Analyzing the vibration parameters of gas-cleaning units operated in coal and mining industry of Kuzbass

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Abstract. Some research results on analyzing parameters of vibration generated during operation of different types of gas-cleaning and aspiration systems dynamic equipment exploited at Kuzbass coal and mining enterprises are generalized in the paper. An attempt to give grounding for developing diagnostic criteria for assessing technical condition of these equipment was done. The purpose of the research is in improving the existing techniques for standardizing vibration parameters and creating an algorithm for developing unified diagnostic criteria based on diagnostic features and rules classification applied for detecting the industrial fan dynamic equipment defects. In the framework of the research a comprehensive approach to analyzing vibration was applied and the obtained results proved the effectiveness of the introduced set of diagnostic techniques for analyzing vibration parameters of industrial fans and for the development of unified criteria of evaluation and forecasting. The obtained scientific results confirm the general effectiveness of the introduced approach to analyzing vibration parameters using the developed unified criteria for diagnosing physical state of the industrial fans.

1. Introduction
The development of modern means and methods for nondestructive evaluation and technical diagnostics made it possible to detect defects in metal structures and energy and mechanical equipment of different sophisticated mechanical systems. Thus, the only method for nondestructive evaluation which allows getting maximum useful information about the real technical condition of the technological equipment without its stopping and/or disassembling is vibration analysis method [1, 2]. The best results in the process of diagnosis can be reached applying comprehensive approach to analyzing vibration parameters and it allows excluding incorrect hypothesis about the real condition of the assembly units due to excluding the impact of coincidence of frequency diagnostic features factor and the manifestation of these features is caused by sometimes diametrically opposed reasons. The whole range of Russian and foreign authors devoted their researches to substantiating the effective implementation of the comprehensive approach to analyzing vibration parameters [3, 4, 5, 6]. However, in all cases the selection of optimal set of diagnostic techniques for analyzing vibration parameters is always defined by the type of the tested unit, structural features and peculiarity of its operation mode.

Gas-cleaning units and aspiration systems operated in Kuzbass coal and mine industry were chosen as an object for the present research. The issues of the expanded analysis of vibroacoustic wave parameters were studied by sampling thirty units of aspiration system equipment (fans, gas-cleaning units of different types and constructions). The analysis of the obtained data allows concluding that the
most widespread defects in the equipment of this type are: electromotor rotor imbalance, installation gear misalignment, bearing defects (including loosening the seating fit and lubrication rate misbalance), jointing sleeve elements defects, fan impeller runout, failure in the support system stiffness.

2. Results and application

The presence of the most common defects of aspiration systems such as gear misalignment, support system stiffness failure in diagnostic features spectrum are presented in figure 1. The technical condition of the unit is inadmissible and high general level of vibration loading, significant noise level and harmonics fluctuation of the spectrum indicate it.

![Figure 1. Gear misalignment and support system stiffness failure in the aspiration system AS1 -1.](image)

Considering the specificity of the construction and actual operating conditions of aspiration system units it is impossible to use only one vibration control method for effective monitoring of vibration parameters and timely detection of the basic defects. Moreover, for today there is no unified universal method which can be successfully applied in the framework of express-testing and intermittent monitoring and also to be used for excluding contradictory diagnostic features of defects presence [2, 7]. Thus, integrated use of different diagnostic techniques for vibration parameters analysis will provide timely detection of the equipment defects and substantiate the recommendations for their correction. The results of the carried out research confirm that the most effective results of gas-cleaning unit operation with minimal time loss spent on measuring and analyzing the obtained data can be reached using comprehensive approach to vibration parameters analysis including spectral analysis in expanded frequency and dynamic ranges, kurtosis and enveloping analysis.

Another most common gas-cleaning unit defect is the misbalancing of rotating elements, for example of motor armature or fan impellers (see figure 2). This type of the defect is dangerous because when reaching a certain level of highly-energetic, low frequency processes formation (usually due to the presence of collateral damages such as gear misalignment and support system stiffness failure) it can cause accidental failure of the unit, separation from bearing supports and partial or complete destruction. All these can also cause significant risks and threaten the life and health of the unit operational staff. About ten diagnostic features correspond to the given defect and they are mostly concentrated in the sphere of spectral analysis, rotor path analysis and time realization analysis [8]. To simplify the interpretation of the obtained results, in the framework of the given research, during developing the algorithm of creating unified diagnostic criteria for gas-cleaning unit equipment, in this case, it was decided to limit the data by the results obtained by applying spectral analysis.
Perhaps, the most studied object from the point of view of vibration-based diagnostics is rolling bearings. They are widely used in constructions of sophisticated mechanical systems owing to high service performance and low price. Figure 3 demonstrates the presence of a developed motor bearing defect in a diagnostic features spectrum and the levels of significant harmonics confirms inadmissibility of its further utilization due to the cage carrier strain and changing the rolling element form. In many cases the problems during diagnosing roller bearings can be caused by non-observance of measuring technique, signal attenuation and coincidence of frequency features of defect presence. That is why, in practice, it can be difficult to detect a certain type of a roller bearing defect or the combination of different types of defects in one roller bearing. In view of this, to increase the effectiveness of the analysis findings the researchers in different countries offer the methodological approach that takes into account the results of applying unified diagnostic criterion as each one of them can substitute a large number of cumbersome diagnostic features and rules and reduce significantly the time required for analyzing initial data and increase the effectiveness of the roller bearing defect detection [3, 9, 10].

Figure 2. Inadmissible misbalance of aspiration system unit AS-7 motor armature.

Figure 3. The developed roller bearing defect from the side of electromotor exposed end of LIOT gas-cleaning unit.
The most common defect of aspiration system unit installation is a gear misalignment and/or belt pulley misalignment [2]. This defect speeds up the wearing-out of roller bearings and belts, reduces general operational resource and the unit performance factor (see figure 4). About five basic diagnostic features correspond to misalignment in the sphere of spectral analysis. Moreover, the sphere of rotor path analysis and time realization analysis contain a number of features. The contribution level of separate harmonics and their linking into overall vibration level depends on the number of the reasons such as the type and the stage of the defect development, structural peculiarities and the operation mode of the unit. A part of the features can coincide with other damage features such as stiffness system failure or rotor unbalance and it complicates the interpretation of the obtained results [11].

![Figure 4. Belt pulley misalignment of the aspiration unit.](image)

The defects connected with physical condition of the belt pulley such as cracking, beating and twisting of the belts bring about significant harmonic activity on harmonic series of the belt frequency shifting (depending on pulley diameter, number and length of the belts) its harmonics and overtones. Frequency features of the given defects group are focused on low-frequency region of a spectrum their distinctive features are the occurrence of significant set of components with close spread sampling which can reach large amplitudes and contribute significantly into overall level of the aspiration unit vibration loading [12].

One more defect of gas-cleaning and aspiration units which can be relatively rare met in the objects of the studied selection (<10% of the total number of technical devices) is operational damages of the fan blades (cracks, chippings, changing the shape of the blades). Overall vibration level can reach significant values due to the presence of this defect and exceeding the limits it can cause the separation of the blade elements and destruction of the structures [13]. Apart from non-productive downtime caused by accident failure of the unit it can implicate significant risks for life and health safety of the unit serving staff (see figure 5).

The results of vibration parameters analysis obtained during the research were used as a basis for developing the complex of diagnostic features and rules for detecting the defects of aspiration and gas-cleaning units. The obtained data can be applied in predictive simulation of the diagnostic equipment defects and damages development. They also can be useful in developing unified diagnostic criteria for evaluating the dynamic equipment of the aspiration system condition.
Figure 5. The defect in VTs 4-75 centrifugal blower rotor blade of PV-1 combined extract-and-input system of ventilation.

The analysis of Russian and foreign scientific papers devoted to the topic of the research showed that the existing mathematical models meant for forecasting the processes of changing the technical condition of sophisticated technological equipment based on the vibration parameters analysis are imperfect. The majority of these models are meant for predicting changes in physical state of separate components situated in energy-mechanical equipment of the machinery and mechanisms (usually, roller bearings installed in the shafts with constant speed frequency are taken as simulation objects [2, 3, 14]). As a result, the implementing sphere of such forecasting models is rather limited and their approbation data are not sufficient enough for obtaining the reliable simulation results. The drawbacks in the existing forecasting models can be explained by insufficient knowledge about aspiration unit dynamics, limitation of theoretical platform and data bases on vibration parameters for monotypic energy-mechanical equipment of gas-cleaning and aspiration units and complications that arise during interpreting the analysis results taking into account different operational modes of the tested equipment.

At present, there are no unified diagnostic criteria for evaluating fan impellers condition of gas-cleaning and aspiration units in the world. Consequently, the developed, in the framework of the research, criterion will be unique considering that it is based on the results of comprehensive analysis of the vibration parameters applying different techniques of vibroacoustic diagnostics. The results of applying the criterion exclude the necessity of using a large number of cumbersome diagnostic features and rules.

Nowadays due to the specificity of the preventive maintenance system it is not important whether the unnecessary replacement of the component which is still in a good technical condition by a new one has been done in the framework of a scheduled maintenance. It is more important to know whether the testing object can operate without any failure till the moment of a scheduled maintenance.

The realization of the algorithms for short-term adaptive simulation based on the principles of using the freshly obtained diagnostic information and meant for building the forecast for about one month period proved its best [3, 15]. The parameters of such model adapt fast for sudden change of the incoming terms and it is an important condition for carrying out short-term degradation process forecasting of complicated technical devices real condition. Unified diagnostic parameter (UDC) taken as simulation parameter can substitute large number of diagnostic features and rules [2, 3]. The
The majority of the existing unified criteria based on vibration parameter analysis principles are focused on detecting roller bearing defects [16].

The fundamental difference of the research carried out in the framework of the given paper is in the attempt of creating unified criterion for diagnosing the defects of industrial fans. It will allow expanding the application boundaries of the existing methodological approaches to analyzing and forecasting the equipment technical condition changes in aspiration and gas-cleaning units.

Using the algorithm for creating UDC filtering and clipping procedures will allow cleaning the signal from “extra” harmonic components as their presence complicates the initial diagnostic data analysis. Unified criteria if used as simulation parameters in mathematical forecasting model allow obtaining fully adequate forecasting results which characterize physical state of the sophisticated mechanical system on the basis of vibration parameters analysis data.

When developing the UDC for detecting fan impeller defects, in the framework of the research, the combination of diagnostic criteria is offered to use and it includes:

- the analysis of the overall level of vibration velocity and vibration acceleration in standard and expanded frequency ranges and also a mean square value of vibration velocity in octave frequency band that includes fav impellers rotation frequency [2];
- frequency bands, harmonic series and peak values of some spectrum components proving the presence of fan blades damages;
- vibration displacement in the range of 10…1000 Hz;
- “similarity measure” of the signals defined according to the enveloping spectrum or wavelet transformation of the reference vibroacoustic signal.

“Side effect” for technical condition degradation process forecasting of the tested unit can give the opportunity to calculate the value of a gas-cleaning unit remaining life expectancy. To carry out the calculation of remaining life expectancy it is important to pick out informative trends of vibration signal deterministic component. The principles for creating UDC for fan impellers diagnosing imply the realization of the principle for analyzing multidimensional space of diagnostic features using the algorithms of gradual scalarization. The employed sampling volume allows segmenting technical devices into three groups with different levels of basic defects development (admissible, inadmissible and satisfactory condition of the tested units) [3]. The integral component of the algorithm for creating UDC is a clipping program for cleaning initial diagnosing data from the constituents of other nature [3, 16]. The number of the developed, in the framework of this research, clipping subprograms equals to the number of potential defects types. The filtering procedures and the algorithm for adjusting rotational frequency were applied during the development of such subprograms. The algorithm is based on searching the components with maximal amplitudes in low-frequency region of a spectrum. It proved its high effectiveness in detecting the rotational frequency in spectrums using the vibration acceleration parameter when spectrum harmonic amplitudes maximums do not initially belong to rotational frequency.

The forecasting simulation results, developed evaluating unified criteria and comprehensive approach to vibration parameters analysis are the basic elements of the system for technical maintenance according to the real condition of the units. Implementing the given conception will allow giving up on the outlived preventive maintenance system and “emergency” maintenance plan of the operated equipment applying which often can be crucial for its real condition. That is why the solution of the problem on creating unified criteria for evaluating coal and mining industry equipment using modern means and methods of non-destructive evaluation is extremely important for improving the effectiveness of monitoring system for sophisticated mechanical systems maintenance.

3. Conclusion

The analysis of the obtained, in the framework of the research, diagnostic data directly confirms the necessity of putting in practice the results of comprehensive approach to vibration parameters analysis for creating the group of unified diagnostic criteria. Each of the criteria is meant for substituting the whole group of cumbersome diagnostic features and rules for detecting defects. It makes the unified
criteria appropriate for carrying out fast and effective evaluation of the equipment technical condition and forecasting the processes of its degradation. As a consequence, implementing into operating cycle the elements of technical equipment maintenance based on the real condition of the equipment will allow refusing from the preventive maintenance of the operated equipment system which is functioning at Kuzbass enterprises nowadays and improving the logistics and storage service of enterprises. It will also improve work performance safety and minimize the risk of accidental outage time.

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