

On one criterion for estimating technical condition of a mining machine reducing gear

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Abstract. The developed Procedures for estimating technical condition of mining machines reducing units based on reference spectral masks got approval at the producer's plant during run-in test at the testing facility and in industries. The approval results of the introduced criterion bear compelling evidence about the rectitude of the chosen approach for diagnosing sophisticated technical systems.

1 Introduction

The analysis of key methods of vibration diagnostics, the existing limits of their application, their advantages and disadvantages showed that, at present, there was not any method that could be successfully used in both express-diagnostics and recurrent monitoring regardless from the type of the tested equipment and conditions of their operation.

Thus, measuring the kurtosis is quite informative in express-diagnostics of roll-bearings but it can not be used for all devices, as it is susceptible to interference and is inferior to spectral methods when applied in recurrent monitoring. Though, spectral methods are liable to errand of II type (accepting deliberately false assumption).

Moreover, many methods are limited by their application sphere. Low revolutions, impact loads, the sources of sudden high-frequency vibrations essentially inhibit the diagnostics. Thus, each of these methods has its own limits and can be used in a number of cases (at a certain stage of the flaw growth, at a certain equipment). Therefore, for effective estimation of the current condition of the sophisticated mechanical systems it is necessary to apply several methods simultaneously and later, on their basis, the diagnostic criteria can be calculated.

Another issue that arise during the diagnostics is the necessity to use additional aprior data (rotary rate, design characteristics etc.). If the rotary rate can be approximately defined, then, for example, geometrical dimension of a bearing or gear set geometry parameters, as a rule, are unknown. That is why, when constructing diagnostic criteria, the use of aprior data should be minimized.

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Any vibration parameters or measurement types obtained at the operating machine contain diagnostic data that characterize a number of machine assemblies condition simultaneously. That is why solving the task of estimating a number of machine assemblies condition applying the vibration parameters it is important to exclude components of different nature. For today, the algorithms of such filtration do not exist, that is why while analyzing vibration acoustic signals it is important to estimate possible influence of different nature forces from other sources (shafts, rotors, couplers etc.) on the character and volume of the mechanical vibrations.

To sum up, it can be affirmed that for testing sophisticated systems, such as a gear set, the best criterion of their technical condition is a vibration reference spectral mask constructed using the technical condition monitoring data. Herewith, it is necessary to keep in mind that while carrying out the vibration process spectral analysis the kinematics of reducing gear operation data should be used as the probability of setting a wrong diagnosis (errors of I type and II type) sharply increases.

Moreover, considering the requirements of the contemporary industry for different forms of technical maintenance and repair organization, in the framework of the created system, it is necessary to forecast, estimate remaining lifetime and schedule maintenance measures optimally at the enterprise. In this regard, while conducting the diagnostics the tasks of picking up the trend out of the noisy data and constructing different types of forecasts should be solved.

2 Setting the task and solution methods

While monitoring technical condition of different reducing units which are used in mining machines and equipment it is necessary to measure both total vibration level in a standard frequency band [1] and to register vibration acoustic signal and its power spectrum using FFT [2, 3] as they are necessary for constructing reference spectral masks [4]. Moreover, the frequency range of the change should cover the components from reducing unit output shaft (as a rule $f_{\text{output}}=2-5$ Hz) to the jugged frequencies overtones (tooth frequency harmonics) f_z (as a rule, $\eta f_z \approx 3-4$ kHz). Measuring the vibration acoustic signal in this frequency range [2-4000 Hz] can be done by using standard accelerometer and magnetic way of fixing them to the mining machines reducing units.

Gear transmissions are the most complicated objects for diagnostics from the view of analyzing vibration diagnostic signals, generated in operating reducing gears, as internal and external factors influence on their formation. [5-9].

To the external factors, the amount and the character of the power volume imposition and the presence in a greasing substance of the agent which brings about the corrosion and the abrasion wear in mating parts can be referred. The manifestation of the internal factors such as reciprocal deflections of the gear wheel and the shaft mounting surfaces, the type of the gear coupling mating surfaces, incorrect driving parts relative position, and the fatigue damage accumulation also have an influence on the performance of the gear drive. All these factors have an influence on the formation of mechanical vibrations which frequency and amplitude are defined by a technical condition of the gear drive.

A well-functioning gear drive, even if there are no faults can show notable vibration activity. The vibration arise in a vast range of frequencies and can be complicated in the content and type (Table 1).

Table 1. Frequencies, distinctive for faults in gear sets of in-line reducing gear.

Frequency	Type of the production fault	Type of the assembly fault	Type of the wear-out fault
f_r	Imbalance		
$k \times f_{r1}$ и $k \times f_{r2}$ ($k = 1, 2, 3$ and 4), $m \times f_z \pm n \times f_r$ ($m, n = 1, 2, \dots$)	Gear pitch variable error	Misalignment (shaft misalignment)	
$k \times f_r$, $k = 1, 2, \dots, 20$ and higher		Excessive flank clearance between the wheels	
f_z	Gear pitch constant error		
$k \times f_z, k \times f_r$ the growth of the noise component $m \times f_m \pm n \times f_r$ ($m, n = 1, 2, \dots$)			abrasive wear
$k \times f_r, m \times f_z \pm n \times f_r,$ $m \times f_m \pm n \times f_r$ (amplitude fluctuation, $n = 0, 1, 2, \dots$)			Chipped teeth
$k \times f_r,$ $m \times f_z \pm n \times f_r,$ $m \times f_m \pm n \times f_r$ (amplitude fluctuation, $n = 0, 1, 2, \dots$), Growth of the noise component			Cracks and (or) broken teeth

Operating faults of the gear drive can be divided into the following types: abrasive wear of a gear coupling, toothed gear wheel pitting, cracks and broken teeth of the toothed wheels and scouring of the toothed gear wheels [10-12]. As far as they are the perturbing factors, the presence of these faults always change the vibration signal features (the form of the signal and the vibration spectrum, especially the envelope spectrum and cepstrum). In particular, the ratio between the main excitation frequencies can change in a spectrum and other spectral components can appear and the noise component changes significantly. In vibration-acoustic signal of a vibration shock pulses can appear and the ratio between periodic and noise components changes. The list of the often-used diagnostic parameters of the gear drive in the assembly of the in-line reduction gear is given in Table 1 and in the assembly of the planetary reduction gear is shown in Table 2.

Table 2. The gear drive faults in the assembly of the in-line reduction gear and their key diagnostic parameters

Type of the fault	Diagnostic feature
Sun gear breakages	$f_o, nf^* \pm f_o, kf_z \pm f^*$
Sun gear tilt	$2f_o, 2nf^* \pm 2f_o, kf_z \pm 2f^*$
Sun gear teeth fault	$knf^* \pm k_1f_o, kf_z \pm k_1f^*$
Satellite tilt	$4f_g \pm k_1f_v, kf_z \pm 2f_g$
Satellite teeth fault	$2kf_g \pm k_1f_v, kf_z \pm k_1f_g$
Corona tilt	$2nf_v, kf_z \pm 2nf_v$
Corona teeth fault	$knf_v, kf_z \pm k_1nf_v$
Gearing faults	kf_z
Carrier breakage	$kf_v, f_o \pm f_v, kf_z \pm k_1f_v$
Satellite bearing fault	$kf_v, f_o \pm f_v, kf_z \pm f_g/2$
Sun gear (carrier) bearing fault	kf_v + the appearance of the shock pulses and RMS on MF growth
Bearing greasing fault	The appearance of shock pulses and RMS on FH growth

Notice. f_o – sun gear rotating frequency; f_v – the carrier rotating frequency; f_z – teeth frequency; f_g – satellite rotating frequency; $f^* = f_o - f_v$ – rotation frequency of an axis with a faulty; MF – medium frequency; HF – high frequency; USF – ultrasound frequency; RMS (ef) – root mean square value; n – a number of satellites; $k=1,2,3,4,\dots$; $k_1=1,2,3,4,\dots$

The number of vibration diagnostic methods are based on the idea that certain mechanical faults, in the process of their development, generate vibration in certain frequency bands with a certain ratio of the parameter values (Fig. 1). Thus, breaking the frequency range of changes into comparatively narrow ones, possibly into overlapping frequency bands, and applying individual, for each band, admissible values and criteria, it is possible to detect incipient defects. [13, 14].

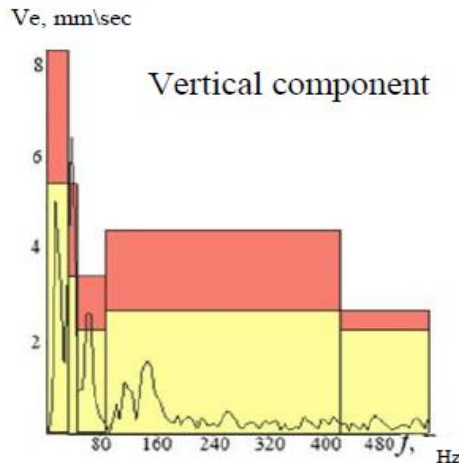


Fig. 1. Spectral mask of vibration on chain-and-flight conveyor gear box.

Defining the technical condition using spectral masks allows detecting the faults in difference frequency ranges:

- $(0,5-2,5) \times f_r$ – for detecting imbalance and misalignment;
- $(7,5-15,5) \times f_r$ – for detecting the rolling bearing faults;
- $(2,5-10,5) \times f_r$ – for preventing stiffness disturbance;
- $(z \pm 1) \times f_r$ – for detecting tooth-type coupling and gear drives faults etc.

Herewith, the criteria of the admissible technical condition, which are defined using the results of some vibration measurements made at the working equipment and obtained during the period of the machine seating-in (Fig. 2), are used.

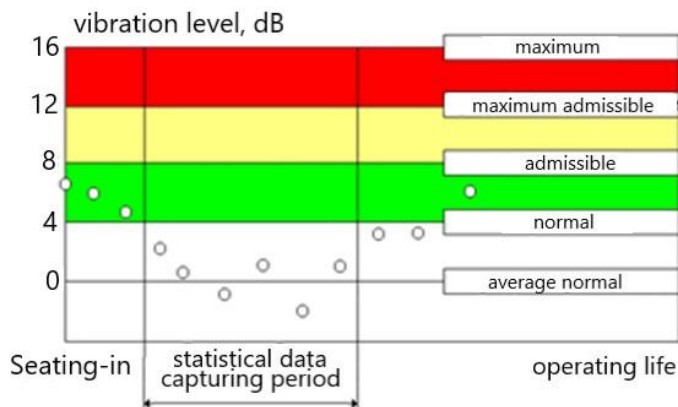


Fig. 2. The scheme of capturing the data for calculating the vibration level and different conditions criteria definition.

The majority of standards that regulate the admissible vibration values is based on statistic processing of a large amount of data on various equipment types and on different research groups. Here, a similar gradation according to the condition classes in them is done. This gradation is based on establishing the dividing boundaries for different technical conditions of the equipment, that differs on 4, 8, ... dB (correspondingly, roughly in 1,6; 2,5; ... times). These relative values are accepted as dividing boundaries for estimating technical conditions of the equipment according to the vibration parameters [5, 13-15].

To check the homogeneity of the selection that characterizes the reliability of the statistical conclusions and exclusion of sharply deviating values out of it, it is reasonable to apply rough monitoring errors admitting that the obtained experimental series of the vibration (selection) values are subjected to the normal law of distribution [16-18]

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

where X_m – arithmetic average of the measurements; S – the estimates of root mean square measurement deviation; $q_{q,n}$ – a value fractile of a probability distribution, taken from the table for level 99% ($q_{q,n}=3$).

All the spectra registered in cognominal check points were studied in the frequency range which contained up to 20th harmonics of the rotor pivoting frequency f_r , for defining the zone of the most harmonic activity. It was proved that with increasing the harmonics number over than 10, the amplitude decreases according to an exponential law.

3 The research results

Let us study the application of the given criterion to the reducing gear boxes, produced by “Anzheromash” JSC, and going through the testing at the factory testing unit before delivering to the consumer [19].

According to the “Procedures on diagnostic measuring of the reducing gearboxes, produced by “Anzheromash” JSC “ (further “The Procedures”) all the gearboxes go through obligatory testing at the factory testing unit with registering the mechanical vibration parameters at the driving engines bearing supports and the reducing gear boxes themselves (Fig. 3).

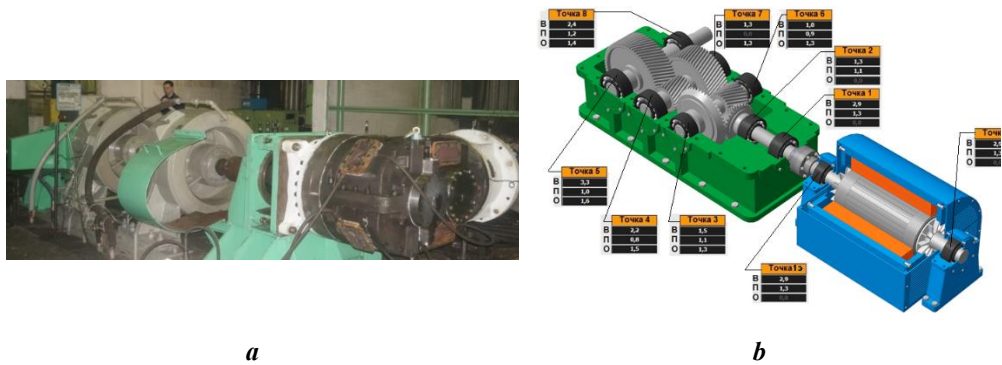


Fig. 3. Testing on the testing unit of the reducing gear box (a) and the kinematic diagram of vibration parameters registering at the given check points (b).

The Procedures sets the types and the accuracy of the measuring necessary for monitoring and estimating the technical condition of the reducing gear boxes during the approval testing.

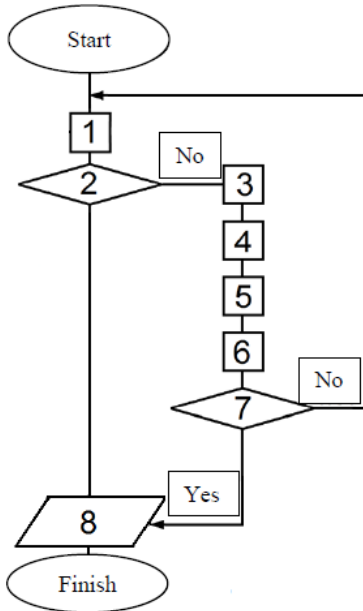
The estimation of the reducing gearbox technical condition is done on the bases of vibration-diagnostic survey.

Hard and software of the vibration-diagnostic survey:

- PC with AD converter and special software (“SafePlant”software);
- Multichannel (not less than 2) vibration analyzer with vibration-measuring converter set (CORVET data converter).

During the reducing gear box vibration testing all the check points divided according to the amount and the type of the monitored vibration parameters were referred to the group with the following characteristics of the measurement parameters: vibration velocity RMS from 10 to 1000 Hz; vibration velocity spectrum in a frequency range from 2 to 3000 Hz, 4 linear averaging (3200 lines); vibration acceleration spectrum from 10 to 10000 Hz, 4 linear averaging (3200 lines); time signal peak, m/sec².

Figure 4 shows the block-diagram and algorithm of production faults identification, assembling and exploitation of the reducing gearbox.



1. Measuring.
2. Comparing the obtained measurements of root mean square value with the admissible value $V_{RMS} (V_{ef})$
3. Vibration velocity analysis V .
4. Reducing gearbox production faults identification.
5. Reducing gearbox assembly faults identification.
6. Reducing gearbox exploitation faults identification.
7. The comparison of the spectral component amplitudes inherent to reducing gearbox faults with maximum admissible values $[V_{def}]$ of these components spectral masks. In case this condition is failed, the gear-wheel drive repair is needed.
8. Forming the vibration passport of the reducing gear unit.

Fig. 4. Block-diagram and the algorithm of reducing gearbox faults identification according to the vibration acoustic signal parameters.

The identification sample obtained during visual and dimensional test of the detected fault applying the Procedures is given in Fig. 5.

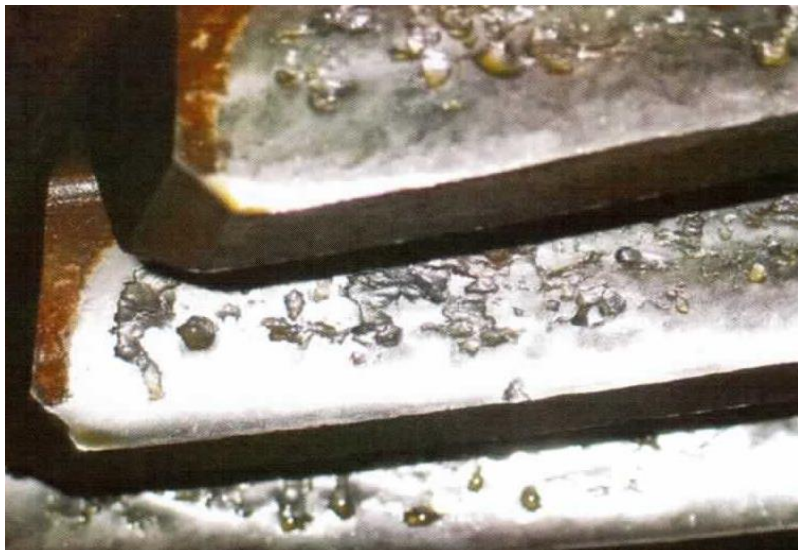


Fig. 5. Confluent pitting of the teeth working area.

4 Conclusion

The developed Procedures on identifying the reducing gearboxes faults got approval at JSC “Anzheromash” and at the open-pit and underground mines of Kuzbass. It proved the effectiveness and reliability of its conclusions.

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