Assessment of the state of a lubricator by the size of the acoustic signal in a loaded pair of friction of a mining machine transmission

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Abstract. As a result of the studies, the possibility of assessing the state of the working surfaces of mining machines, in particular bearing assemblies as a whole without disassembling the gearbox, is confirmed. An innovative solution in this matter is to ensure the delivery of the lubricator to tribocoupling through the channels of the lubrication system, according to its state, determined by the size of the acoustic signal of the ultrasonic range in the friction pair.

1. Introduction
Today, the development of the mining industry cannot be imagined without the operation and use of mining machines of increased reliability and power of mining equipment. It is possible to increase its reliability by preventing the identified causes of failures of mining equipment operating in difficult geological conditions of open cuts under adverse weather conditions, against the background of high dynamic and stationary loads in the transmissions of mining machines, and timely and high-quality maintenance and repair.

The time to eliminate the consequences of unscheduled shutdowns, depending on the severity of the consequences of failures in the current situation, is determined by the complexity of the work to restore the working condition, the repair manufacturability of a failed unit or element, and the mechanization of repair and maintenance work. Moreover, in the systematization of failures, they are divided into three groups: failures associated with the mechanical system of the mining machine, electrical or hydraulic system, and work on setting up the drives.

2. Systematization of the causes of mining machines failures
Figure 1 shows the Poreto diagram for the failures of the mechanical part of the excavator. The diagram shows that one third of failures is associated with failures of the excavator's running mechanism. Such failures should be classified as constructive. Approximately the same level of reliability has a lifting mechanism, slewing ring, pressure mechanism. Failures of these elements of the system are caused by the action in excess of normative loads during excavator operation, associated with difficult mining and geological conditions, poor preparation of the face and operator control of the excavator, insufficient lubrication of moving parts of mechanisms and transmissions. As a result, intense degradation processes take place in the drive elements, a break in the teeth of the gear wheels [4].

The wear process is the leading degradation process for excavator drives. Approximately 79% of all failures in mining equipment are associated with the wear of elements of electromechanical equipment.
Figure 1. Analysis of breakdown time of excavators due to failures of elements of the mechanical system.

The process of wear of the elements in contact with each other is accompanied by an increased level of vibration, which further activates this degradation process, exacerbated by the growing imbalance of the rotors; alignment of shafts of aggregates and mechanisms; weakening of landings, changing the shape and size of the elements of the movable joints, and in particular gears, accompanied by distortions of the supports; increased wear of other resource-determining tribocouplings - transmissions and other kinematic pairs of mining machines as a whole.

In order to ensure a high level of reliability and maintainability of mining equipment, statistics were collected on the failure of components and assemblies of mining machines, from 2016 to 2019. It was established that the transmission system is the weakest point of the mining machine, and in particular their bearing assemblies. The service life of the bearing assemblies depends on many reasons, but the most common causes of damage are the drawbacks and defects of the lubricating composition (figure 2).

Figure 2. Failure analysis of bearing assemblies.

3. The need to assess the lubricant in the transmission of the mining machine
To ensure the normal operation of mining machines, in severe operating conditions, the grease must guarantee the separation of the contacting surfaces, prevent scuffing and seizing, and reduce the wear rate. The selection of the appropriate type of grease for the bearing assemblies is critical. A reasonable choice of lubricants plays an extremely important role in ensuring a high level of operational reliability of mining equipment. Therefore, the lubricating medium should be considered an equal element of the tribological system [2, 5]. At the same time, if the attitude to the selection of the composition and grades of steels for the manufacture of parts of mining machines, as well as the technological processes to improve their mechanical properties is serious, the choice of a lubricant is not always the same.
Since the main cause of failure of mining machines is the increased wear of resource-determining tribological couplings [2, 3], therefore, the lubricating medium should be considered an equal element of the tribological system.

At present, physical and mechanical laboratory tests of materials is of great importance, since they allow to get the most accurate forecast with a minimum of material costs [3, 5]. The current level of development of friction and wear tests is characterized by a wide variety of test designs. Laboratory tests are reduced to obtaining the necessary information about the object using its model [3]. In this case, the adequacy of the results obtained to real processes is possible when there is a unified physical nature of the phenomena occurring in the studied object and in the model accepted as the basis by the researcher [2, 3].

In the gears of mining machines, the contact in the gearing of the transmissions occurs along the line, while the temperature in the contact can reach 150 ... 600 °C. Under these operating conditions, the grease should guarantee separation of the contacting surfaces, prevent scuffing and seizing, and help reduce the wear rate. In addition, the lubricant should have a stable viscosity, low pour point, good anticorrosion properties [2].

When assessing the lubricity of oils, it is necessary to reliably determine the nature of the friction in the contact, which in turn can be estimated by the value of the coefficient of friction. The acoustic signal of the ultrasonic frequency range in the friction pair allows us to fully evaluate the nature of the friction. It also says a lot about the state of the lubricator, the friction pair where it is located [3].

4. The experimental part

A stand was developed to identify the patterns of change in the acoustic signal of the ultrasonic range from the specific load and speed in the contact, the friction pair according to the "counterbody-plate" scheme. A detailed description of it is given in the paper [1]. As an artificial medium, TAD-17 and Mobil ATF 3309 grease were used. The counterbody pressure on the plate was in the range from 0.773 MPa to 9.01 MPa at a counterbody rotation speed of 30.89 rad / s to 60.2 rad / s.

Changes of the size of the acoustic emission signal of external friction in the kinematic pair were carried out by device METKATOM ARP-11. In the course of the experiments, the parameter D was estimated, which is proportional to the value of the acoustic signal in the ultrasonic frequency band that occurs in the contact during friction in the "counterbody-plate" pair.

Figure 3 shows the changes in the value of the acoustic signal, expressed by indicator D, for a sequential series of angular velocities at constant vapor pressures for the TAD-17 lubricant. The experimental data were processed to obtain the average harmonic estimate of three measurements, followed by approximation by a power function. As can be seen from the figure, there is a stable tendency for indicator D to increase with increasing angular velocity, and the higher the pressure in the friction pair, the more rapidly the D increases, which indicates the deterioration of the friction conditions in the pair, squeezing the grease out of the contact and switching to dry friction.

![Figure 3](image-url)

**Figure 3.** The change in the size of indicator D because of the speed in pair of friction with grease "TAD-17".

Similarly figure 4 shows the changes in the value of the acoustic signal, expressed in terms of D, for a series of angular velocities at constant pressures in a pair for grease Mobil ATF 3309.
Figure 4. The change in the value of indicator D from the speed in the friction pair with the lubricant "Mobil ATF 3309".

Figure 5 and figure 6 show the changes in the size of the acoustic signal, expressed in terms of indicator D, for a sequential series of pressures in the friction pair at constant angular velocities for lubricants TAD-17 and Mobil ATF 3309.

Bearing in mind the presented trends, according to the results of laboratory experiments, it was possible to identify areas of boundary friction below 6 MPa. Friction conditions with TAD-17 and Mobil ATF 3309 lubricants generally have a common trend. In case of high loads and speeds when applying TAD-17 grease, the indicator of the acoustic emission signal of friction increases sharply, which indicates that at high loads and speeds this type of gear oil should not be used for transmission elements of mining machines in similar operating conditions. Based on previous studies presented in [1], it was also revealed that this region of boundary friction is the limit for the type of industrial oil I-20 lubricant during the copper-coating process, and such friction will be the most preferred as a result, even in comparison with Mobil ATF 3309 greasing.

Figure 5. The change in the size of indicator D from the pressure in the pair of friction with lubricant "TAD-17".

Figure 6. The change in the size of indicator D from the pressure in the friction pair with grease "Mobil ATF 3309".

As a result of the studies, the possibility of assessing the condition of the working surfaces of mining machines, in particular bearing assemblies in general, without disassembling the gearbox has been confirmed. An innovative solution in this matter is to ensure the delivery of the lubricator to tribological coupling through the channels of the lubrication system, upon receiving the acoustic signal of the ultrasonic range in the friction pair, the value of which is above the permissible limit. As a part of the maintenance and repair strategy for the actual condition, implementing the technology of routine maintenance of mining equipment and identifying defects in resource-defining mates, it is possible to effectively replace, recycle, clean and restore the properties of oils, lubricants, and working fluids for mining machines.
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