Comparative Analysis of Gearboxes Wear in Excavators and Mining Trucks

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Abstract. The primary task of all enterprises in mining industry is to increase the durability and reliability of the mining complex. These very indicators provide nonstop minerals mining, and as a result, productivity increases. Indicators maintaining at high level can be achieved by different ways, but the most effective method is repair-in-place diagnosis of the actual technical condition of the main units and assemblies of equipment, as it is less costly and the most informative. To identify gear malfunctions, the physical and chemical analysis of the used oil is used to determine metallic impurities. A comparative analysis of wear products accumulation in rotary gears of mining excavators and gearboxes of the motor-wheel of dump trucks revealed the similarity of mathematical models for the determination of metallic impurities in used oil. The "universal" mathematical model is given in the paper; it allows to determine the actual technical condition of gearboxes for various equipment with a few assumptions. Moreover, the model takes into account various indicators of the environment, used oil, as well as the operating parameters of the equipment.

1 Introduction

Mining enterprises use a variety of mining technologies. Therefore, open and closed methods of coal mining are the most widely used in mining industry. At the same time, the modern level of technology allows to use various machines and equipment, thereby facilitating the work of people [8, 14]. The open-pit mining of coal deposits has shown itself as the most efficient, less costly and safer method. Despite all these advantages, this method has a number of drawbacks: mining complex downtime associated with unforeseen failures of various units and assemblies of one type of equipment.

Thus, the mechanisms low reliability leads to decrease in this indicator for the equipment, and as a result, there is decrease in the mining complex productivity in general, because the failure of at least one unit from the production line leads to its full stop. Moreover, if a mining truck fails, the production rate will only decrease, but if the excavator fails, the line will stop completely.

Therefore, it is necessary to increase the reliability of each production equipment unit by reducing the failures associated with the failure of its units and assemblies. This can be achieved by many options, such as improving the equipment design at factories, reducing the load on mining equipment, increasing the number of equipment maintenance, etc. However, all these methods are either not effective enough or the improvement is gradual and slow, and some methods will lead to sharp increase in the cost of excavated coal. It is the most rational way to introduce in-place diagnosis into the list of routine maintenance of additional equipment units; it allows identifying unforeseen failures, which are the cause of most equipment breakdowns [10, 13].

During operation of units and assemblies of coal mining equipment, the wear of rubbing parts occurs, leading to decrease in their resource and, as a result, to decrease in reliability and durability [12]. In addition to natural wear and tear, decrease in quality indicators is also connected with physical and chemical properties of the used oil, in which aging processes occur, as well as the accumulation of wear products of mechanisms.

Accumulation of metal products of rubbing surfaces wear in the units and assemblies of mining equipment occur because of the oils washing properties. After conducting physical and chemical analysis of oil used in a gearbox, it is possible to determine, by the number of extraneous components, the actual technical condition of the mechanism. In addition, many gears inside gearboxes are made of various metals, or with different impurities of metals, so it is possible to identify a worn gearbox element by the presence of metal in the oil. This technique has established itself as an effective tool to increase machine reliability. Due to the timely identification of the beginning of increased processes of parts wear in the gearbox, it is possible to carry out repairs or change the routes of traffic in time, without stopping the production line.

2 Results and discussion

One of the largest coal mining enterprises on the territory of Kemerovo region is “Kuzbassrazrezugol”. The company has over 500 units of mining dump trucks and more than 200 units of mining excavators; also, there is a tendency to increase the number of mining equipment units each year. A significant part of the equipment is worn, 30% of excavators and 22% of dump trucks. This affects the increase in the number of downtime due to the failure of equipment units and assemblies. Thus, in comparison with the previous year, the number of downtime increased by 2.7 times, which led to decrease in the productivity of the enterprise in general [10].

The downtime analysis at Kuzbassrazrezugol revealed that of all failures that occur, the most common are failures associated with the breakdown of the motor-wheel gearbox in mining trucks, and it is 18.8% of all downtime. A similar study among excavators showed that 15.3% of failures are rotary gearbox failures [12].

The gearbox failures relate to unforeseen failures, both among excavators and mining trucks, which in turn negatively affects the planning of the current repair of all equipment, and makes adjustments to the organization of route traffic and production lines of open pits. Therefore, it is necessary to develop and implement a methodology for in-place diagnosis of the actual technical condition of equipment units, and it is necessary to carry out diagnostics simultaneously with maintenance. The in-place diagnostic method is the most effective, since it reduces the downtime of equipment during maintenance.

Among the existing methods to assess the gearbox condition, the most informative method to assess the gearbox parts wear is the method by heating the oil in use. There is the rubbing parts wear out during gearbox operation, the products of which accumulate in the used oil, so it begins to lose its lubricating properties and metal impurities fall into the gaps between the parts, which leads to heating of the gearbox itself and increase in the oil temperature. Therefore, if to establish a numerical relationship between temperature and the amount of metal impurities, it is possible to assess the degree of gear parts wear [8].

Therefore, in previous studies, the accumulation of wear products in used oil was studied. Oil samples were taken from excavator rotary gearboxes and motor wheels gearboxes of mining trucks. The interval with which samples were taken is 50 operating hours, as the most optimal value that allows to track changes in metallic impurities in the dynamics [5, 6]. The combined results of these experiments are presented in figure 1.

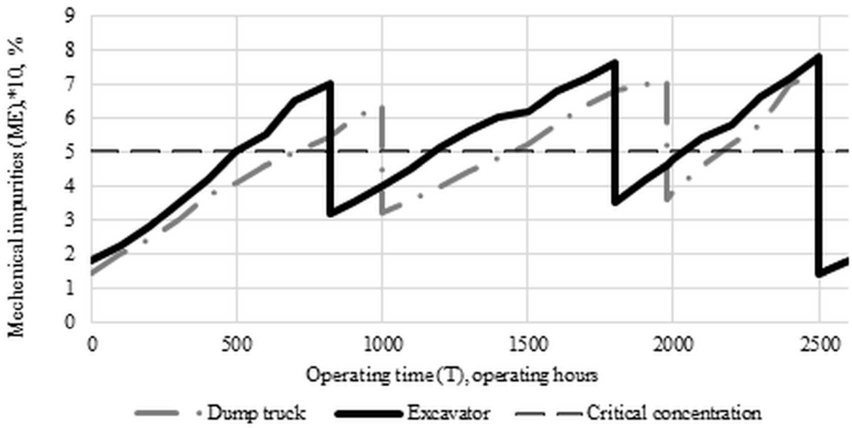

Fig. 1. The diagram of metallic impurities content in dump trucks and excavators gearboxes.

The figure shows graphics of changes in the content of metallic impurities in the oil used in a gearbox of a motor-wheel of a mining truck and a rotary gearbox of an excavator, and it shows the critical level of impurities in the oil. Exceeding this level will lead to increased wear of rubbing surfaces and, as a consequence, to increase in gearbox temperature. Extreme reduction of wear products in the oil coincides with the maintenance of oil change in the gearbox. The difference in the fall between the graphics is determined by the technical regulations of the factory at technical maintenance intervals.

Analysing the obtained graphics, we can conclude that during the equipment operation smooth accumulation of impurities occurs in the oil. This means that the equipment operates without critical loads; therefore, the parts are evenly worn. However, a more detailed study of the diagram allows to see that at small extremes the amount of wear products in the oil does not drop to zero, but becomes higher than with the previous oil change, oil was added to the gearbox at these intervals. Thus, comparing both graphics on the change in the content of metallic impurities in the operating oil of the mining wheel gearbox of the mining truck and the excavator rotary gearbox, we can conclude that the accumulation occurs according to the same laws.

Despite the advantages of physical and chemical oil analysis method with the impurities determination in percentage, it has several disadvantages. For example, either the enterprise itself must have its own chemical laboratory for evaluation the quality of the oil, and there must be qualified employees, who can work in it, or the enterprise must involve an outside organization that can perform chemical analysis, and this is an additional expense. In addition, this technique has a significant drawback during the maintenance procedure, when changing the oil in the gearbox. Since the oil is completely replaced, the impurities accumulated during operation are discharged together with the used oil. Therefore, to assess the wear degree of the rubbing surfaces of the gearbox is not possible. Thus, it is necessary to develop a methodology in which the evaluating indicator of the wear degree will reliably inform about the actual technical condition of the gearbox.

To assess the influence of weather conditions on the temperature change of the gearbox oil, additional experiments were conducted. This study lasted more than a year, it allows to analyse and compare the results under different environmental conditions [5, 6]. The data obtained are shown in figure 2.

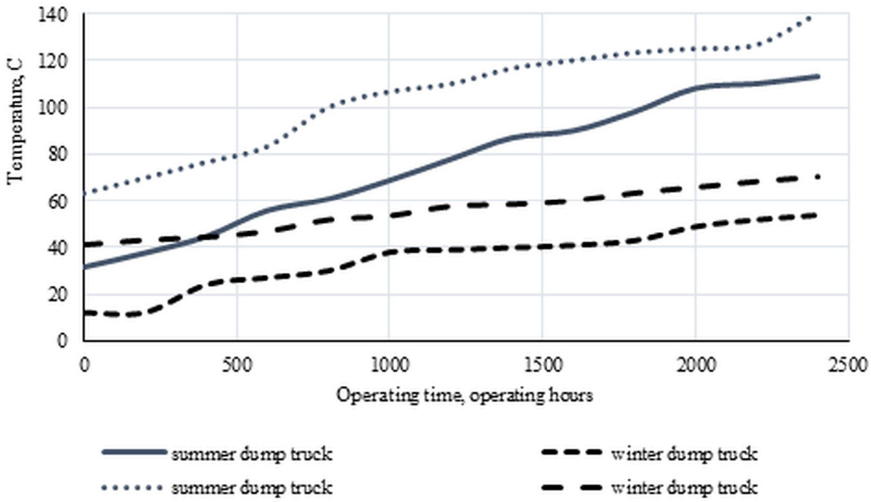

Fig. 2. Changes in oil temperature in the gearbox of the dump truck and excavator in summer and winter.

The figure shows 4 graphics of the oil temperature change in the gearbox from the operating time of equipment, 2 are related to mining trucks and 2 to excavators. In this case, the charts are divided into two groups: “summer” and “winter”, the separation is conventional, the calendar year is divided into warm days – this is “summer”, that is, the average monthly ambient temperature was above zero, and cold days – “winter”, when the average monthly temperature dropped below zero.

From the initial analysis it can be seen that for both types of equipment, the heating of the gearbox oil in operation occurs almost identically, moreover, both during the “summer” period and in the “winter” one. An increase in temperature is directly related to an increase in the amount of impurities in the oil. A more detailed study of the graphics revealed that temperatures in the cold and warm periods only at the initial stage are close in value. Further operation of the equipment leads to a significant increase in temperature in the “summer” days, and with negative – the rate of increase is not so great.

An important factor in this experiment is the critical temperature, for mining trucks it is 120°C, and for excavators it is 90°C. Oil temperature exceeding the above this level leads to wear acceleration. Therefore, it is necessary to achieve such oil change frequency and such equipment working conditions so as not to cross this boundary [5, 6].

A study of the graphics shows that in the “winter” period the change in the observed parameter for both types of equipment is not significant, this is both a positive effect and a negative one. For the gearbox operation, this situation is explained by additional cooling of the gearbox housings due to negative temperatures, and acquires a negative phenomenon to evaluate the actual technical condition, as it complicates the diagnosis of malfunctions.

Studies of changes in the technical condition of the mining trucks gearbox and excavators allow, based on the data obtained, to carry out mathematical modeling of the accumulation of metallic impurities in the used oil, for each machine under consideration, depending on the operating time, oil temperature and weather conditions [5 , 6].

$$Me = \frac{t-(42.47+0.002T+0.88\,t_{oc})}{108.41} \quad (1)$$

$$Me = \frac{t-(14.98+0.005T+0.43t_{oc})}{118.39} \quad (2)$$

Formula (1) is a mathematical model of metal impurities accumulation in the motor wheel gearbox of a mining truck, and formula (2) shows the change in the amount of impurities in the excavator rotary gearbox. To do this, it is necessary to know the operating time of the equipment, the ambient temperature and the used oil. The disadvantage of this approach is that a large number of various equipment is used in open-pits for minerals mining, so, it is necessary to carry out a series of experiments for each of the equipment type, and draw up a mathematical model.

Based on research and mathematical modeling for excavator gearboxes and dump trucks, the similarity of the processes of wear and accumulation of metal impurities in the oil is revealed. Applying the mathematical model (1) for the obtained data for the accumulation of impurities in the excavator gearbox, a comparative analysis was carried out to identify the relative error of the model used. As a result of the mathematical processing, it was found that the use of formula (1) is acceptable for assessing the actual technical condition of the excavator rotary gear with a confidence of 5.6%. Using equation (1) predicts the results of accumulation only when the content of impurities is more than 2%, at lower rates the percentage deviation exceeds 10%.

Therefore, it is possible to predict the technical condition of gearboxes with small assumptions, assuming the mathematical model for mining trucks as universal. Since at low contents of impurities in the oil, the technical condition is considered to be in good condition. A higher content of impurities is the most important to capture and anticipate wear increase, which this model allows to do.

3 Conclusion

Studies to compare the wear of mining dump truck gearboxes and excavator gearboxes revealed a similarity in the friction processes of the interacting parts of the components under consideration. A universal mathematical model has been obtained, it allows to evaluate the actual technical condition of gearboxes by repair-in-place way. The use of this model is limited by small assumptions of impurities minimum content in the used oil. Thus, it is possible to reduce significantly the number of downtime occurring because of unforeseen gearboxes failure. Further expansion of the mathematical model of gearbox parts wear will increase the range of equipment covered, and the use of this equation will increase the reliability of both the equipment and the mining complex in general.

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