Diagnostic methods and tools for truck parts and components

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Abstract. This article discusses a variety of diagnostic parameters and different control methods applied to trucks which are operated in open-pit mines. It contains the classification of truck parts and components based on their functions and the description of the main diagnostic parameters for each classification group. It analyzes equipment health monitoring practices and methods of predicting mean time between failures (MTBF) for the reduction drives of wheel motors produced by different companies. It describes one of the operational factors determining the choice of a nondestructive testing (NDT) method for the selected equipment. It analyzes the cost-effectiveness of using NDT methods and describes effective ways to reduce costs when using OTR tires taking into account the dependence of tire life on tire pressure and temperature.

1. Introduction

During the operation of mining vehicles in a harsh environment, where operations are associated with high dynamic stresses, it is necessary to adopt a set of equipment health monitoring measures aimed at the creation of an adaptive maintenance and repair system for truck parts and components.

The failures occurring in trucks are accompanied by significant costs which may eventually exceed the cost of diagnostic equipment that makes it possible to calculate wear rate for parts in contact with each other and to find internal defects and stresses in metal frames with sufficient accuracy and efficiency in accordance with methods approved by State Technical Inspection [1].

When analyzing methods and means of health monitoring equipment, it is necessary to take into account many factors determining the effectiveness of selecting testing equipment and approaches to testing [2].

In the case of vehicles with rubber tires, the vibration analysis method and the spectral analysis method applied to oils are considered to be the most effective. They make it possible to assess the wear rate of a working surface, gap sizes in joints, and processes occurring in diesel engines and hydraulic drives.

It is necessary to deal with vibration in machines and mechanisms in order to increase their reliability and durability. It is impossible to develop effective means of reducing vibration without knowledge of why, where from, and how vibration propagates in mechanisms and structures, which requires that vibration analysis tools and equipment should be developed. Vibration analysis is also one of the main elements in the equipment of life cycle extension, which is a set of measures aimed at extending overhaul periods and reducing the likelihood of sudden equipment failure during operation. The emphasis is put on identifying causes of defects, assessing dangers associated with defects, and finding ways to reduce vibrations in the object. One of the main sources of increase in vibration in mechanisms being operated is defects in rolling-element bearings.
In the mining industry, oil analysis has been used in the health monitoring of reduction drives in wheel motors. As there are different operation modes for dump trucks, reduction drives will have different wear rates, which means that MTBF values can fluctuate over a wide range (depending on the manufacturer). BelAZ-7521 failure mileage varies from 80 to 200 thousand kilometers, while that of M200 (Unit Rig) ranges from 40 thousand to 100 thousand kilometers and that of HD1200 (Komatsu) varies from 60 thousand to 150 thousand kilometers. It can be seen from the data presented above that the behavior of BelAZ dump trucks is the most difficult to predict because there is a wide range of failure mileage values.

2. Methods

At Yakutugol enterprise, it was found that early failures happen due to technical reasons. The studies performed by the vehicle diagnostic service in the company showed that there were metal particles in reduction gear oil whose sizes reach tens and even hundreds of micrometers. The greater their concentration, the greater the wear rate of the reduction drive.

Today, there are several trends in the development of nondestructive methods of testing physical and mechanical characteristics of materials and structures:

1) finding correlations between physical and mechanical parameters of materials;
2) assessing empirical correlations and statistical data on the strength and a given physical parameter of an object under study;
3) developing multiparameter control methods;
4) creating nondestructive methods of testing the integral strength of objects and structures [3].

When choosing NDT methods for testing specific parts and components, the following factors should be taken into account: the character of discontinuity and its location, sensitivity of the testing method, conditions in which a mechanism is operated, technical specifications, type of material, surface roughness, part size and shape, and ease of access for testing [4].

NDT methods include:

• visual testing. This method relies on the visual inspection of an object with the use of a magnifying tool.
• liquid penetrant testing. This method is aimed at finding defects by applying liquids to the surface of an object which penetrate into cracks, pores, and welding defects.
• magnetic particle testing. This group of methods is based on detecting anomalies in flux patterns above defects or determining the magnetic properties of an object being tested.
• electromagnetic testing (eddy current testing). This method is based on detecting changes in the eddy current density induced by the coil in an electrically conductive object being tested.
• radiographic testing. This group of methods relies on the interaction between electromagnetic radiation and a solid object.
• ultrasonic testing. This method is based on analyzing ultrasonic wave propagation through an object being tested.

3. Results

The main test parameters depend on the types of parts and components which can be divided into several groups. Table 1 and Figure 1 show test parameters and part groups for a mining dump truck [5-8].
Table 1. Test parameters for a mining dump truck.

| Equipment                        | Main parts and components | Main test parameters                                                                 |
|----------------------------------|---------------------------|--------------------------------------------------------------------------------------|
| Air supply system                |                           | Vacuum parameters; manifold pressure; exhaust gas temperature; compressor run-down time after the engine stops; oil pressure in the centrifugal compressor. |
| Engine and its components        |                           | Fuel injection advance angle before TDC is reached; fuel consumption; exhaust gas temperature; manifold pressure; nozzle vibration values. |
| Cooling system                   |                           | The temperature of the coolant in the engine cooling system and the temperature of the air; pressure in the engine cooling system and boost air pressure. |
| Exhaust system                   |                           | Turbine exhaust pressure.                                                            |
| Engine                           |                           | Oil parameters; fuel consumption; maximum engine power; differences in oil flow between cylinders. |
| Electric machines                |                           | Support bearings; Vibration parameters; noise parameters; heating temperature.        |
| Armature winding                 |                           | Armature current; current and voltage in the power circuit.                          |
| Electric commutators             |                           | Assessment of electrical commutation characteristics                                 |
| Power supply system              |                           | Voltage maintained by the voltage regulator during generator operation.              |
| Engine starting system           |                           | Voltage maintained by the batteries when the engine is started; starter motor current. |
| Power transmission               |                           | Current and voltage of the electric motor depending on the engine speed; voltage in the synchronous generator and the exciter. |
| Mechanical transmission          | Wheel motor reducer; power takeoff; fan drive reducer. | Oil parameters; drum brake free play; vibration values.  |
| Wheel                            | Tire; wheel hub; rim.     | Standard pressure; tire temperature; rim temperature; wheel hub temperature.         |
The fact that there is a wide variety of parameters to be tested requires that various testing methods including NDT ones should be used. For example, one of the most important operational factors concerning vehicles with rubber tires is the violation of tire pressure norms which can cause such consequences as uneven tread wear, a decrease in tire tread puncture resistance, structural (physical) damage to the tire carcass, and an increase in heat generation. It is not by chance that costs for purchasing and maintaining OTR tires are among the major cost items for open-pit operators. Taking into account the impact of OTR tires on the cost structure of the company and the production process itself, leading producers and consumers of OTR tires are interested in finding ways to manage tire maintenance more effectively [10].

Pressure values for different types of tires lie within limits indicated in specifications and depend on external loads and operating conditions. When there is excessive pressure, the main load is distributed to the central part of the tire contact patch, while low pressure means that the main load is distributed to the peripheral parts, resulting in the so-called bridging effect, which in both cases leads to an increase in tread wear in these zones [11].

The effective way of reducing costs when using OTR tires is constant performance monitoring during operation. For this purpose, tire-pressure monitoring systems (TPMS) are used. They promptly detect deviations from the recommended values of tire pressure, which helps to prevent emergencies, reduce wear, and use tires to their full potential. The decrease in tire wear will cause a reduction in a negative impact on the environment as a result of a decrease in the number of harmful particles emitted in the air. Tire-pressure monitoring systems are quite easy to operate and usually contain sensors transmitting signals to a monitor located in the driver’s cabin. The system can also be integrated into the dispatch system (if it is used by the company), which will make it possible for an operations controller to monitor parameters remotely.

According to data provided by Michelin, if a tire pressure value is higher or lower by 1% than the recommended values, it will result in a 1.5% decrease in tire life. If there is a bigger deviation (more than 15%), the tire carcass starts to disintegrate. This is a critical situation in which the tire is most susceptible to wear, punctures, and sidewall cuts, and, as a result, to an explosion, which will mean downtime due to tire loss [12].

Each tire manufacturer guarantees that their products will operate properly if recommended pressure values are maintained. If there is a slight deviation from these values, it will cause the increase in tread wear.

Figure 1. Nondestructive testing devices
Attention should also be paid to tire operating temperature, which is one of the main factors affecting tread wear. At the moment, there are no recommendations describing optimal temperature ranges for OTR tires. This issue requires further study. However, a temperature of 120 °C is considered to be critical for modern tubeless tires. At higher temperatures, the tire will start to disintegrate. This is why temperature monitoring is also one of the ways to reduce costs when using OTR tires.

The main method of dump trucks maintenance used today is planned preventive maintenance (PPM). However, OTR tire maintenance usually involves only scheduled tire replacement and surface repair. Condition-based maintenance (CBM) seems to be a better strategy for this type of objects [12].

4. Conclusion
Condition-based maintenance systems which involve the application of several NDT methods depending on equipment part types are already used by companies operating mining dump trucks. Information systems being implemented can not only decrease the probability of failure but also increase truck fleet availability by monitoring the parameters of truck parts and components.

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