Diagnostic assessment of base components of mining machinery of potash mines by analysis of excited vibrations

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Abstract. The relevance of the wide use of diagnostic equipment to assess and predict the condition of mining machineries of potash mines is presented in this paper. A promising method of diagnosing the base components of mining machineries (load frames and integral body), which involves an analysis of excited vibrations, is described. The equipment for its implementation is presented. An example of assessing the condition of steelwork of the body of a self-propelled loader bunker BPS-25 is given in the paper. The implementation of an analyzer of the synchronous vibrations «Kamerton» manufactured by Scientific-Production Enterprise «ROS» LLC (Perm) is instrumental in determining the presence of structural changes in a body’s steel of a loader bunker and in confining the position of fatigue cracks. It is shown that the wear of the sides and body’s floor pan of the loader bunker is not uniform. The limiting values of the loss of metal on the sides and floor pan are determined. In this paper, the search for faults was carried out in the entire metal volume of the examined unit. The evidence that the use of «Kamerton» equipment allows reducing material and time costs for the assessment of the mechanical condition of the structural steelwork of mining machineries is presented.

1. Introduction
The tasks of increasing the reliability of hauling-and-winning machines and self-propelled hauling machines, and reducing the cost of their maintenance and repair (MaR) remain topical for enterprises extracting potash-magnesium ores by underground mining [1-3]. The complexity and high labor intensity of technological operations during diagnostic assessment and not always a reliable predictive estimate of their residual service life lead to an increase in the number of downtimes of the main mining and hauling equipment due to emergency failures. The reliability and accuracy of evaluation of the mechanical condition of mining machineries are possible to increase by development and wide usage of nondestructive inspection aids. Advanced methods of maintenance and repair, in particular, the strategy of servicing based on the actual mechanical condition instead of the preventive strategy need to be introduced into the servicing of extracting and hauling machines [4-7].

Prediction of the service life of parts of mining and hauling machines includes a set of tasks: assessment of the current mechanical conditions of the unit; prediction of the development of this state; adjusting MaR measures based on the received information with a predictive estimate of the residual service life of the machine [8-11]. A comprehensive assessment of the residual service life of the mining machine is possible by determining the service life of a base non-replaceable component. Such components for mining and hauling machines are load frames and integral bodies.
Nowadays, one of the most promising methods of diagnostic assessment of units of technological equipment of potash mines is to assess the mechanical condition of steelwork of base components be a method of excited vibrations [12]. The implementation of such method of diagnostic assessment is considered through the example of the body of the self-propelled loader bunker BPS-25 (figure 1).

2. Parameters of loader bunker BPS-25
The loader bunker BPS-25 with the carrying capacity of 30 tons is designed to accumulate mined material that has been mined by such cutters as «Ural» and further loading of the material to self-propelled cars. The loader bunker runs on four pneumatic wheels: two front wheels are steering, but not driven; others are driven but not steering. The base component of the BPS-25 is a body with two-chained flight conveyor incorporated in its floor. The loader bunker BPS-25 and self-propelled cars BC-30 have unified bodies and conveyors.

![Figure 1. Self-propelled loader bunker BPS-25: 1 – body; 2 – steering wheels; 3 – propulsion motor; 4 – oil pumping station; 5 – driving wheels; 6 – steering system; 7 – side of the body; 8 – conveyor double-chain; 9 – floor pan of the body; 10 – drive shaft of the two-chained flight conveyor](image)

3. Formulation of the problem
The body of the loader bunker is a subject to significant loads, and is a base component. The repair services of base components are not provided by the measures taken during servicing processes. The body of the BPS-25 is a subject to intense abrasive wear. They are not usually subjected to emergency fails due to the lack of oversized pieces of potash ore as a result of shearer mining. The process of wear of the floor pan and sides of the body leads to a loss of metal thickness, discontinuities, and uniformity of the material, and, as a result, to the appearance of faults and through holes.

The monitoring of the condition of the bunker BPS-25 body is carried out on a shift basis using organoleptic methods. However, such methods do not provide a reliable predictive estimate due to the subjectivity of the received information and insufficient instrumental precision. Measurement of only the thickness of body’s material does not provide sufficient information due to the fact that it does not show the structure of the material and its possible defects.

The aforementioned factors necessitate the usage of a comprehensive method for periodical diagnostic assessment of the base component of the mining machine, which at the same time has sufficient reliability and does not require large costs. In this case, it is necessary to consider the fact that, in addition to sheet material, the body has its own frame, which gives rigidity to the body and perceives static and dynamic loads from the transshipped and transported cargo.

4. Theoretical and practical research
It is advisable to control the thickness of body’s material, as well as to diagnose units of mining
equipment, using methods of excited vibrations on the individual parts of the body with a single impulse followed by analysis of the response, in order to assess the condition of the material of the body of the loader bunker BPS-25. The measurement of the thickness of the material provides control over the wear of the body’s surfaces. The assessment of the time parameters of the wave motion inside the unit allows analyzing the parameters of the medium and identifying and confining the zones of occurrence of faults. Therefore, the comprehensive assessment of the mechanical condition of the base component is provided with the relatively low labor intensity of such diagnostic operations. The points for monitoring the thickness of the body’s sheet, as well as places of installation of the sensors for detecting excited vibrations are presented in the figure 2.

![Figure 2. The installation diagram of the sensors on the sides and floor pan of the body of the self-propelled loader bunker BPS-25](image)

The indicated method is implemented by a set of devices: «Bulat-1M» ultrasonic thickness gauge by the company «Constanta» LLC (figure 3b) and the «Kamerton» multichannel synchronous analyzer of vibrations (figure 3a) with expert software for analyzing signals and detecting faults by the Scientific-Production Enterprise «ROS» LLC [13].

![Figure 3. Diagnostic tools: a – multichannel analyzer «Kamerton» by the Scientific-Production Enterprise «ROS» LLC; b – ultrasonic thickness gauge «Bulat-1M»](image)
The complex analysis of «Kamerton» includes piezo-accelerometer sensors designed to measure excited vibrations, synchronous analog-to-digital convertor used to normalize and convert the initial signal, personal computer analyzer and a generator [14].

The method of monitoring the mechanical condition using the «Kamerton» multichannel analyzer considers the installation of sensors directly on the sides and floor pan of the body of the loader bunker BPS-25 (figure 2). Sensors’ locations are cleaned with rags prior to installation.

Single impulse excitations of the vibrations are registered by the sensors of the «Kamerton» analyzer and are carried out using the standard tool of the analyzer (hammer), which makes it possible to exclude the influence of a variable load applied by the weight of the impulse source of vibrations on the examined unit. According to the experimental plan, four cycles of measurements in a row at each control point of the body (figure 2) were carried out with the measurement data of the excitation and response signals stored in the «Kamerton» analyzer non-volatile memory for further processing. The excitation signal was a smoothly damped harmonic vibration in which there were no sharp local spikes, kinks or overshoots (figure 4).

The time, velocity and frequency parameters of the response signal are identical to the parameters of the excitation signal in the mediums uniform in density. The conditions of the transmission of the vibrations, generated by identical impulse loads, are different from each other in different parts of the unit in the presence of faults (cracks, cavities and discontinuities). Analysis of the energy components of each registered signal allows not only qualitative, but also quantitative assessment of the mechanical condition of the unit.

5. Results
The signals recorded by the device were processed using expert software for analyzing and detecting faults. This software implements the analysis of the spectral composition of the vibrations of the body’s sides and floor pan of the loader bunker BPS-25 and calculates the generalized quality parameters of metal structures. The damping rate of the vibrations, the impulse (carrier) frequency, and the presence of deviations of the impulse frequency from the normal range of values for a given material were calculated for each signal. The image of spectral pattern of the response signal was recognized (figure 5). The spectral image of faults in individual units of the steelworks is the same; therefore, it is possible to identify them with high reliability.
Further, the processing of the signals from all registrations was carried out using methods of mathematical statistics. The expert software of «Kamerton» uses the following parameters to determine the quality parameters of the unit:

- the average carrier resonant frequency for all available signals for the unit;
- the average damping rate in the unit;
- mutual frequency deviations in the unit;
- the probability of thinning of the sides or lowering of the density, weakening of the metal structure of the unit;
- the probability of the presence of cracks, cavities, discontinuities in the unit.

A generalized conditional quality factor $k$ is determined for integral assessment of the mechanical condition of the units of the steelworks. This factor is calculated based on the correlation of the aforementioned parameters. A quality scale is proposed based on the analysis of the collected statistical material, results of inspections and evaluations. Such quality scale describes the degree of risk or the probability of failure. The metal is considered to be in an unacceptable state if the values of the conditional quality factor are in the range $k \in (0; 0.35]$; the metal is considered to be in an alarming state if the values of the conditional quality factor are in the range $k \in (0.35; 0.65]$; the metal is considered to be in an acceptable state if the values of the conditional quality factor are in the range $k \in (0.65; 0.8]$; the metal is considered to be in a good state if the values of the conditional quality factor are in the range $k \in (0.8; 1]$. 

The values of the generalized conditional quality factor of the metal obtained during the diagnostic assessment of the sides and floor pan of the body of the loader bunker BPS-25 using the «Kamerton» equipment are presented in table 1. The results of the measurements of the thickness of the steelworks carried out using the «Bulat-1M» thickness gauge are presented in table 2. The initial thickness of the sheet metal of the sides and floor pan of the body of the bunker BPS-25 is $10 \pm 1$ mm.

The analysis of the results of the experimental studies shows that the largest wear on the floor pan of the body is recorded in the ore-loading zone of the bunker. The ore flows from the two-chained flight conveyor of the shearer to the body of the bunker. It leads to the intensive abrasion wear and the formation of multiple fatigue micro cracks. Visually, there is the formation of the «seabed topography» in the loading zone on the sides and floor pan of the body. Therefore, there is a weakening of the metal structure. The most significant wear of the sides with the formation of through holes is recorded in the section 3 of the body (figure 2, point 4.2 and table 2) due to the presence of a zone with a sharp change

Figure 5. Examples of the images of the response signals obtained during the diagnostic assessment using the method of excited vibrations: a – presence of the crack in the metal; b – absence of the fault.
in surface shape (narrowing of the body), which is the subject of intense exposure to moving abrasive ore mass.

Table 1. The values of the generalized quality factor k obtained as a result of diagnostic assessment of the body of the BPS-25 using the analyzer «Kamerton»

| Control zone | Sensor location | Quality factor, k | Condition | Note |
|--------------|----------------|------------------|-----------|------|
| Sides of the body | a | 0.32 | «Unacceptable» | Weakening of the structure of the material, cracks. |
|               | b | 0.56 | «Alarming» | Micro cracks. |
|               | a' | 0.39 | «Alarming» | Weakening of the structure of the material, micro cracks. |
|               | b' | 0.47 | «Alarming» | Weakening of the structure of the material, micro cracks. |
| Floor pan of the body | A–B | 0.27 | «Unacceptable» | Multiple micro cracks, significant weakening of the structure of the material. |
| Central zone (A–D; B–C) | | 0.52 | «Alarming» | Micro cracks, weakening of the structure of the material. |
|               | C–D | 0.68 | «Acceptable» | Minor micro cracks, minor weakening of the structure of the material. |

Table 2. The results of the thickness measurements of the sides and floor pan of the body of the bunker BPS-25 using the device «Bulat-1M»

| Sides of the body | Left side | Right side |
|-------------------|-----------|------------|
| Gauge point       | 1.1       | 2.1        | 3.1        | 4.1        | 5.1        | 6.1        |
| Thickness, mm     | 7.0       | 6.5        | 6.3        | 6.4        | 6.8        | 7.4        |
| Gauge point       | 1.2       | 2.2        | 3.2        | 4.2        | 5.2        | 6.2        |
| Thickness, mm     | 9.0       | 8.5        | 7.0        | 5.5        | 7.1        | 7.9        |

| Floor pan of the body | I.1 | II.1 | III.1 | I.2 | II.2 | III.2 |
|------------------------|-----|------|-------|-----|------|-------|
| Thickness, mm          | 6.3 | 6.4  | 6.4   | 7.0 | 7.0  | 7.6   |
| Gauge point            | 1.3 | II.3 | III.3 | 1.4 | 1.4  | 1.4   |
| Thickness, mm          | 7.8 | 8.1  | 8.4   | 9.6 | 9.6  | 9.5   |

Wear of the floor pan of the BPS-25 is uniformly decreasing from the loading end of the bunker to its discharge end. The metal losses in thickness do not exceed 1 mm in the zone of discharge (figure 2, section 4). Minor micro cracks were revealed using the method of analysis of excited vibrations. The values of the generalized quality factor are maximum and are k=0.68, which corresponds to the acceptable state on the proposed scale.

Comparison of the data on assessing the mechanical condition of the body of the loader bunker BPS-25 using the method of analysis of excited vibrations and the thickness measurement of the sides and floor pan allowed determining the maximum permissible value of metal loss for this equipment (figure 6). A decrease in the thickness of the floor pan and sides of the body of the self propelled loader bunker
to 6.5-6.8 mm from the initial values of 10±1 mm is critical. Prolonged use of the machine in such condition leads to the formation of cracks, through holes and the destruction of the metal structure of the body.

Figure 6. Change in the values of the generalized conditional quality factor of the metal depending on the thickness of the sides and floor pan of the body of the self-propelled loader bunker BPS-25

6. Conclusion
The conducted studies showed that the diagnostic assessment of the machineries by comprehensive method using the «Bulat-1М» and «Kamerton» devices followed by the assessment of the mechanical condition of the mining machine by the generalized conditional quality factor $k$ of the base component of the loader bunker BPS-25 (as of the sides and floor pan) allows monitoring the mechanical condition of the mining machine with the sufficient accuracy for practice. The suggested method can be implemented in the technologies of maintenance and planning of repair work as part of the servicing for the actual condition.

It was determined that the metal of the sides and floor pan of the body in the loading area is described by the presence of multiple micro cracks, which will likely lead to its destruction.

The «Kamerton» equipment allowed conducting the diagnostic assessment of the body of the loader bunker BPS-25 without its dismantling by installing a minimum number of sensors in accessible locations of the steelworks. At the same time, the search for the faults was carried out in the entire metal volume of the examined unit.

The implementation of the «Kamerton» equipment allows reducing material and time costs for the execution of the assessment of the mechanical condition of the steelworks of mining machines.

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