Development of Innovative Methods for the Assessment of the Technical Condition of the Gearboxes of the Mine Belt Conveyors in the Parameters of the Lubricating Oil

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Abstract. This article shows that a significant part of the cost of coal is the cost of transporting it from the long wall to the mine surface, which makes it important to search for reserves in order to increase the efficiency of using mine vehicles, in particular, belt conveyors. This article proposes a method for diagnosing the state of gears of mine belt conveyors based on the actual condition of the lubricating oil. The advantages of combining the study of oil parameters by spectroscopic and microscopic methods are shown. The results of testing lubricating oil of the mine gearboxes located on belt conveyors installed in a single transport and process chain. In order to determine the concentration of wear products the oil was examined with an optical emission spectrometer. For lubricating oil, in which excess wear was observed, a microscopic examination was carried out to clarify the types of wear. Micrographs of wear particles in lubricating oil are given. It characterizes one or another type of wear or their combination. This particular combination of methods increases the probability of identifying possible malfunctions of gearboxes at an early stage of defect development. Thus, the introduction of this technique will reduce the duration of unplanned emergency downtime of belt conveyors and improve the safety of mine transport.

1 Introduction

The economy of the most developed countries is moving to the use of innovative technologies and modern automated equipment in many areas of production. The mining industry, which is one of the basic industrial branches the Russian Federation, is not an exception. Modern mining equipment mostly determine the prospects if the coal mining development. The improvement of its reliability and safety of operation should be taken into account. The condition of the equipment is considered to be in good condition if all its components and parts are operational, and the parameters meet the requirements of normative and technical documentation. The criteria, which determine the technical condition of components and equipment elements do not approach the limit values. And the

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dynamics of these parameters within a certain period allows to predict a sufficiently long period of safe operation.

Maintaining conveyor compliance with industrial safety requirements depends on the rational organization of maintenance and repair. In practice, if the turnaround time based on the calendar operating time is planned, the actual operating time and load intensity are not taken into account. Unreasonable replacement of worn parts increases the probability of emergency repairs. The most promising strategy for the maintenance and repair of mining equipment today is the maintenance according to the actual condition, since the limiting states of structures are the result of a gradual accumulation of damage in parts, assemblies and components. The defects identification and elimination at the initial stage of development, providing the minimization of repair work, is possible only with the introduction of effective diagnostic methods, including in the framework of the expert survey [1, 2].

2 Materials and methods

2.1 Condition monitoring of gearboxes by the spectroscopic method

The condition of industrial oils used as a lubricant for belt conveyor gearboxes significantly affects the working condition of the machine. Chemical and physical properties have a direct impact situation with the lubricating. On the other hand, the oil characteristics provide information about the condition of the machine. Wear and tear alone can lead to significant financial costs for the mining company. The effective use of lubricating oil is surely one of the cost-saving measures. It is an important part of the maintenance policy [3, 4]. Condition monitoring is an important part of the preventive maintenance process and can be carried out, for example, by means of oil analysis, vibration monitoring and monitoring of the technological parameters of the rock mass transportation process. If the process of monitoring the condition of the lubricating oil parameters deviates significantly from the standard criteria is, it the type of the wear process is possibly understood. It is also possible to improve maintenance by replacing the oil or the gearbox elements subjected to the degradation processes.

Analysis of the parameters of lubricating oil during the life of the gearbox will not reduce production costs, due to the rational timing of its replacement. In addition, it improves the efficiency of the transport and technological chain of belt conveyors while ensuring the temperature of the drive. Oil analysis can also help in determining the condition of machines. It also predicts possible malfunctions before catastrophic failures can occur. It helps to reduces repair costs and prevent production losses [5, 6].

Increased concentration of metals in the oils can inform the maintenance personnel about the wear of the machine elements or contamination of the oil with other process chemicals. It can often happen in underground conditions. Tanks containing emulsifier residues for hydraulic stations are used to pour oil into the reducer. When oil is added to the reducer, coal and rock dust can get into it due to the poor cleaning of the filler hole. The methods used to analyze metal wear are numerous, for example, atomic absorption spectroscopy, atomic optical emission spectroscopy, mass spectrometry, x-ray fluorescence spectroscopy, erosion, and magnetic chip detectors [7-11]. Spectroscopic methods typically require pretreatment of oil samples before analysis, whereas magnetism-based instruments allow analysing directly from oil. However, spectroscopic methods are more versatile than those based on ferromagnetism. Spectroscopic methods can be used in order to determine most metals and even some nonmetals depending on the application.
2.2 Condition monitoring of gearboxes by the microscopic method

The size of the wear particles is an important indicator of the condition of the lubrication system. At present, it has been established that wear particles having a nominal size of up to 5 microns are observed in the hydrodynamic lubrication mode; up to 15 microns are in the boundary lubrication. In the transitional lubrication mode with traces of setting the nominal size of wear particles is not more than 150 microns. In corrosion-mechanical wear is up to 150 microns. In catastrophic wear it is up to 1000 microns. With the degradation of friction pairs in the transition to catastrophic not only a sharp increase in the concentration of wear particles in the oil occurs, but also an increase in their size [12]. In addition, the morphology of wear particles is changing. For example, at the burn-in stage wear particles are observed in the form of spheres, plates and flakes of 1-20 µm in size. And at steady wear they are observed in the form of plates and flakes of less than 15 µm in size (with an average particle size of 2 µm). Then at catastrophic wear plates with surface grooves of 20-150 µm in length and more appear. Chips of 5-100 µm in length and 2-15 µm in width are formed. The relationship between the types of wear of lubricated friction units and the characteristics of wear particles is shown in table 1.

| Type of wear            | Characteristics of wear particles                                      |
|-------------------------|-----------------------------------------------------------------------|
| Oxidative wear          | Smooth plates the particle size of 0.5 to 15 µm., the thickness of the particles of 0.15...1 µm. |
| Abrasive wear           | Particles of abrasive wear rod or needle shape with a length of 5 µm. and a thickness of 0.25 µm. |
| Adhesive wear           | Spherical or scaly particles, sizes up to 20 – 50 µm.                 |
| Fatigue wear            | Flaky flat plate with a smooth surface and a chaotic, disorderly form of periphery. The particle sizes of 10 to 100 µm. and more |
| Fretting corrosion wear | Fine particles of Fe₂O₃ iron oxides from light brown to light red      |

Thus, the shape and size of the wear particles can be judged on the types of wear. the change in these parameters can serve as an indicator of the transition towards an undesirable type of wear, as well as an indicator of some other damage to the surfaces of contacting bodies. So, the presence of spherical wear particles indicates the appearance of fatigue micro cracks. It should be noted that the lubricating oil could also contain corrosion products, coke particles, which were formed during destructive processes in the oil. In addition, there can be dust particles penetrated from outside [13-15].

3 Research result

Samples of working oils from the gearboxes of mine belt conveyors were selected to be studied. The layout of the mine belt conveyors is shown in figure 1.
An MFS-11 spectrometer is used for analyzing industrial oils checking the products of wear in the parts of mine belt conveyors gearboxes.
The concentration of worn products in the oil of belt conveyor gearboxes depends not only on the wear rate, but also on the oil lifetime. In order to determine the technical condition of the gearbox, it is necessary to know the dynamics of the process of changing the content of metal particles in the oil. Dynamic balance can be written in the form:

\[ m_{w} - m_{p} = \frac{dM_{w}}{dt} \]  

(1)

where \( m_{w} \) – the intensity of receipt of wear products in oil, kg/h;

\( m_{p} \) – rate of removal of wear products from the system, kg/h;

\( M_{w} \) – the mass of wear debris in the oil system, kg.

The results of the analysis are presented in table 2.

### Table 2. The results of the analysis of wear debris.

| Name of samples | Fe   | Si   | Al   | Cu   | Pb   | Sn   | Cr   |
|-----------------|------|------|------|------|------|------|------|
| Clean oil       | 0.004| 0.002| 0.007| 0.006| 0.000| 0.014| 0.020|
| G1              | 51.878| 43.590| 0.000| 0.422| 0.074| 0.602| 0.273|
| G2              | 43.173| 0.728| 0.637| 0.555| 0.026| 0.451| 0.263|
| G3              | 66.493| 82.279| 0.740| 1.034| 0.208| 0.625| 0.211|
| G4              | 73.872| 20.132| 0.908| 0.700| 0.154| 0.822| 0.280|
| G5              | 22.623| 5.529| 0.000| 0.849| 0.020| 0.668| 0.123|
| G6              | 1.672| 0.971| 0.000| 0.157| 0.000| 0.501| 0.001|
| G7              | 35.119| 28.881| 0.000| 0.258| 0.035| 0.276| 0.149|
| G8              | 69.797| 106.552| 2.763| 0.545| 0.277| 0.589| 0.411|
| G9              | 822.717| 222.531| 21.575| 7.547| 2.179| 6.186| 10.042|
| G10             | 137.064| 132.201| 2.813| 2.746| 0.090| 1.133| 0.846|
| G11             | 422.278| 139.085| 7.748| 3.162| 0.225| 2.747| 2.666|
| G12             | 415.119| 81.156| 4.571| 4.226| 0.284| 2.383| 1.755|
| G14             | 156.113| 107.135| 3.542| 1.580| 0.027| 1.073| 0.522|
| G15             | 174.202| 73.747| 6.219| 2.959| 0.043| 1.713| 1.534|
| G16             | 211.651| 29.018| 5.286| 2.218| 0.336| 1.999| 2.019|
| G17             | 252.065| 55.217| 4.246| 1.886| 0.481| 1.488| 0.541|
The concentration of wear products in the oil can be defined as the proportion of the mass of wear products in the oil to the total mass of the substance in the gearbox:

\[ k_w = \frac{M_w}{M_o + M_w} \]  

(2)

where \( M_o \) – the mass of pure oil in the system without worn products.

When the wear intensity of the parts of any coupling of the reducer increases, it leads to the overall wear intensity and to an appropriate increase in the concentration of wear products in the oil. However, the nature of the increase will depend on the nature of the defect. This circumstance should be used in the diagnosis.

Micrographs of wear particles in gear oil, which have exceeded the content of iron and silicon (G9, G11, G12, G17) are shown in figures 2 – 5.

![Fig. 2. Photomicrographs of particles in the oil of the gearbox G9.](image)

![Fig. 3. Photomicrographs of particles in the oil of the gearbox G11.](image)
An increase in the concentration of iron in the oil indicates the wear of the rolling bearings or of the gear teeth. An increase in the concentration of silicon indicates the degree of contamination of the oil with dust; the presence of aluminum, copper and tin in the wear products indicates the wear of the bearing separators [16].

In addition, it should be taken into account that several types of wear can be simultaneously realized in friction units. Therefore, in some cases it is necessary to analyze the distribution size of worn particles contained in the oil. It can serve as a criterion for the technical condition of lubricated friction units itself [17].

In the oil of the gearbox G9 of the observed particles, showing fatigue wear (Fig. 2. a); oxidative wear (Fig. 2 c); abrasive wear (Fig. 2. d); and dust particles (Fig. 2. b). The particle sizes of 1.5 – 21 µm.

In the oil of the gearbox G11 particles indicating fatigue (Fig. 3. a) and oxidizing wear (Fig. 3 b) have been also found, dimensions 0.5 – 3.0 µm.

In the gearbox G12 fatigue wear of friction pairs dominates (Fig. 4 a, b).

In the gearbox G17 the presence of fine particles in the oil shows more oxidative wear (Fig. 5. a, b).

Thus, the assessment of the current state of lubricated friction pairs in order to identify possible malfunctions at an early stage of their development is rationally carried out by monitoring the content of wear particles in the oil. It is necessary to take oil samples periodically from the lubrication system of the operating mechanism and analyse these samples by laboratory methods.

4 Conclusion

The use of these techniques makes it possible to apply maintenance of belt conveyor gearboxes according to the actual state. It depends on the fact that the limited state of the units and elements of the shaft conveyor reducers are the result of a gradual accumulation of damage in them. The application of complex techniques can significantly reduces the
time spent on the mechanism failure. It can also significantly improve the efficiency of the lubricants usage. It also significantly reduces the time of conducting the analysis of lubricants. Spectroscopic examination takes about ten minutes, and microscopic examination takes about twenty minutes per sample. The norms for the indicators of worn products for this type of gearboxes have not been approved yet. They depend on the specific operating conditions, the type of unit, its technical condition, etc. so research in this area is continuing. In the future, this technique will be improved.

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