Control of rotary equipment unbalance with using statistical criteria comparison of vibration spectrum

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Abstract. The article offers statistical criteria for comparison of vibration spectra for detecting the unbalance of rotor equipment. The method of rejection is described. Experimental studies were carried out on an axial fan.

Introduction
Rotary equipment (electric motors, pumps, fans, compressors, etc.) is widely used in almost all industries. One of the most common defects of such equipment is the unbalance of the rotor (unbalance). An unbalance arises from the action of a centrifugal force, which can cause the rotor to vibrate in the radial and axial directions. The causes of the unbalance can be: heterogeneity of the rotor material, manufacturing and assembly errors, wear of the assemblies, sedimentation of polluting particles, etc.

The method of spectral analysis of vibroacoustic signals has been obtained a wide application for the control of rotary equipment [1-3]. By changing the frequency components of the vibration spectrum, it is possible to identify the main equipment defects, including the unbalance of the rotor. Due to the presence of a large number of harmonic components in the spectra, such analysis is quite often difficult. Due to the presence of a large number of harmonic components in the spectra, such analysis is quite often difficult.

The control method and statistical comparison criteria
The proposed methodology is implemented in the application package [4-8]. The rejection of equipment is proposed to be performed depending on the results of comparison of the reference and current spectra from the values of three statistical comparison criteria:

– correlation coefficient;
– Spearman's nonparametric rank estimate;
– statistics of Fisher signs.

To calculate the correlation coefficient, use the following relationship:
where \( a_i \) is the amplitude at the \( i \)-th frequency of the current spectrum; \( a_{si} \) is the amplitude at the \( i \)-th frequency of the reference spectrum, \( n \) is the number of spectra compared to the standard.

In addition to the correlation evaluation between the tested and reference spectra, a nonparametric rank estimate of the Spearman is calculated:

\[
 r = \frac{1}{6} \frac{\sum (\text{rank } a_i - \text{rank } a_{si})^2}{n(n^2-1)}
\]

where \( \text{rank } a_i \) is the rank of the amplitude \( a_i \) in the variational series of amplitudes of the tested spectrum; \( \text{rank } a_{si} \) - also for the reference spectrum.

Statistics of Fisher signs \( S \) is calculated as the number of frequencies of the positive amplitude of the difference spectrum (half of the number of frequencies of zero amplitude is added to this sum). The Iman approximation is calculated:

\[
 S^* = \frac{(S - n/2)}{\sqrt{n/4}},
\]

To classify the equipment as suitable or defective, the used approach is typical for the procedures for rejecting anomalies: the program interprets the set of computed comparison criteria \((p_1, p_2, ..., p_m)\) as a set of measured values of an abstract parameter and applies the following procedure to this set of values [9,10]:

1) calculate the position estimate \( \bar{p} \);
2) calculate the spread estimate \( S \);
3) construct a confidence interval for a given level of significance \( \alpha \)

\[
\bar{p} \pm St(1 - \frac{\alpha}{2}, m - 2),
\]

where \( t(\alpha, m) \) is the \( \alpha \)-quantile of the Student’s distribution with \( m \) degrees of freedom.

If the parameters of the monitored product go beyond the confidence interval, the program automatically issues an alarm and the control object is recognized as defective.

### Information-measuring complex

The block diagram of the developed information-measuring complex is shown in figure. 1.

![Figure 1](image)

**Figure 1.** Structural diagram of the information-measuring complex:

- \( S \) - vibration acceleration sensor AP2038P, MD - matching device AG01-3;
- ADC - analog-to-digital converter NI USB-6229, PC - personal computer with installed package of applications.

Vibration transducer AP2038P allows simultaneous measurement of vibration acceleration along three orthogonal axes: \( x \), \( y \), \( z \). Processing and analysis of signals is performed with the help of a set of programs implementing the proposed principle of rejection of equipment.

### Experimental research

The 8-blade axial fan with a rotation speed of 2830 rpm was chosen as the monitoring object. The three-component vibration transducer was mounted on the bearing support of the fan shaft. The
The vibration signal was registered simultaneously in three directions (Figure 2): x - axial, y - transverse horizontal, z – vertical.

The unbalance of the fan shaft was created by alternately fastening to its blade cargoes in masses of 0.56 and 1.12 grams. The reference spectrum was formed by averaging the spectra of signals taken from a defect-free fan. The sampling rate of the ADC was 44100 Hz. The length of the signal for the formation of the spectra is 22050 counts. The limits of the confidence intervals for all comparison criteria are formed in accordance with the significance level of 0.05.

The obtained spectra of vibro-acoustic signals are shown in figures 3-5. The spectra were compared with the standard in the frequency range from 0 to 2 kHz.

![Figure 2. The control object with the notation of the direction of the vibration detection axes.](image)

![Figure 3. Spectra of vibro-acoustic signals along the x-axis: a) reference spectrum; b) a fan spectrum with a load of 0.56 g; c) fan spectrum with a load of 1.12 g.](image)
Figure 4. Spectra of vibro-acoustic signals along the y axis: a) reference spectrum; b) a fan spectrum with a load of 0.56 g; c) fan spectrum with a load of 1.12 g.

Figure 5. Spectra of vibro-acoustic signals along the z axis: a) reference spectrum; b) a fan spectrum with a load of 0.56 g; c) fan spectrum with a load of 1.12 g.
The proposed statistical criteria for comparing the spectra showed a stable determination of the unbalance of the fan rotor in all three measurement axes. In figures 6-8 the results of a comparison of the vibration spectra along the y axis are shown. It can be seen from them that the values of the comparison criteria for signals taken from a fan with a load go beyond the limits of confidence intervals. The greatest sensitivity to determining the degree of development of unbalance was shown with the statistics of Fisher signs. The larger the unbalance of the fan is, the farther away its values are from the limits of the confidence intervals. To make a reliable decision about the defectiveness of the control object, the results obtained for a series of experiments are recommended to be subjected to median averaging.

Figure 6. Results of comparison of vibration spectra by the correlation coefficient (y axis). The following experimental results were singled out by the regions: 1 - on a working fan; 2 - fan with a load of 0.56 g; 3 - fan with a load of 1.12 grams.
Figure 7. Results of comparison of vibration spectra according to Spearman's rank estimate (y-axis).
The following experimental results were singled out by the regions: 1 - on a working fan;
2 - fan with a load of 0.56 g; 3 - fan with a load of 1.12 grams.

Figure 8. Results of comparison of vibration spectra according to statistics of Fisher signs (y axis).
The following experimental results were singled out by the regions: 1 - on a working fan;
2 - fan with a load of 0.56 g; 3 - fan with a load of 1.12 grams.

Conclusion
The proposed statistical comparison criteria allow analyzing the spectra of oscillations over a wide
frequency range. In the course of experimental studies, the possibility of their application to control
the unbalance of rotor equipment has been revealed.
The developed information-measuring complex with a package of applied programs makes it possible
to carry out express control of the unbalance of rotor equipment in the process of its production and
operation.

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