 https://doi.org/10.1051/e3sconf/202133002002

Estimating highwall miner technical condition using vibration diagnostics methods

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Abstract. Based on the results of Highwall Miner diagnostic testing, reference spectral masks for every component and assembly were built. They standardize vibration intensity level in different frequency domains of spectra and previously were used for estimating their technical conditions. Two-year period of monitoring proved the effectiveness of the approach for shifting to the system of preventative maintenance.

1 Introduction

The analysis of using basic technological equipment for coal excavation in open-pit and underground mines showed the increasing dependence of the open-pits and underground mines on imported equipment and spare details procurement [1, 2]. It can be clearly seen during the open-pit mining where the share of the imported equipment reaches 84% and during the open-pit-to-underground mining where it makes 100%.

Under such conditions the issues of technical repair and maintenance of this equipment arises point-blank [3]. It is connected with the issue that the approaches to utilizing material mining and conveyor equipment keep changing, technical equipment and technological procedures for their operation starts to be more sophisticated and the requirements to industrial and ecological safety get stringent. The major part of different components and assemblies this equipment consists of bears hidden character of faults origin and development, which cause accidents [4]. Some accidents and industrial disasters of different scale demand the requirements to the reliability of estimating the current condition of the technical equipment and defining its remaining life to be revised considering the latest novel scientific achievements in technical diagnostics [5, 6].

Nowadays coalmining enterprises of Kuzbass employ the system of scheduled preventive repair of the equipment. The basic task for this system is to provide its operation within a given period of time at minimal labour and material values costs. Regardless of the working condition of the parts and assemblies of the mining equipment, the repairs are scheduled according to:

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– calendar (or machine) operation time;

– volume of the processed rock mass.

It leads to [7…10]:

– underutilization of the lifetime for some parts, machines and assemblies of the mining equipment;

– increasing the volume of disassembly and assembly works which do not correspond to technical condition of the mechanisms and heighten up the possibility of high-speed wearing of details due to their frequent disassembly and assembly;

– long-time presence of the equipment in maintenance.

The scheduled preventive repair system in many cases can be taken as a basis for maintaining non-sophisticated machines and mechanisms. As for the basic non-reserve equipment, the application of this system is rather counterproductive and unreasonable. This is the reason why the development of the repair and maintenance system should provide for:

– setting differentiated criteria for estimating lifetime of the mining equipment parts and assemblies which take into account their operation conditions;

– defining certain periods and volumes of the mining equipment maintenance depending on its real technical condition.

It is not enough to have only diagnostic data to solve the whole range of tasks connected with improving the operation reliability of the equipment and reducing the maintenance costs [5, 6, 11]. A large-scale complex of measures united in the framework of general effective operation, repair and maintenance of the equipment strategy is necessary. These measures are:

– accurate estimation of the technical condition of the whole technological equipment depot;

– early recognition of the faults and forecasting remaining lifetime applying the whole range of tools and methods of technical diagnostics;

– control of mining equipment components and assemblies at all life-cycle stage (initial stage, installation check, acceptance checkout, operation, pre-maintenance and post-maintenance control).

2 Setting the task

“Superior Highwall Miners” system for open-pit-to-underground mining is being successfully applied for decades [12, 13]. Models SHM-28 and SHM-29, produced by SHM Company (Berkley, Virginia state, the USA) are first systems of such kind being employed in Russia (Fig. 1). These systems are identical and allow extracting coal from the wall of the open-pit into the depth down to 270 meters. Adjustable swinging height of the executive element (from 1.2 to 3 meters) allows producing effective excavation of coal out of the seams with the thickness from 1.3 to 3 m.

Servicing experience of these two SHM-28 and SHM-29 complexes at ZAO “Razrez Raspadski” PAO “Raspadskaya” [14, 15] showed good results of coal excavation employing open-pit-to-underground method but revealed some peculiar disadvantages of this complex. Thus, the absence of a service center required creating and introducing the system of preventive maintenance for SHM complex based on monitoring its technical condition and forecasting its changes.

Fig. 1. Superior Highwall Miners Complex overview.

3 Research method

To monitor technical condition of the mechanical equipment vibration control method proved to be good [7, 10, 16]. It allows detecting about 77% of the wear-out failures. The vibration diagnostics is applied:

– for monitoring current condition of the equipment;
– for dividing the variety of possible technical conditions of the assemblies into two subsets – properly functioning and out-of-order;
– for detecting a possible failure at the early stage and forecasting its development in time;
– for reducing the risk of accidents;
– for estimating the remaining lifetime, periods and volumes of repair maintenance.

A number of vibration diagnostics methods are based on the fact that certain mechanical failures during their development generate vibration at certain frequency bands with definite ratio of the parameters values. These all require applying so called spectral masks to standardize the vibration level at different frequency ranges:

– $(0.5...2.5)\times f_r$ – for detecting imbalance and misalignment;
– $(7.5...15.5)\times f_r$ – for detecting failures in roller bearings;
– $(2.5...10.5)\times f_r$ – for preventing stiffness failures;
– $(z \pm 1)\times f_r$ – for detecting tooth-type coupling and stroke gear mechanism failures.

Here f_r is the rotating frequency of the driving engine, z – is a number of teeth.

To define "normal" condition of SHM equipment a "mid-normal" status method was used. In this method, the average values of the controlled parameters of the properly functioning machine obtained during processing the data of several repeatable measurements were taken as the criteria of "normal" functioning condition.

Selecting a type of defining the limits of a "good" condition depends on statistical dispersion of the registered data.

Firstly, the data, which raised doubts about their reliability, were excluded out of the data meant for analysis. To check the homogeneity of the selection, which characterizes the reliability of the statistical conclusions and to exclude from further processing the outlying data, connected with abnormal functioning of the machines it is reasonable to use rough-monitoring-errors criterion admitting that the obtained experimental number of vibration values (selection) complies with the distribution law.

$$X_{np}=X_m + S\, q_{q,n},$$

where X_m – is an arithmetic average of the measured results; S – the estimation of a mean-square deviation of the measured results; qq,n – fractile of a probability distribution taken from the significance level table α = 99% (qq,n=3).

All spectra, registered at cognominal check points were studied in a frequency range containing to 40^{th} harmonics of the rotor pivoting frequency for defining zones of the largest harmonic activity.

As far as ISO 2372 standard recommendations were taken as a ground for national standards of the industrially developed countries (including Russia) so while introducing the technical condition monitoring program reference spectral masks were used. They are introduced in table 1.

According to the requirements of Table 1, the reference spectral masks characterizing every type of the assembly unit used in SHM Complexes were built.

Table 1. Reference spectral masks.

Frequency band	**Coefficients to vibration velocity mean-square value V_{ef} or (V_{RMS})**	
	Alarm	**Warning**
10... 1000 Hz	1	0.63
2 (10) Hz ...1,5×f_r	0.75	0.50
2×f_r	0.50	0.32
(3...4)×f_r	0.32	0.20
(5...20)×f_r	0.40	0.25
(21...50)×f_r	0.25	0.20
Peak value of the vibration acceleration, m·sec.$^{-2}$		
1 ... 10 kHz	40	20

In Figure 2, the reference spectral masks of the right and of the left functioning element of drive gears are given as an example, their "warning" limit is coloured in yellow, and the "alarm" limit is coloured in orange.

The reference spectral masks for all assembly units (functioning element of a drive gear, drive gear of a loader, drive gear of a worm conveyor, drive gear of a high-pressure pump station and a cooling pump, drag conveyor drive, a loading belt drive) used in SHM complexes were built in a similar way.

4 Research results

The work on carrying out the vibration diagnostics was done in compliance with GOST ISO 10816-1-97 standard "Controlling the Condition of Machines Using the Vibration Measuring Results in Non-rotating Parts" and GOST 12.1.012-2004 standard "Vibration safety. General requirements".

The changes and the analysis of the vibration parameters were done using the data collector/analyzer device Kvarts CU-060 No.15 and a software program Diamante 2.04.

The constructed, according to the results of the initial testing, reference spectral masks allowed speeding up the process of analyzing the obtained, in the process of monitoring, data. It happened due to the issue that the results, where the level of the vibration signal did not go over "warning" level, were excluded out of the analysis.

For further analysis, two assembly components (a drag conveyor drive and a loading belt drive, Fig. 3) were taken. The elevated vibration that exceeded the "alarm" limit was registered in them.

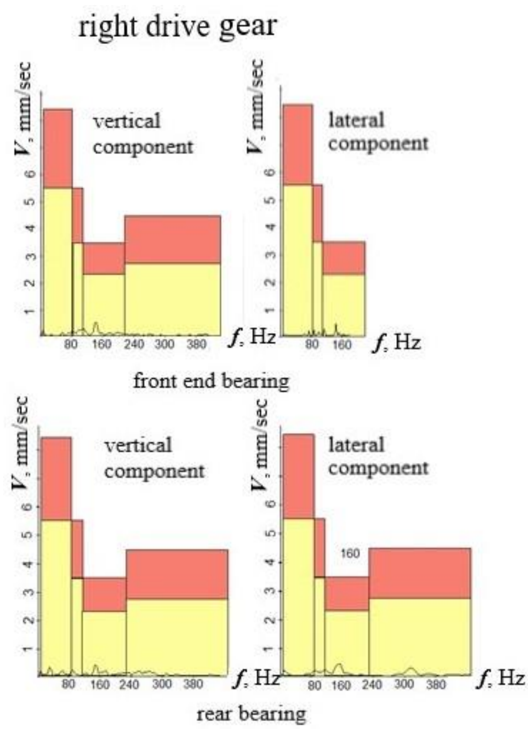


Fig. 2. Overall spectral masks for a cutting part of Superior Highwall Miners drive gears.

(a) (b)

Fig. 3. A drag conveyor drive (a) and a loading belt drive (b) of Superior Highwall Miners Complex.

According to the general level of vibration intensity, the technical condition of a loading belt drive is estimated as inadmissible one. The maximal value of the vibration intensity is registered at the front bearing of the reducing unit output shaft.

Fig. 4 shows vibration spectra at the rear bearing of a loading belt power driven hydraulic motor, Fig. 5 shows vibration spectra of a reducing unit output shaft.

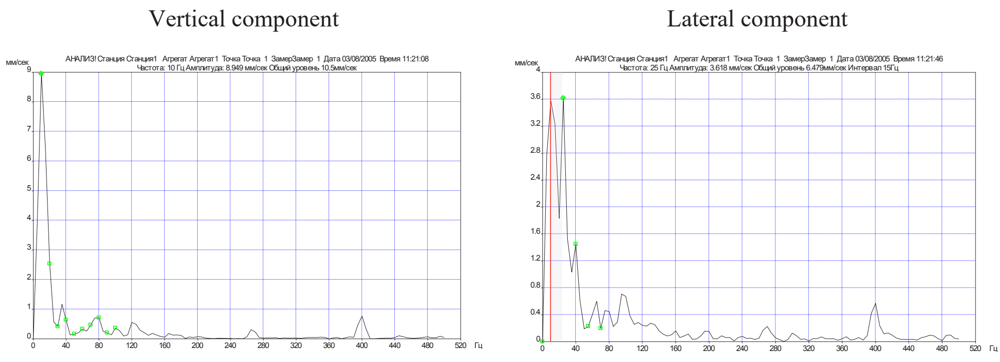


Fig. 4. Vibration intensity at the rear bearing of a loading belt power driven hydraulic motor.

Spectral analysis of mechanical vibrations indicates inadmissible imbalance of the reducing unit output shaft (and consequently, driving drum of the loader). The spectral components amplitudes at the frequency of ≅ 5 Hz reach inadmissible values (for example, at a vertical component of the vibration velocity measured at the second checkpoint, the amplitude of this component equals ≅ 17 mm/sec). Moreover, in this spectrum the tooth meshing frequencies are registered (secondary features of inadmissible imbalance reveal themselves). The analysis results allow confirming the necessity of the reducing unit output shaft and drum drive balancing.

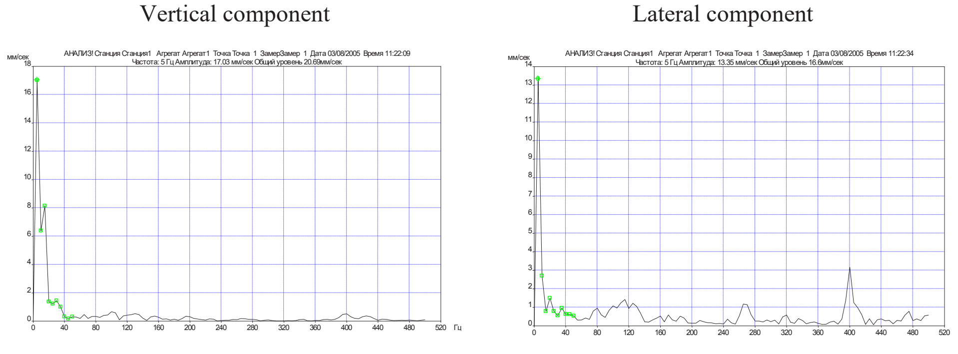


Fig. 5. Vibration intensity at a belt loader reducing unit.

According to the general level of vibration intensity, the technical condition of a drag conveyor drive is also estimated as **inadmissible**. Maximal value of the vibration intensity is registered at the rare bearing of a motor.

Maximal registered value V_{ef} *(or* V_{RMS})= 13.7 mm/sec. speaks for inadmissible vibration level of the electric drive motor (Fig. 6).

Spectral analysis of the mechanical vibrations indicate inadmissible imbalance of a motor armature. The reducing unit technical condition is admissible (the tooth meshing frequencies in the mechanical vibration spectrum are registered). It can be concluded (as a recommendation) about the necessity to carry out two-plane balancing of the motor rotor and an inspection of the reducing unit.

 https://doi.org/10.1051/e3sconf/202133002002

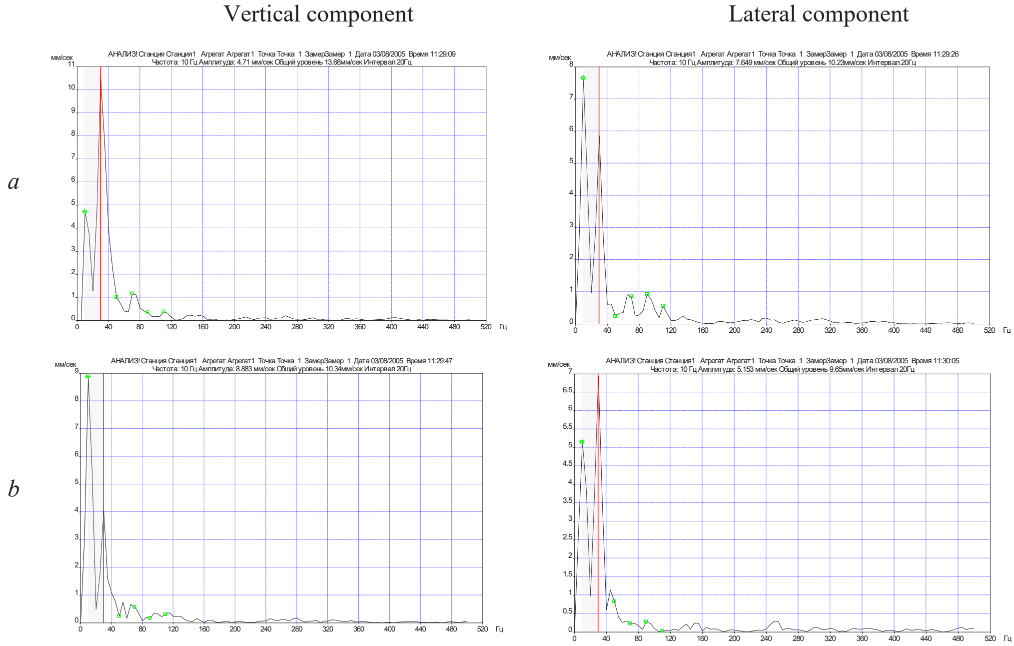


Fig. 6. Vibration intensity at the motor of a drag conveyor: a – front bearing, b – rare bearing.

5 Discussions

As it is known, the most effective vibration diagnostics method is the continuous (not less than 2 times per month) monitoring. This method allows obtaining accurate and reliable information about the condition of the equipment. This task is important for SHM Complexes, as there is no technical service centers in Russia. Monitoring the technical condition of SHM Complexes will allow creating a regulatory-procedural framework for estimating and forecasting technical condition using technical vibration parameters (for this purpose, a significant volume of statistical data is needed for constructing the forecasting models). Moreover, vibration parameters monitoring will allow both early detecting of the incipient failures with the estimation of their danger degree and becoming the bases for the development of the expert system for diagnostics of this complexes.

The fulfilling the abovementioned requirements and recommendations allowed significantly increasing the lifetime service of some components and assemblies of SHM-29 Complex and preventing failures and downtimes. It positively influenced on the productive capacity of the Complex and allowed minimizing the costs connected with the sudden failures.

Processing statistical data, captured during SHM-29 technical condition monitoring allowed constructing statistical pattern of the belt loader drive performance capacity loss (Fig. 7).

As it is seen from the chronometration readings of SHM-29 operation before and after implementing the developed measures on climatic adaptation of SHM complex hydraulic system and the developed “Procedures…” (Fig. 8) emergency downtimes and performance restoration of its components reduced. The coefficient of technical utilization increased nearly in 1.3 times from $K_{ТИ}$ = 0,617 to $K_{ТИ}$ = 0,824. The developed technical solutions on improving technical maintenance and repair of SHM-29 Complex based on using forecast estimates of the remaining lifetime of hydraulic-mechanical equipment will allow reducing the costs connected with emergency failures and optimizing storage facility logistics.

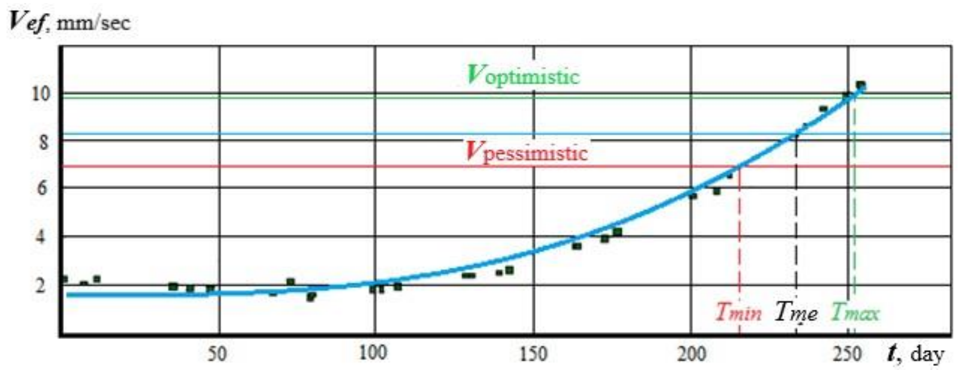
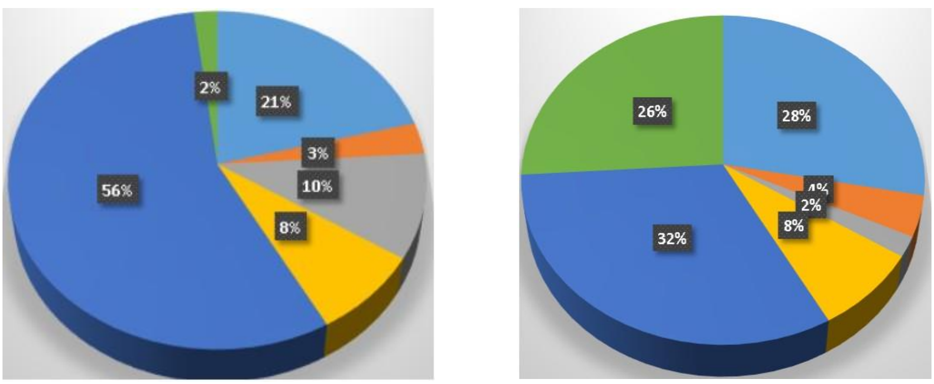


Fig. 7. Changing ef (RMS) vibration velocity in time under imbalance of the reducing unit output shaft



(a) (b)

Fig. 8. The analysis of chronometration readings of SHM-29 operation before (a) after (b) implementing the developed measures: here ■ - productive work period; ■ - auxiliary operations period; ■ - technical maintenance period; ■ - emergency repairs period; ■ - technological downtime period; ■ - operational delays period.

The reported study was funded by RFBR and Kemerovo region, project No. 20 45 420018\20.

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