Developing the methodology on creating unified criterion for diagnosing the mining machinery equipment defects

P B Gerike¹ and P V Eshcherkin²

¹Federal Research Center of Coal and Coal Chemistry of Siberian Branch of the Russian Academy of Sciences, 10 Leningradskiy Ave., Kemerovo, 650065, Russia
²Branch of T.F. Gorbachev Kuzbass State Technical University in Belovo, 32a Ilyicha str., Belovo, 652644, Russia

E-mail: am_besten@mail.ru

Abstract. In the framework of the research the consolidation of the results on analyzing vibration parameters, registered during operation of electric shovel energy-mechanical equipment (of EKG and ASH type) was fulfilled. It was done in the respect of solving the problem on improving vibration control methodology and developing unified criterion for diagnosing and forecasting technical condition degradation of open-pit excavator dynamic equipment. Methodology for creating the algorithm for unified diagnostic criteria on the basis of mathematical processing of the existing vibro-diagnostic properties during detecting the defects in rolling bearings and jointing sleeves used in designing electric shovels was worked out. The effectiveness of the introduced approach for selecting diagnostic methodology of obtaining initial data suited for developing unified diagnostic criteria was proved. The results showed the effectiveness of the methodological approach for creating the algorithm of developing unified criterion for detecting technical condition and forecasting the degradation processes of rolling bearings and jointing sleeves used in designing electric shovels.

1. Introduction

The share of the mining equipment in unacceptable condition used in Kuzbass open-pits and mines totals 25 percent of all the technical devices that are subject to industrial safety expert reviewing. The combination of preventive and emergency maintenance systems exploited by the enterprises nowadays make it possible to use defective equipment provoking the manifestation of the emergency situations and significant emergency downtime by it. The existing protocols of assessing technical condition of the mining equipment by the vibration parameters are non-perfect, they hinder the interpretation of the controlling data and cause the difficulty in detecting defects in case there are alternating impact and other factors that change the frequencies [1, 2, 3].

In the framework of the researches performed on the RFBN grant # 20-48-420010/20 given for researching the parameters of the vibration loading of completely foreworn mining machines mechanisms the sampling of twenty electric shovels of EKG and ASH type was done. These machines were used in coal open-pits of Kuzbass and were subjected to the procedures of industrial safety expert reviewing.

The basic purpose of the research is to create unified diagnostic criteria (UDC) based on the results of vibration parameters analysis; the vibration is generated during the operation of the basic energy-mechanical equipment of electric shovels (generating groups, steering gears, hoisting winches) and...
these criteria can help in effective and fast diagnoses of real technical condition of the tested technical devices. Another purpose of the research is in improving methodological approaches to diagnosing complex mechanical systems through solving the problem on short-term forecasting of changes in components and assemblies of mining machinery dynamic equipment technical condition. The selection of certain diagnostic features and parameters essential for creating UDC for each group of monotypic defects will be unique as it will be changing depending on the type of the tested objects and their operation mode [4]. Rolling bearings and jointing sleeves were chosen as the objects of the given research (see defects samples in the figure1-3). These rolling bearings and jointing sleeves are used in designing the components and assemblies of electric shovels that is why the set of diagnostic techniques for identifying vibro-acoustic signal parameters is limited in the framework of the given research by the results of the integrated diagnostic approach which covers direct spectral analysis, kurtosis and envelope analysis. The composition of these vibro-diagnostic methods is the most optimal and allows getting maximum useful data under minimal labor costs considering the specific character of the studied sampling and measuring methodology.

2. Achieved results and application

The created unified diagnostic criteria can be interesting from the perspective of simulating degradation processes in complex mechanic systems. Imperfection of the existing mathematic models meant for forecasting the defect growth processes on the basis of analyzing the vibration generated during mining machinery equipment operation is conditioned by low application area, low approbation level of the received results and insufficient number of simulation diagnostic feature sets [5, 6]. The basic reason for deficit of universally applicable mathematical forecasting model in the software market for today is poor knowledge in mining machinery dynamics and limited volume of data on monotypic mining device equipment vibration parameters. The results of the integrated approach to analyzing vibration parameters and developed unified diagnostic criteria give the opportunities for improving the existing models. It will allow giving short and medium-term assessment to the processes of changes in tested technical devices condition.

The occurrence of random components of the frequency spectrum influences significantly on the application area of the developing UDC. This occurrence can be caused by mistakes made while choosing the installation place for a detector, damages in “detector-wire-device” system, shock stress and/or temperature change, unpreparedness of the measuring surface etc. That is why it is important to apply filtration procedures that allow getting “clear” signal free from blurring and random noise while creating algorithm of UDC calculation [7, 8].

Putting into practice short and medium-term forecasting models which will allow assessing technical condition and predicting its change in time interval that finishes right after the latest maintenance meets the requirement of the acting preventive maintenance system at most. The most effective solution of the problem with the specified conditions is using adaptive short-term forecasting algorithms that take into account the change in the input parameters and the correction of the forecasting method parameters made on their basis. It allows the models of that type to change fast adapting to the environment [4, 9]. The analysis of the scientific works devoted to simulating the processes of mechanical systems technical condition degradation shows that the application area of the majority of the existing algorithms is limited by monotypic simple mechanical objects and upon this the reliability of the results obtained by applying the existing software complexes depends strongly on the type of the diagnosing object and the quality of the original signal [10].
Figure 1. Joining sleeve defect at the side of the right electric engine of the EKG-10 excavator delivery head.

Analyzing the parameters of the vibration generated during the operation of the electric shovel dynamic equipment allowed grouping the defects of the mining machineries for that type into seven basic groups (failure in stiffness system; toothed wheel gear defects; unbalancing of the rotating parts; misalignment, shaft misalignment and bending; jointing sleeve defects; rolling bearing defects and failure in their lubricating mode; electric origin defects). Over a hundred of diagnostic features in the sphere of analyzing vibration parameters the majority The majority of the features underwent formalizing process for convenient use while working out the algorithm of UDC creation for diagnosing components and assemblies of dynamic equipment.

Figure 2. The example of multiple defects occurrence on a small generating group of ASH 11/70 excavator. Inadmissible rotor imbalance of auxiliary generator, vivid failure stiffness system, failure of a bearing fit and its lubrication mode.
At present, there is no UDC which is based on the results of vibration analysis parameters appropriate for diagnosing rolling bearings and jointing sleeves of excavation shovels and application of which in practice would allow getting maximum of useful data under minimal labor costs spent on initial data analysis.

The received in the framework of this research results allowed forming basic diagnostic features acceptable for assessing technical condition of the analyzed objects on the vibration parameters and admissible for developing unified diagnostic criteria for assessing and forecasting technical condition of the rolling bearings and jointing sleeves used in designing excavation shovels, in particular:

1. General level of the signal and a peak value on vibration acceleration parameter within the range of 50…10 000 Hz;
2. General level of constituent bearing frequencies on vibration velocity and vibration acceleration parameters in standard and expanded frequency band;
3. General level on vibration velocity parameter in the area of low and medium frequency spectrum that contain signs of defects in the jointing sleeves;
4. Modulation depth of the spectrum that envelops the vibration signal in the area of frequencies generated by the defects of jointing sleeves and fluctuation level of significant harmonics at reference, intermediate and modulation frequencies (see figure 1);
5. Restricted level on vibration velocity parameter in frequency bands including the frequencies of bearings and jointing sleeve defects manifestation;
6. Specified value of the kurtosis calculated for the bearings with constant speed fitting shaft;
7. Match criteria defined on the comparative results of enveloped real and referenced signals spectrum characteristics.

The analysis findings of vibration parameters for open-pit excavator energy-mechanical equipment prove the effectiveness of utilizing the results of comprehensive approach to diagnostic process. The comprehensive approach data should supplement each other in case there are mixed controlling results and the set of the applied diagnostic techniques must be limited by time costs and benefits of carrying out the control and the following testing [11, 12]. Thus, UDC developed for diagnosing separate elements of the mining machinery equipment must be based on the comprehensive analysis of polyharmonic waves parameters generated during the operation of the equipment.

Figure 3. Multiple defects of auxiliary generator bearing for a small generator group of ASH 10/70 excavator (the development of the retainer crack and changing the form of roller bearing).
The analysis of the scientific papers devoted to the development of unified criteria for assessing vibration parameters vividly prove the effectiveness of applying scalarization algorithm for developing UDC meant for diagnosing technical condition of single-type mechanical objects [4, 13, 14, 15]. Applying scalarization mechanisms is based on stepwise division principles which divided technical equipment into different groups depending on the degree of the defect development and allows substituting the diagnostic properties vector set on scalar observation. While creating UDC for diagnosing jointing sleeves and bearings used in energy mechanical equipment of the mining machines it is important to take into consideration the specificity of the algorithms applied for diagnosing these parts and the analysis of the registered characteristics and also it is important to clean the spectrum from “extra” harmonics which are not connected to the studied defects i.e. to perform a clipping procedure (see the examples in figures 2 and 3). The given procedures should filter the initial data and use rotational frequency adjusting algorithm applied on the principles of detecting spectral components with maximum amplitudes in a low frequency band. Considering the number of the existing algorithms the preference, in the framework of the paper, was given to the procedure the application of which is the most effective for technical devices with inexact maximum of rotational frequency varying [4, 16].

3. Conclusion

The analysis of the diagnostic data received in the framework of the research, proves the effectiveness of the introduced methodology for developing UDC and the importance of comprehensive approach to analyzing vibration parameters for developing unified criteria meant for substituting the whole group of cumbersome diagnostic features and rules for detecting dynamic equipment defects by vibration-based-diagnostic methods. The developed unified diagnostic criteria meant for assessing degradation processes in mining machinery equipment and the vibration parameters analysis based on them can be used as basic elements for maintenance of the operating equipment considering its physical state. The use of such criteria as modelling criteria in adaptive degradation processes allows carrying out short- and medium-term forecasting of the mining machinery equipment defect development processes. Considering the condition of the currently existing combination of the operating equipment preventive and emergency maintenance systems applied at mining enterprises of Russia it fully covers the demand on forecasting. Utilizing the introduced methodological approaches to improving the assessment system of mining machinery real condition will allow Russian mining enterprises to transfer to a brand new system of mining equipment maintenance that will minimize the probability of the break downs caused by technical conditions of the operating equipment, reduce non-production downtime of the expensive manufacturing equipment and increase the safety work of maintenance personnel at the industrial enterprises.

Acknowledgements

The research was carried out with to the financial support of the Russian Foundation for Basic Research and Kemerovo Region in the framework of the scientific project # 20-48-420010.20.

References

[1] Gerike P B 2017 News of the Ural State Mining University 3 60–64
[2] Pozhidaeva V 2005 Proc. of World Tribology Congress III (Washington, D.C., USA)
[3] Reference book 2005 Non-destructive Testing vol 7 ed. V V Klyuev (Moscow) p 828
[4] Sushko A Ye 2007 The Development of Special Mathematical and Informational Software for Automated Detection of Complex Systems Cand Sci. Thesis in Engineering (Moscow:MEPhI) p 170
[5] Puchalski A and Komorska I 2018 Applied Condition Monitoring 9 91–101
[6] Balducchi F, Arghir M and Gaudillere S 2014 Proc. of ASME Turbo Expo 2014: Turbine Technical Conference and Exposition GT2014 (Düsseldorf, Germany)
[7] Puchalski A 2015 Mechanical Systems and Signal Processing 56-57 173–180
[8] Trebuna F, Šimčak F et al 2014 *Engineering Failure Analysis* **37** 86–95
[9] Gerike P B 2015 *Bulletin of Kuzbass State Technical University* **3** 11–19
[10] Schreiber R 2016 *Proc. of the 17th Int. Carpathian Control Conf., ICCC* pp 668–672
[11] Shardakov I, Shestakov A et al 2018 *Proc. of AIP Conference Proceedings* **2053** 040090
[12] Shirman A R and Solovyyov A B 1996 *Practical Vibration-based Diagnostics and Monitoring of Mechanical Equipment* (Moscow) p 276
[13] Barkov A V, Barkova N A 2004 *Vibration-based Diagnostics of Machinery and Equipment Analizing Vibration. Studybook.* (Sankt-Peterburg: SPSMTU) p 156
[14] Wang T, Han Q et al 2019 *Mechanical Systems and Signal Processing* **126** 662–685
[15] Ghasemloonia A, Rideout D G and Butt S D 2013 *J. of Energy Resources Tech.* **135** 032902-1
[16] Gerike P B 2014 *Bulletin of Kuzbass State Technical University* **1** 26-30