A new approach to predictive modeling of dragline equipment

P B Gerike and V I Klishin
Institute of Coal, the Federal Research Centre for Coal and Coal Chemistry, Siberian Branch of Russian Academy of Sciences, 10 Leningradskiy pr., Kemerovo, 650065, Russia
E-mail: am_besten@mail.ru

Abstract. This paper is an attempt to generalizing analytical data on vibration parameters of powered mechanical equipment of draglines with a view to solving the problem connected with development of unified diagnostic criteria for short-term degradation modeling aimed at prediction of technical degrading of test objects. The goal of this study is to colligate experimental data on parameters of vibration generated in operation of dragline equipment with intent to classify signs of the equipment defects into reference groups for convenient formalization. This research used the expanded range of diagnostic methodologies, including spectral analysis in broadened frequency and dynamic ranges, analysis of runout characteristic, excess and analysis of spectrum envelope. The research findings prove efficiency of the proposed methodology for normalization of mechanical vibrations and the algorithm for creation of unified diagnostic criteria usable as basic elements in the system of mining machinery maintenance by the actual technical condition.

1. Introduction
As of today, there is yet no universal mathematical forecast model to reliably describe mining machinery degradation by analyzing parameters of vibration and predicting defects of mechanical (bearings, gear transmission, coupling, axis misalignment and unbalancing of revolving parts) and electrical nature (coil bridging, faulting of rods, disfunction of stator-to-rotor gap, etc.). The underlying conditions are insufficient knowledge of mining machinery dynamics, limited data bases on vibration parameters of standard-type and model-type mining equipment, as well as difficulties in interpretation of experimental research findings [1, 2].

As a rule, the available mathematical models on the software market for vibration analysis have common disadvantages. For instance, they can model degradation processes for a limited number of structural members (electrical engine bearing of dragline) or a group of the same type defects (modeling of a unified criterion of bearing frequencies). It is often that a model parameter is only general vibration. Furthermore, the common fault of the most models is low-level validation of the obtained results when developers limit themselves to a small sampling of the same-type objects. The modeling results obtained for a structural element or a group of basic defects are often extended to the whole complex mechanical system, which discredits adequacy of the mathematical models [3, 4].

The subject of this research is dragline. The sampling includes 25 draglines. The collection period of test information coincides with the repeatability of the industrial safety expertise of hazardous production objects and is from once to three times a year. Within this research, we used an expanded range of testing procedures, including spectral analysis in broadened frequency and dynamic bands, the analysis of runout characteristics, excess and the spectrum envelope analysis. Such combination of
the methods is optimal for the analysis of parameters of vibro-acoustic waves generated in operation of powered mechanical equipment of mining shovels, which is substantiated in [1, 5].

The problem connected with mathematical forecast models of actual degradation of various facilities and devices was addressed by V.V. Klyuev, Yu.M. Krakovskii, A.S. Goldin, A.V. Barkov as well as by many other Russian and foreign researchers.

However, the forecast model capable to describe reliably technical degradation of electrical excavator equipment generally in the short- and mid-term yet remains to be created. The limits of integral vibration are strictly specified for powered mechanical equipment of mining shovels. At the same time, it is often impossible to predict the rate of defect growth and the moment of failure due to unthoroughness of a forecast model and owing to the narrow application range of the limit state criteria for mining machinery. Thus, forecasting of the change in the technical state parameters of intricate mechanical systems in terms of equipment of draglines based on the analysis of vibration is a relevant scientific problem.

2. Results and implications

The analysis of the data obtained in the framework of this research allows grouping defects of powered mechanical equipment of draglines into 6 groups. Depending on the risk of random failures, their causes and propagation, all defects can conventionally be divided into two prime segments (the first segment embraces defects that can cause emergency stop of equipment within a minimum set span of time; the second segment rakes all other defects). The main defects of dragline equipment are misalignment (figure 1) and/or skewing of shafts (including the lift and pull reduction gears), weakening of platform, unbalance of revolving parts (in particular, imbalance of rotors, figure 2), damage of bearings (breach of lubrication mode, weak seat, enlarged clearances, defects of rings and separators, transformation of rolling bodies, figures 3 and 4), defects of gear transmissions and couplings, electrical damage of generators and motors. These faults are described by around 100 diagnostic characters in the area of vibration control. A half of these characters can be formalized to be used in development of unified testing criteria for assessment of actual condition of mining machines.

Depending on the cause of origin (violation of manufacture or assembly technologies, operational defects), risk and propagation rate, the formalization process involved first of all defects accompanied by high-energy events in the low and medium frequency range, as well as defects represented by many clear attributes in the spectral analysis.

Draglines can have many defects; for this reason, the clipped-noise modulation algorithms are developed to reveal information components of a defect in the conditions of implicit maximum of rotation speed. The number of the clipped-noise modulation algorithms should equal the maximum
possible number of defects of dragline equipment, while the array of diagnostic information should be filtered in order to eliminate influence of unreliable data due to procedural violations in measurements, faults of connector cables or error of mathematical processing of signals [6].

The inherent stage of a forecast model algorithm is selection, substantiation and valuation of limit criteria for the assessment of actual technical condition of test equipment by the parameters of vibration generated during the equipment operation [7, 8].

![Figure 2. Mature unbalance of pull generator rotor in dragline ESH 15/90.](image)

For each unified criterion, it is required to define a unique set of diagnostic properties and indexes which give the fullest description of condition of a test object [9, 10]. For instance, from the research results, the efficient collection of diagnostic properties of gearing within the pulling winch reduction unit includes:

- Assessment of maximum amplitudes of the “gearing” frequencies in the standard frequency band by the parameter of vibration velocity;
- Contribution of the “gearing” components in the total root mean square values of the vibration velocity and vibration acceleration in the standard and expanded frequency bands;
- Modulation rate of the “gearing” components, presence of subfrequencies and overtones of harmonic series having signs of gearing defects, fouling of the main harmonics of the “gearing” nature with adjacent frequencies;
- Presence of misalignment and skewing of reduction shafts in spectrum [fR… 4…6fR]);
- Increment of noise components and fluctuation of harmonics at the “gearing” frequencies.

Normalization of contribution of the “gearing” spectrum components and levels in frequency bands is a separate major problem addressed by many scientists. The main difficulty of this problem consists in the fact that when the test object is replaced, vibration parameters should be normalized again [11–13]. The available recommendations on estimation and normalization of vibration of mining machines, in particular, draglines were assumed as the basis for normalization of the “gearing” components to the overall vibration, and were used by the present paper authors in development of an algorithm for creating a unified criterion for assessment and forecasting of actual state of gearing transmissions.

The obtained results prove efficiency of the proposed collection of diagnostic properties in formation of a unified criterion for gearing transmissions [12]. The key advantage of the adaptive model is its capability to use a set of the unified diagnostic criteria, which allows assessing and forecasting operation of all assemblies and elements of powered mechanical equipment for draglines. The current forecasting models mostly simulate the overall vibration by the parameters of vibration velocity. Moreover, the application range of such modeling results is often limited to a minimum
family of the best studied test objects, which complicates or even makes it impossible to use the results in prediction of technical degradation of complex mechanical systems.

Figure 3. Shortage of oil of swiveling device motor bearing in dragline ESH 6/45.

Figure 4. Defect of bearing inner ring in input shaft in swiveling device reduction unit of dragline ESH 13/50.

Forecasting of change in the technical condition of process equipment is the basic element in the mining machinery maintenance with regard to its actual technical condition. In the meanwhile, efficient logistics and warehousing are impossible without such maintenance. Coal mines in Kuzbass employ the scheduled maintenance system, which makes long-term prediction unnecessary for mine repair units. It seems to be important to carry out the shot- and medium-term forecasting which answers the main question of the scheduled maintenance: whether the test object is capable to operate until the next maintenance or repair.

The problem is most effectively solved by the adaptive short-term degradation prediction for assemblies and units of shoveling machines based on the fresh vibration measurements, correction of the model parameter on this base and adaptation of the model to the change in the input data.

Improvement of methodology for normalization of parameters of vibration generated during operation of draglines within the framework of this research used individual highly detailed spectral masks developed for all assemblies of powered mechanical equipment of draglines. This approach to normalization of vibration parameters is advantageous for flexible adjustment of the parameters and maximum allowable values of some frequency bands, which offers ample opportunities for refinement of forecasting models. The analysis of the data bank by vibration parameters of equipment on
draglines ESH made it possible to select the most efficient frequency ranges for assessment of actual condition of reduction units on the lift and pull winches, as well as to develop individual allowable values for each range with regard maturity of basic defects.

Misalignment and skewing of shafts in reduction units of draglines, usually a consequence of ill-skilled repair, are the often cause for rapid buildup of gear defects such as increased abrasive wear, pitting corrosion, roughening or binding of teeth. To take into account these processes in development of a unified criterion for reduction units, it is required to analyze modulation frequencies of tooth changeover, level of noise and fluctuations in amplitudes of significant harmonics. The spectral analysis outcome in the unified criterion framework should be added with diagnostic properties in the analysis of the spectrum envelope and temporary implementation of vibro-acoustic signal parameters. This combination of the vibro-test methods will enable the fullest solution of applied problems with the development of the unified criterion for assessment and forecasting of technical degradation of reduction units. An illustration of the aforesaid is in figure 5 in the form of the misalignment of shafts in the first and second steps of the pull winch reduction unit of draglines ESH 10/70. The misalignment brought considerable modulation of spectrum components reflective of double-quick abrasive wear of gear wheels. The data obtained from the spectral analysis were added with the examination results on the spectrum envelope in the range of the “gearing” components in the low- and medium-frequency range, which proved validity of the conclusions drawn about the required centering adjustment of shafts of pull reduction units.

![Figure 5. Misalignment of shafts in pull winch reduction unit of dragline ESH 10/70.](image)

3. Conclusion

The efficiency of the unified diagnostic criteria is greatly governed by distortion of outlet signal parameters. When spectrum contains spurious components, diagnostics is erroneous and the use of the unified criteria is impossible. Distortion of spectrum is usually caused by the improper selection of sites for measurement transducers, damage of cable connections of vibration measuring instrumentation, high impact loading during measurement, unpreparedness of measurement surfaces and by some other causes [3, 14]. The problem can be solved using filtration modules that can remove distortions and noise from the initial diagnostic data. The example of the fruitful application of the adaptive model with the unified diagnostic criterion as the main modeling parameter of misalignment is forecasting of faultless operation of small generator group of dragline. The model showed high efficiency with the selected set of objects, which enabled productive maintenance planning and minimization of expenses connected with probable outage time [1]. Under conditions of scheduled maintenance, it is also of practical interest to assess remaining life of mining machines with expired
normative period of operation. This problem would be impossible to handle without finding trends of
deterministic component of vibro-acoustic signal, which is the first-order condition of the short- and
medium-term prediction using adaptive exponential models [1, 7, 8]. The existing mathematical
models of this type have very limited application range, which calls for their further development [6].

The novelty and the distinguishing feature of the proposed model as against the algorithms
currently in use is that this is the integrated approach undertaken for the first time to utilization of
model parameters, i.e. prediction of change in values of unified diagnostic criteria of technical
condition of every unit in a test mechanism. As a result, this will make it possible to forecast changing
of the total complex mechanical system. The unified diagnostic criteria created for each group of
defects are described with maximum efficiency using algorithms of scalarization for multidimensional
space of diagnostic properties [7].

4. Conclusion

The scheduled maintenance system now in force in coal and ore mines in Kuzbass is obsolete and
incapable to effectively handle problems connected with quality of repair, assessment of residual
lifetime of equipment, supply and logistic of mine repair units. The methodological approach proposed
in this paper to modeling technical degradation of complex mechanical system is of high practical
importance. This approach can be used to build predictive models based on modeling changes in
vibration parameters which are suitable for forecasting actual condition of many mining machines.
And this is one of the basic conditions of equipment maintenance based on factual condition [12, 15].
The research findings prove that the developed unified criteria can be used for efficient assessment
and prediction of technical degradation of mining machinery. The application of the proposed
methodological approach to the analysis of vibration parameters will enable transition to maintenance
of mining machines based on the factual condition, which will reduce risks of accidents and
unproductive downtime of process equipment, and will improve mining safety with minimization of
cost.

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