Actual technical condition assessment of mine excavators’ slewing gear based on the operating oil parameters

A V Kudrevatykh¹, A S Ashcheulov¹ and A S Ashcheulova²

¹ T.F. Gorbachev Kuzbass State Technical University, 28 Vesennya St, Kemerovo region, Kemerovo, Russia
² Kemerovo State Agricultural Institute, 5 Markovtseva St., Kemerovo region, Kemerovo, Russia

E-mail: dobriyandrey@mail.ru

Abstract. During mining equipment operation, great attention should be paid to durability and reliability increase of their units and assemblies, since the greatest number of equipment failures in Kuzbass mines occurs precisely because of the failure of excavators’ slewing gears. Today this very problem is relevant for coal mining enterprises. One of the ways to improve the reliability of gears is the introduction of additional technological processes to diagnose the mechanisms actual technical condition of an excavator-automotive complex. However, the equipment and methods used do not fully meet the requirements for a comprehensive analysis of the technical condition of gears. Thus, there is a strong need to develop a modern technique to diagnose assemblies, based on the parameters of the operating oil. With the help of experimentally identified dependencies of the oil temperature in a gear on the parameters of the operating oil, a mathematical model of the wear process of slewing gears rubbing parts was obtained; the mathematical model has the possibility to predict possible failures of excavators. The introduction of this model in production will significantly reduce the downtime of mining equipment in coal mines; it also will affect the reduction of total costs of enterprises.

If we compare all methods of mining, the surface mining takes the leading position due to such factors as safety, efficiency and the highest productivity. What is more, in the nearest future this type of mining will retain its leading positions. Using various methods to reduce the downtime of mining machinery and equipment, the reduction in production costs, the significant increase in the productivity of mining equipment and mining complexes are achieved [1-10].

Equipment downtime reduction is possible to implement by increasing the durability and reliability of mining machines and units. All cases of downtime should be rationally divided into planned and unplanned. The unplanned equipment downtime can include such factors as lack of service specialists, equipment failures and accidents; the planned downtime includes technological breaks. In this regard, it is necessary to reduce unplanned downtime, especially those connected with breakdowns. This problem is solved by carrying out preventive measures, such as periodic diagnostics of technical condition of units and assemblies of the excavator-automobile complex. This is because one excavator shutdown entails a number of dump trucks shutdown that are servicing an excavator; it leads to the entire coal production line shutdown [1-10].

Studies conducted at JSC “MC Kuzbassrazugol”, aimed to identify the reasons of downtime excavator, showed that 8.12% of downtime was unplanned; a significant proportion was because of
equipment failures. At the same time, more than 50% of downtime occurred due to the failure of the mechanical part. [9] Considering the causes of downtime in open pits, we can conclude that the most frequent breakdowns occur with buckets and gears. Studying the causes of dump trucks downtime at the enterprises of Kuzbassrazrezugol, we can conclude that failures of slewing gears are estimated as 23% of the total downtime and this time was lost. The analysis of mining and transportation equipment downtime causes showed the need to introduce measures to prevent gears failures or reduce the repair time [6].

During the entire service life of equipment, the maintenance and repair cost exceed its initial cost several times, which is due to the low reliability of the equipment itself; thus, it is necessary to pay great attention to improvement of reliability of mining equipment elements. With the introduction of additional technological operations in repair and maintenance technology, the usage increase of mining equipment and machinery is achieved. [5] Such technological operation is the diagnosis of the actual state of mining equipment. There are a large number of different methods for diagnosing the actual condition of the equipment, but the most promising, informative and least labor-intensive method of diagnosis is the diagnosis method based on the parameters of the operating oil. This method allows us to observe in dynamics the downtime resource of the diagnosed equipment, as well as to predict its failure [7].

Studies of rubbing and wear in the units and mechanisms of mining equipment have revealed many factors affecting reliability: the materials contacting surfaces are made from; mechanical and physical and chemical properties of the lubricant. During operation, the oil interacts with the rubbing parts of the equipment in excavators gears; it leads to changes in physical and chemical properties of the lubricant. [9] Chemical analysis of the lubricant allows to monitor the state of the working surfaces of units and mechanisms of equipment simultaneously, as well as to assess their performance without disassembling the equipment. Based on the data obtained, a mathematical model of the processes in oil was created; it revealed the reasons of equipment reliability.

Together with the method to diagnose the equipment wear degree according to the physical and chemical analysis of operating oil, there is a method to determine the technical condition without dismantling according to the indicators of temperature of the lubricant during operation. If the local temperature increases, it indicates the critical state of the rubbing parts and irreversible changes within the unit [7].

Thus, the simultaneous use of both methods of diagnostics allows identifying malfunctions and preventing unplanned failure of mine equipment.

When studying the “mechanism-oil” system, it is necessary to take into account many factors affecting the processes in this system, such as the design features of the related parts, operating parameters of the equipment, the properties of the used oil, and a number of other factors. In this case, the determining parameters are selected for each system individually and their critical values are detected during many experiments, the results of which are recorded in the data array. Application of a statistical analysis of the obtained values will allow to predict further failures of units and equipment, and, if necessary, to stop the equipment being operated.

It should be noted that oils used in machines units, work cyclically in the machines, accumulating the parameters of the ‘mechanism-oil’ system state, which allow to diagnose the technical condition of the investigated unit. Repeated studies have shown that the oils properties change much faster than equipment failure occurs. This happens because with the development of the pre-failure state the content of metallic impurities (wear products) increases in the operating oil, the temperature increases as a result and it accelerates the oxidative processes occurring in oil and its viscosity increases.

A series of experiments aimed to determine the mechanical impurities concentration growth in the operating oil during the operation of excavators’ slewing gears were carried out. Maintenance assessment of wear elements of rubbing parts was carried out by means of the MFS-7 multichannel photometric system. On the basis of a number of preliminary studies, a rational frequency of oil sampling was determined, which totalled to 50 operating hours of the excavator. Oil was sampled by a syringe through an opening to control the oil level in a slewing gear, after which the samples were sent to the
laboratory for analysis. The results were recorded in summary tables, because of which comparative graphics of changes in the mechanical impurities concentration during operating time were built. Almost all graphics showed the same shape of the curve of wear products accumulation, the difference was only in a slight displacement of the line relatively the excavator operating time. Figure 1 shows a general graphic of the metallic impurities accumulation (%) relative to the operating time (equipment operating hours).

In the 1 figure, the vertical axis shows the accumulation of mechanical impurities in the operating oil (in % content), and the horizontal axis shows the operating time of the slewing gears of excavators (in operating hours). Extremes occur due to the need to add transmission oil to the excavator unit; it is regulated by the maintenance instructions. A significant change in the ratio of impurities to the total mass of the oil happens, since the amount of impurities remains unchanged at the moment, and the amount of oil increases. The graphic shows that wear products of rubbing parts accumulate in the oil during operation; the accumulation at the beginning of the curve, up to the first extremum, does not occur as intensively as in the subsequent intervals. The sharp decrease in the concentration of metallic impurities in the operating time of 2,500 hours is due to the routine replacement of oil in the gear.

As there is a need to maintain the oil level by adding it, as well as a complete replacement of oil, according to the excavator maintenance regulations, the information content of the oil indicators is happened. Thus, for further research oil properties are insufficient, as well as an indicator of the actual state of the gear. Therefore, another diagnostic parameter is introduced – the temperature.

In order to determine the influence of mechanical impurities in the operating oil, a series of experiments was carried out. In the slewing gears of EKG-5A excavators, temperature sensors transmitting the records to the computer were installed. Measurements were carried out throughout the year, thus it is possible to identify the effect of outside temperature on the oil temperature increase in a gear. On the basis of the data obtained, the diagram of oil temperature (t) dependence in a gear on the operating time (T) was constructed; and the diagram of amount of metallic impurities (Me) in the oil on the excavator's operating time. Figure 2 shows the dependencies in summer.
The graphic shows that with the excavator operating time (T) increase, the oil temperature in the gear and the percentage of metal impurities (Me) in oil increase too. When repeated measurements were done, a similar temperature change was observed. From the above it is evident that with the routine replacement of oil in a gear, the percentage of impurities decreases sharply. It was assumed that the amount of impurities, but not the operating time influences in temperature increase.

After conducting a correlation and regression analysis of the operating oil parameters the excavators gears for a year, a mathematical model of oil temperature dependence on the oil production time, metallic impurities in it, as well as the average outside temperature (toc) was obtained. The results of the correlation analysis are presented in Table 1. According to Cheddock scale, it can be seen that the oil temperature and the amount of metal impurities in it are in close relationship, while the connection of the oil temperature with the operating time and outside temperature is average, but also direct. There is no influence of the parameters of operating time and the outside temperature on each other, since these two parameters flow independently from each other.

| Table 1. Correlation parameter. |
|---------------------------------|
|                                |
| Oil temperature                |
| Operating time                 |
| Metallic impurities            |
| Outside temperature            |
| 1                              |
| 0.684                          |
| 0.967                          |
| 0.498                          |
| 1                              |
| 0.686                          |
| -1.6673E-17                    |
| 0.377                          |
| 1                              |

Due to the regression analysis, a mathematical model (1) was obtained:

\[ t=14.98+0.005T+118.39Me+0.43toc \]  \( (1) \)

This mathematical model describes the change in oil temperature in a gear of an EKG-5A excavator with 96% accuracy and does not take into account only 4% of the factors. Investigating the received equation, we can conclude that the average seasonal temperature and oil operating time have little effect on the oil temperature, unlike the amount of metallic impurities; it confirms the earlier assumption.

Found from equation (1) the amount of metallic impurities, we got

\[ Me=\frac{t-14.98-0.005T-0.43toc}{118.39} \]  \( (2) \)

Using this mathematical model to diagnose excavators, it is possible to predict the definite amount of impurities in the operating oil; it will indicate critical wear and tear, and as a result, unplanned downtime. Such complex method of diagnosing excavators’ gears is possible to implement on other mining equipment, with the preliminary series of experiments to identify the dependence of oil temperature and the amount of impurities.

Thus, the proposed method of complex diagnostics of units and mechanisms of mining equipment by means of parameters of operating oil allows detecting the actual technical condition of the excavators' slewing gears, constantly monitoring the condition of oil; it will allow avoiding possible failures by repairing the equipment in time.

The results of researches given in the article have proved the benefits of the complex approach to the diagnosis of units and mechanisms of the operating equipment. Thus, further work to improve this method by identifying additional parameters of gears is necessary, in order to determine the residual life of excavator-vehicle complexes more accurately.

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