear. Thus, we can assume that in this area there is an intensive formation of degradation products of lubricating oil with properties different from the original commercial oil, and their distribution in the volume of oil.

Zones B and C generally correspond to a moderate pattern of wear, while the amount of wear is close to maximum. It should be noted that the model zone data are planes, i.e. within certain limits of the change in parameters, wear does not change. Between these zones, the boundary of the phase transition is clearly visible, corresponding to the formation of qualitatively new products of oil destruction, that is, the transition between the zones is associated with the processes of a new stage of destruction of oil components. This transition is shown in figure 3 in the form of the dependence of the maximum rate of change of the amount of wear on the optical density.

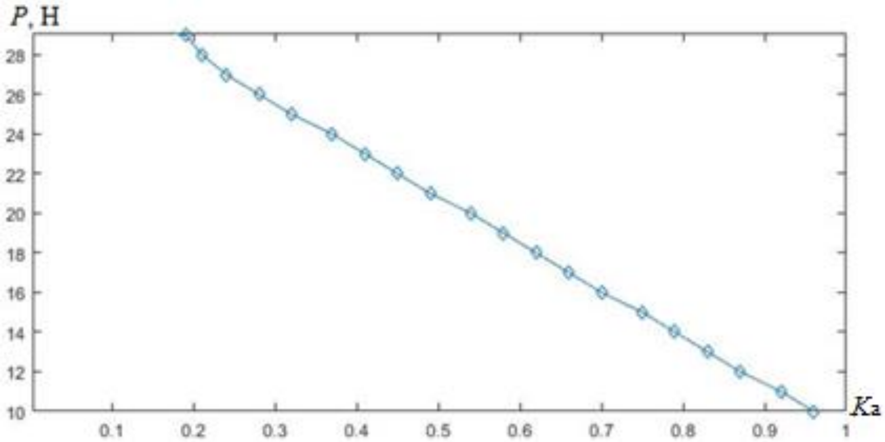

Figure 3. The dependence of the maximum rate of change of the diameter of the wear spot on the optical density of the synthetic engine oil ESSO Ultron 5W-40 SL/CF.

By analogy with the results of previous studies on the thermal oxidative stability of lubricating oils [8–14], the bend zone of the wear model surface was adopted as an indicator of critical wear. The resulting dependence makes it possible to create a methodology for prompt decision-making about the critical condition of equipment by express-assessment of the condition of the tribosystem node based on the measurement of optical density at known loads and temperature conditions of lubricating oil.

Analyzing the obtained dependence (figure 3), it can be noted that the “crest” of the rate of change of wear is almost linear in the plane of the parameters “load - optical density”.

Similar processes can be observed in the partially synthetic TNK Super 5W-40 SL/CF motor oil, with the difference that the lubricity in this oil is low both at high loads and at low loads. This is confirmed by a sharp curve bend during the transition from zone A to zone B (figure 1).

4. Conclusion

The obtained forecast models are indispensable for explaining the fundamental processes of wear that occur during the operation of lubricating oil. In addition to this, it should be noted that the results obtained make it possible to take the next step towards the creation of a new technique for the rapid assessment of the condition of the oil and the corresponding character of the process of wear of the tribuno. At the same time, it is possible to evaluate not only the maximum allowable values of the controlled parameters of the state of the oil and the nature of wear, but also taking into account phase transitional (critical) processes that occur as a result of qualitative transformations in the lubricating oil due to its destruction.

In practice, during the operation of the oil within the framework of the developed monitoring methodology, it will be necessary to periodically monitor the condition of the oil, taking into account the nature of wear, loading conditions, temperature conditions, as well as indirect indicators, one of which is the optical density of the oil.

References

[1] Novikov E and Kiryukhin M 2015 Analysis of oils during their operation *Methodology* **3** 36-47
[2] Voitov V A, Mazepa V A and Jarokhno S Yu 2007 A systematic approach to selecting engine oils for internal combustion engines and determining the timing of their shift *Bulletin of the Kharkov National Automobile and Highway University Mechanics and Engineering* 1-4
[3] Matveevsky R M 1971 *Heat resistance of boundary lubricating layers and solid lubricant coatings during friction of metals and alloys* (Moscow: Science)
[4] Wenzel S V 1979 *The use of lubricating oils in internal combustion engines* (Moscow: Chemistry)
[5] Foster N S and Amonnete J E 2001 Derection of trace levels of water in oil by photo acoustic spectroscopy *Sensors and Actyatous* **77** 620–4
[6] Barnes M 2002 *Fourier transform infrared spectroscopy* (Moscow: Practing oil analysis Magazine)
[7] Chichinadze A V, Brown E D and Buyanovsky I A 2003 Directory *Engineering Journal* **9** 47-51
[8] Vinogradov G V 1969 Lubricating properties of hydrocarbon fluids *Methods of assessing the extreme pressure and anti-wear properties of lubricating materials* 3-11
[9] Goodfellow Y, Benjio I and Courville A 2018 *Deep learning* (Moscow: DMK)
[10] Shram V G, Agafonov E D, Lysyannikov N N, Lysyannikov A V and Kovaleva M A 2019 Prediction life of lubricants on the analysis of experimental data on their optical density *Journal of Physics* **1399**
[11] Shram V G, Agafonov E D, Lysyannikov A V, Lysyannikova N N, Egorov A V and Kaizer Yu F 2019 Identification of qualitative regularities in the functioning of neural network models of a critical resource of lubricating oils *IOP Conference Series* **315**
[12] Bezborodes Yu N, Shram V G, Sokolnikov A N, Petrov O N and Ignatiev A A 2012 Determination of the lubricity of motor oils by the parameter of the total duration of deformations *Vestnik of Irkutsk State Technical University* **8** 125-9
[13] Kowalski B I, Shram V G, Petrov O N and Khimich G N 2015 Assessment of the bearing capacity of a lubricating boundary layer during sliding friction *Bulletin of the Irkutsk State Technical University* **10** 173-7
[14] Shram V G, Lysyannikov A V, Agafonov E D and Lysyannikova N N 2018 Forecast of thermooxidizing properties of lubricating oil using machine learning methods *News of TSU Technical science* **12** 576-81