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ASSESSMENT OF THE STATE OF TECHNICAL OBJECTS BY THE PARAMETERS OF VIBRATION SIGNALS AND THEIR TRENDS

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The state of observed technical objects is determined by parameters and characteristics. When analyzing the vibration state of a mechanism or unit, the primary characteristics are the vibration signals recorded on its bearings or housings. As a result of their processing and transformations, informatively significant parameters and characteristics are obtained. An approach based on the use of decision functions is proposed, which differs in that they are applied in relation to both the primary informative-significant parameters of vibration signals and the results of statistical processing of time trends of primary parameters. RMS trends, turnover components, crest factor, kurtosis, asymptotes, RMS trends in narrow frequency bands are processed. Examples of decisive functions and results of processing real vibration signals are given. This approach allows you to automate the process of making a decision about the state of the controlled object and issuing recommendations for its technical maintenance.

Keywords: condition, vibration, characteristic, trend, decision-making

1. Introduction

The state of a production facility is characterized by many parameters of different physical nature. For mechanisms and units of the rotary type, whose mechanical functioning is based on rotational motion, one of the most important parameters is the amplitude and spectral composition of vibration [1-3]. Therefore, solving the problem of proactive maintenance of such equipment requires continuous monitoring of the vibration of its components and detection of the most insignificant changes in vibration signals, which can be an indicator of the initial stage of wear and defects.

Registration of vibration signals can be carried out using computer measuring and computing systems, consisting of: mobile or desktop computer; ADC module connected to a standard computer interface; vibration measuring channels with primary piezoelectric transducers; problem-oriented software [4-5]. Along with the use of measuring and computing complexes, special autonomous collector-recorders can be used to input and save long-term vibration signals [6].

Figure 1 shows an example of a signal obtained using the «Timbr-M» measuring and computing complex [5].

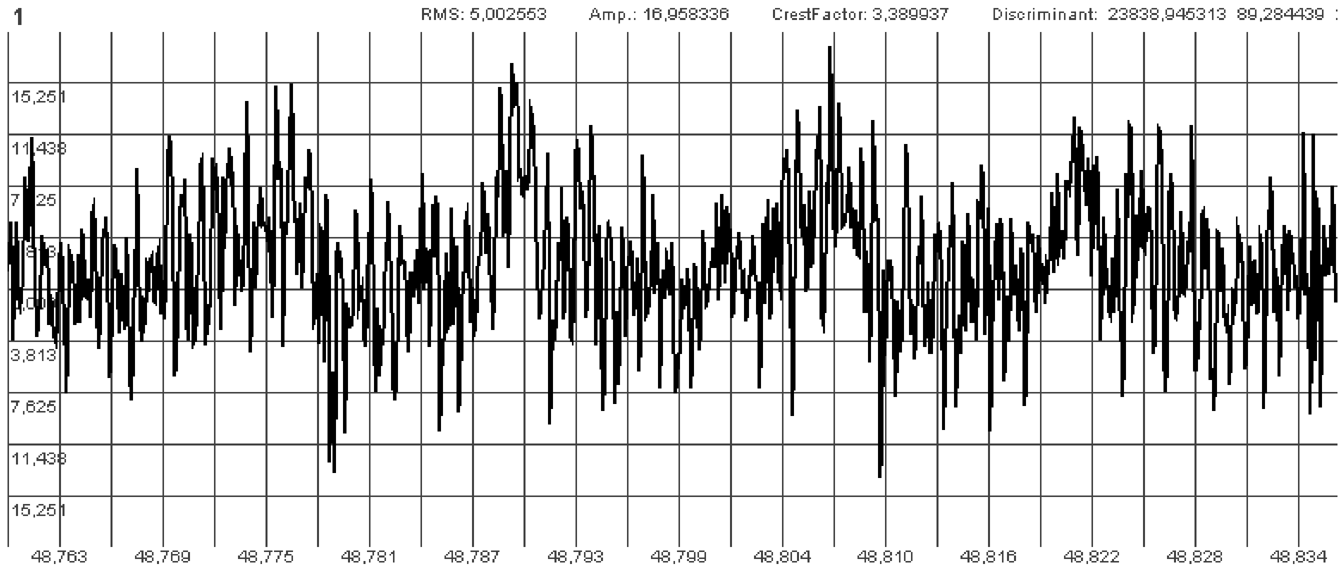


Figure 1: The original vibration signal in units of vibration acceleration
(abscissa axis - time, s; ordinate axis - vibration acceleration, m/s^2)

After registration of the vibration signal, it is digitally processed to detect anomalous bursts [7] and (or) calculate certain parameters of the vibration signal at specified time intervals (building their trends in time), which can be used to assess the technical condition of the object. In this work, the problem of automating the decision-making process for assessing the technical condition of the controlled unit is solved by analyzing the values of the parameters of the vibration signal, which reflects the oscillations of its bearing supports. This direction of scientific research is a solution to one of the subtasks of the general problem of creating computer systems for vibration monitoring and diagnostics for automatic decision-making on the protection of controlled mechanisms and assemblies.

2. Trend processing and decision making

When assessing the vibration state of a technical object, the following main parameters are usually used, calculated by mathematical processing of the original vibration signal: amplitudes of the spectral components of the vibration signal at fixed frequencies (for example, f_1=25 Hz, f_2=50 Hz, ... , f_k= 2000 Hz); power or root-mean-square value (RMS) of vibration in the frequency band $f_s \div f_e$ (multiple bands can be set); peak factor; excess; asymptote; vibration signal envelope modulation factor; RMS of the vibration components emitted by wavelets with certain central frequencies of their frequency response [8].

In the presence of high-performance computers, the processing of the vibration signal can be carried out in parallel with its registration. Figure 2, as an example, shows the hourly time trend of the parameters calculated by processing the vibration signals obtained by monitoring the vibration of the bearing support of the turbine unit.

Visual analysis of trends in vibration parameters allows you to detect their possible changes and, accordingly, a change in the technical condition of the controlled object. However, its implementation is associated with a significant time expenditure of a technical specialist, moreover, it is desirable to obtain some numerical estimates of the data being processed. Therefore, it is important to automate this procedure.

The processing of time trend data is performed according to the algorithms of probability theory and mathematical statistics [9], which are quite simply implemented in software [10].

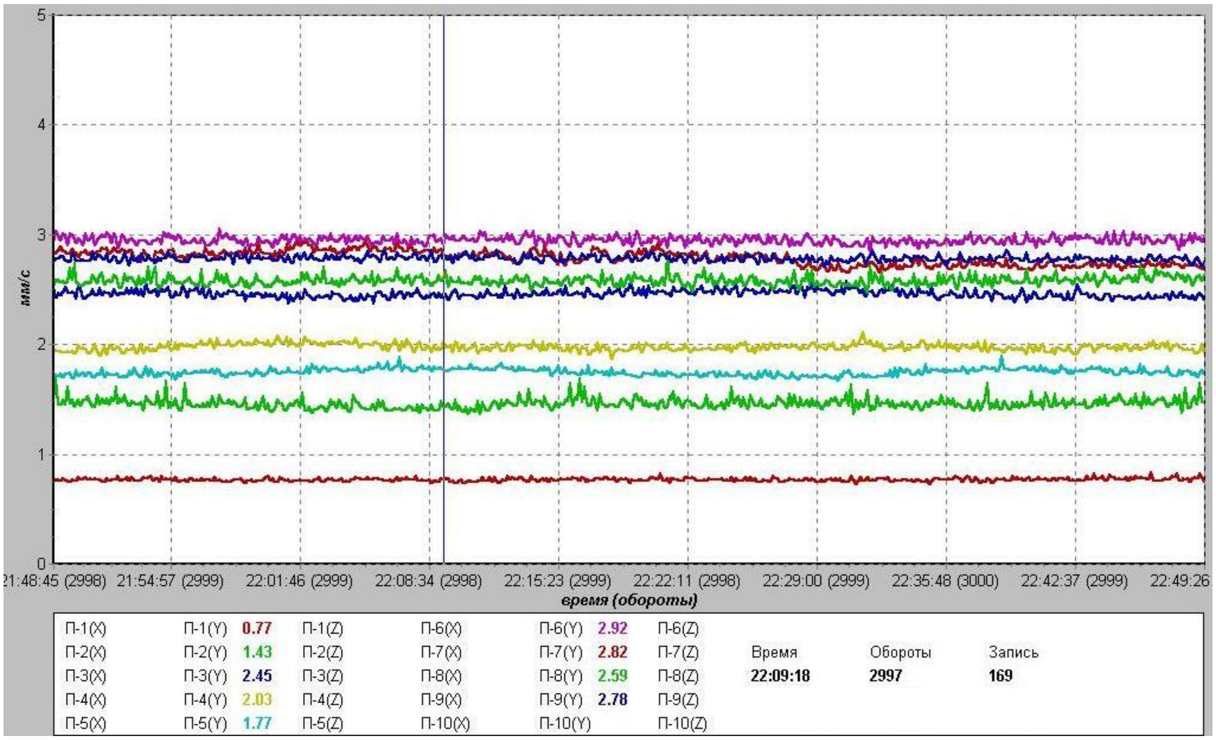


Figure 2: RMS trend of vibration velocity (vertical) of bearing supports
turbine set during normal operation
(abscissa axis – time (revolutions per minute) ; ordinate axis – vibration velocity, mm/s)

Figure 3 shows an example of such processing, as a result of which a histogram of the RMS vibration velocity distribution by level and numerical values were obtained that determine the distinctive features of its change.

Discrete mm/s	***Probability***
0.00	0.0000
0.25	0.0000
0.50	0.0000
0.75	0.0000
1.00	0.0000
1.25	0.0000
1.50	0.0000
1.75	0.0000
2.00	0.0000
2.25	0.0000
2.50	0.0000
2.75	0.0000
3.00	0.0000
3.25	0.0741
3.50	0.5484
3.75	0.3410
4.00	0.0330
4.25	0.0035
4.50	0.0000
4.75	0.0000
5.00	0.0000

Average vibration velocity for the observation period:	***3.706***
RMS spread of vibration velocity values for the observation period:	***0.155***
Maximum value:	***4.483***
Minimum value:	***3.339***
Change range:	***1.144***
Number of samples analyzed:	***10800***

Figure 3: Results of processing the daily RMS time direction
vibration speed of the generator bearing during normal operation

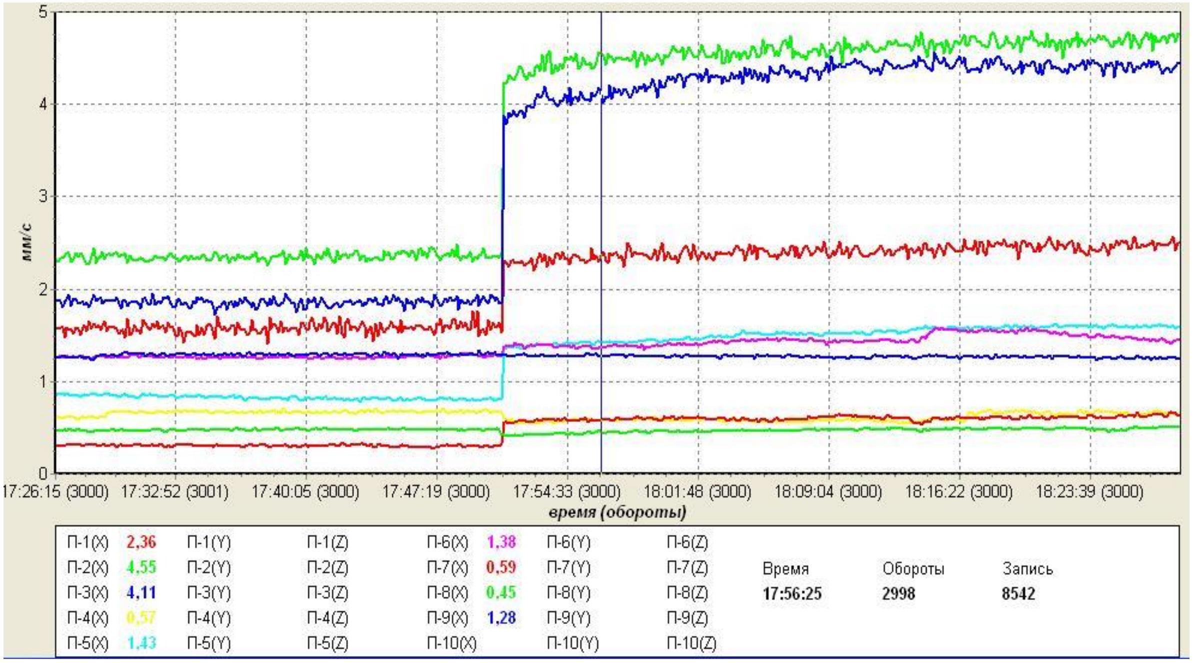


Figure 4: RMS trend of vibration velocity (horizontal) of bearing supports turbine set during normal operation
(abscissa axis – time (revolutions per minute) ; ordinate axis – vibration velocity, mm/s)

However, its implementation is associated with a significant time expenditure of a technical specialist, besides, of course, I would like to get some numerical estimates of the data being processed. Therefore, it is important to automate this procedure.

Statistical processing of data obtained by the measuring and computing complex "Lukoml" can be performed using a fairly simple software tool. Figure 3 shows an example of such processing, which resulted in a histogram of the distribution of the parameter under study by level and numerical values that determine the distinctive features of its change. These calculated values can be taken as a vector of informative-significant parameters for the decision support system for assessing changes in the technical condition of the controlled object.

As an example for comparison, Figure 4 shows changes in the RMS of the vibration velocity of the turbine unit bearings in the event of a defect, and Figure 5 shows the results of statistical processing of one of these parameters.

The amplitude range for constructing a histogram is selected taking into account the actual vibration state of the controlled object and regulatory requirements for the vibration level.

Analyzing the obtained results, a number of conclusions can be drawn.

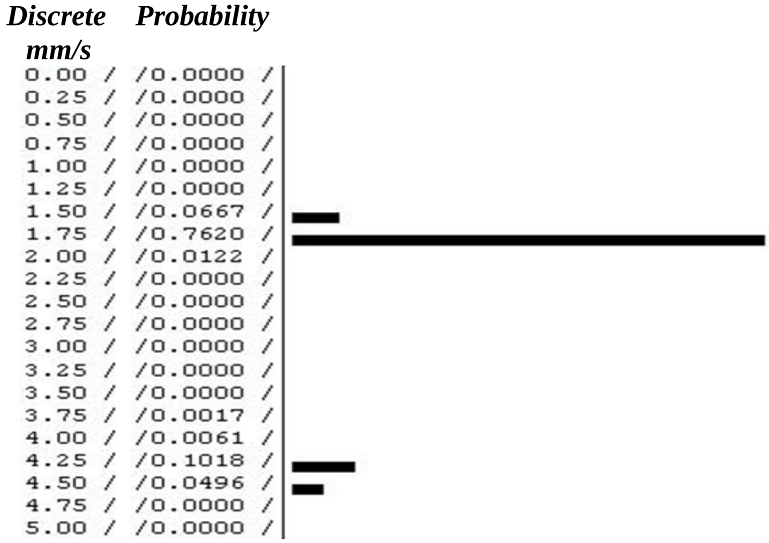
During normal operation of the mechanism:

− the parameter "*RMS of the spread of vibration velocity values for the observation period*" has a significantly lower value compared to the "Average value of the RMS vibration velocity for the observation period";

− “*Mean RMS value of vibration velocity for the observation period*” falls into the quantile of the maximum probability of the distribution histogram;

− “*Range of change*” is less than “*Mean RMS value of vibration velocity over the observation period*” (although in the presence of random surges, interference or short-term significant changes in the regime, this condition may not be met);

− the form of the histogram of distribution by level for the analyzed parameter is several, adjacent to each other, significant quantiles.



Average vibration velocity for the observation period:	***2.253***
RMS spread of vibration velocity values for the observation period:	***0.958***
Maximum value:	***4.685***
Minimum value:	***1.621***
Change range:	***3.063***
Number of samples analyzed:	***10800***

Figure 5: Results of processing the daily time trend of RMS vibration velocity turbine unit bearing in the event of a defect

In case of a possible defect or malfunction of the mechanism:

− the parameter "*RMS of the spread of vibration velocity values for the observation period*" is comparable in value with the "*Average RMS value of vibration velocity for the observation period*";

− "*The average value of vibration velocity RMS for the observation period*" in many cases does not fall into the quantile of the maximum probability of the distribution histogram;

− "*Range of change*" is comparable or even exceeds the "*Average RMS value of vibration velocity for the observation period*";

− the form of the level distribution histogram for the analyzed parameter can have an arbitrary form, and the significant quantiles can be located with a gap along the amplitude scale.

Thus, a preliminary statistical processing of the time trends of vibration parameters can greatly facilitate the work of a technician.

The parameter "Average value of vibration velocity for the period of observation" - , can be used for a general assessment of the technical condition of the controlled object. For this, the decision function is used [11, 12]:

$$FR\left(V_{Av,RMSvel}\right)=\begin{cases}0.25,\ if\ V_{Av,RMSvel}\le V_{A,Av,RMSvel};\\ 0.5,\ if\ V_{A,Av,RMSvel}<V_{Av,RMSvel}\le V_{B,Av,RMSvel};\\ 0.75,\ if\ V_{B,Av,RMSvel}<V_{Av,RMSvel}\le V_{C,Av,RMSvel};\\ 1.0,\ if\ V_{C,Av,RMSvel}<V_{Av,RMSvel},\end{cases} \tag{1}$$

where $V_{A,Av,RMSvel}$, $V_{B,Av,RMSvel}$, $V_{C,Av,RMSvel}$ − are RMS values of vibration velocity corresponding to the boundary levels of the technical condition, and $V_{A,Av,RMSvel} < V_{B,Av,RMSvel} < V_{C,Av,RMSvel}$. The specific values of these levels can be determined by: standards; by analyzing the change in the vibrational state of a sufficiently large number of objects of the same type; based on expert assessments. The levels usually differ from each other by 4-8 dB [1].

If $V_{Av,RMSvel}$ = 0.25, then the mechanism is in a very good vibrational state (these are usually new (after repair), run-in machines) and can be operated without time restrictions. If $V_{Av,RMSvel}$ = 0.5, then the mechanism is in a satisfactory vibration state and can be operated for several more months or thousands of hours. If $V_{Av,RMSvel}$ = 0.75, then the state of the mechanism is assessed as insufficiently satisfactory, and restrictions are imposed on the operation of the mechanism for the allowable operating time, usually several days or tens or hundreds of hours. If $V_{Av,RMSvel}$ = 1, then the state of the mechanism is emergency-dangerous and prompt response is required, up to its immediate stop.

However, providing a generalized characteristic of the vibration state of an object over a long time interval, the parameter $V_{Av,RMSvel}$ does not reflect possible changes in the amplitude-frequency composition of vibration in certain operating modes, when its significant changes can be observed, determined by the "*maximum value*" − $V_{\max,RMSvel}$. When estimating the state with respect to $V_{\max,RMSvel}$, it is also possible to apply a decision function of the form (1), taking into account the regime factors and preliminarily removing possible random outliers from the sample. The variability $V_{Av,RMSvel}$ is characterized by the parameter "*RMS spread of vibration velocity values over the observation period*" − S_{RMSvel}, as well as the range of change − D_{RMSvel}.

It is much more difficult to establish the boundary levels of the decision function for these parameters. As $S_{A,RMSvel}$, $D_{A,RMSvel}$, can be taken, increased by 20-25 percent, the values $S_{A,RMSvel}$, $D_{A,RMSvel}$, obtained during the operation of new, run-in machines, when they go through all typical operating modes. It is advisable to choose the boundaries of zones B and C based on the results of long-term operation of control objects and taking into account expert assessments. The growth of the parameter S_{RMSvel} or D_{RMSvel} indicates a certain change in the technical condition of the object, even with a slight increase $V_{Av,RMSvel}$. The same decision function can be applied to other parameters.

On the basis of decision functions for separated parameters, it is possible to form generalizing decision functions for a group of parameters. In the simplest case, this is a linear combination of decision functions with respect to separated parameters with weight coefficients [11]. In general, it looks like:

$$FR(P_i) = \begin{cases} 0.25, \; if \;\; P_i \le P_{A,i}; \\ 0.5, \; if \;\; P_{A,i} < P_i \le P_{B,i}; \\ 0.75, \; if \;\; P_{B,i} < P_i \le P_{C,i}; \\ 1.0, \; if \;\; P_{C,i} < P_i, \end{cases} \tag{2}$$

Where P_i − i -th vibration signal parameter; $P_{A,i}$, $P_{B,i}$, $P_{C,i}$ − values of the i -th parameter corresponding to the boundary levels of the technical condition, and $P_{A,i} < P_{B,i} < P_{C,i}$.

The main problematic task in this case is the choice of specific values $P_{A,i}$, $P_{B,i}$, $P_{C,i}$ and the determination of the permissible time intervals for the operation of the equipment corresponding to the boundary levels of this parameter.

On the basis of decision functions for separated parameters, it is possible to form generalizing decision functions for a group of parameters [11]. In the simplest case, this is a linear combination of decision functions with respect to separated parameters with weight coefficients. For example:

$$FR_\Sigma = \frac{1}{N}\sum_{i=1}^{N}\frac{k_i}{k_{i,\max}}FR(P_i), \tag{3}$$

where FR_Σ − the value of the generalizing decision function; N − the number of decisive functions for individual parameters of the vibration signal; $FR(P_i)$ − the value of the decision function in the i-th parameter; k_i − weight factor for decision function $FR(P_i)$; $k_{i,\max}$ − the maximum weight coefficient of all weight coefficients for the values of the decision functions used to calculate the value of the generalized decision function.

The value of the decision function, which has the maximum value, taking into account the normalizing coefficients, can also be taken as the determining factor in the decision-making system:

$$FR_\Sigma = \max\left(\frac{k_i}{k_{i,\max}} FR(P_i)\right), \tag{4}$$

where $i = 1 \div N$; $k_{i,\max} = \max(k_1, k_2, ..., k_N)$.

The decision function for a group of vibration signal parameters is represented as a certain function of the decision functions for individual parameters:

$$FR_{\Sigma,f} = f\left[FR(P_1), FR(P_2), ..., FR(P_N)\right],$$

or as a decision function FR_{S_φ} with respect to some generalizing parameter S_φ, which, in turn, is a function of a group of parameters:

$$S_\varphi = (P_1, P_2, ..., P_N).$$

The following are examples of such functions [11]:

$$FR_{\Sigma,f} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left[FR(P_i)\right]^2};$$

$$FR_{\Sigma,f} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left[FR\left(\frac{k_i}{k_{i,\max}} P_i\right)\right]^2};$$

$$S_\varphi = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(P_i)^2};$$

$$S_\varphi = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(\frac{k_i}{k_{i,\max}} P_i\right)^2};$$

$$S_\varphi = \frac{1}{N}\sum_{i=1}^{N}\left[\frac{k_i}{k_{i,\max}} 20\lg\left(\frac{P_i}{P_{0,i}}\right)\right],$$

where $P_{0,i}$ − is the reference level for the parameter P_i.

3. Conclusion

Analysis of the vibrational state of technical objects by informative features and their trends calculated on the basis of vibration signal analysis is not a trivial task, which is associated with significant time costs and requires highly qualified engineering and technical personnel. The creation of decision support systems, in which the basis of logical analysis is performed by decisive functions, is aimed at automating the processing of vibration signals, time trends of vibration parameters and providing users with a convenient tool to facilitate the solution of tasks of this plan. An approach is proposed for solving the problem of automating the decision-making process for assessing the technical condition of the monitored unit, by comparative analysis of the values of the vibration signal parameters, reflecting the vibrations of its bearing supports.

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