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# IMPROVING THE ACCURACY OF VIBRATION MEASUREMENT RESULTS

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***Abstract.*** *The current state of control of vibration measuring equipment is studied in the work, the analysis of technologies of control of vibrating measuring machine equipment is carried out. It is determined that during the control a sufficient requirement for the analysis of changes in the state over time is to conduct periodic vibration measurements in the same modes of operation of the object. Therefore, the urgent task is to increase the reliability and accuracy of measurement results. It can be enhanced by obtaining additional information. For this purpose, recommendations for optimizing the vibration control points of the mechanism are formed. To increase the accuracy of measurement results when controlling the equipment for vibration signals, the methods of mounting the measuring transducer in the equipment monitoring system are considered. It is shown that the method of mounting the measuring transducer can affect the results of vibration measurements.*

**Keywords**: vibrations, measuring transducer, vibroacoustic parameters, vibration measurement

## POPRAWA DOKŁADNOŚCI WYNIKÓW POMIARÓW DRGAŃ

***Streszczenie.*** *W pracy badany jest aktualny stan sterowania wibracyjnymi urządzeniami pomiarowymi, prowadzona jest analiza technologii sterowania wibracyjnymi urządzeniami pomiarowymi. Stwierdzono, że podczas kontroli wystarczającym wymogiem do analizy zmian stanu w czasie jest prowadzenie okresowych pomiarów drgań w tych samych trybach pracy obiektu. Dlatego pilnym zadaniem jest zwiększenie wiarygodności i dokładności wyników pomiarów. Można go ulepszyć poprzez uzyskanie dodatkowych informacji. W tym celu formułowane są zalecenia dotyczące optymalizacji punktów kontroli drgań mechanizmu. Aby zwiększyć dokładność wyników pomiarów przy sterowaniu aparaturą na sygnały wibracyjne, rozważono sposoby montażu przetwornika pomiarowego w systemie monitorowania aparatury. Wykazano, że sposób mocowania przetwornika pomiarowego może wpływać na wyniki pomiarów drgań.*

**Słowa kluczowe**: drgania, przetwornik pomiarowy, parametry wibroakustyczne, pomiar drgań

## Introduction

At the present stage of development in production, a continuous technological process is very important, which is ensured by trouble-free operation of the equipment. Thus, the study of oscillatory processes is of great interest to all sectors of the economy. For these purposes, work is being done to study the technical condition of the equipment and further analysis of its changes. Machine failures are accompanied by increased vibration.

The main task of monitoring the state with the help of the simplest system is the timely detection of the dangerous state of the mechanism, ie. minimization of the probability of omission of the developed defect, sufficient for the occurrence of an emergency situation between the periodic measurements of the controlled parameters.

Detection of changes in the state of the mechanisms using the simplest monitoring system can be done in the main way, i.e. by analyzing the changes in the controlled signals of the object and their parameters over time, as well as by comparing the values of these parameters in a group of identical objects at identical control points in identical operating modes. The second method allows you to assess the state of the mechanism by single measurements by comparing each of the controlled parameters with thresholds for each control point and each of the possible modes of operation. In this way, the thresholds are calculated from single measurements of these parameters in a group of identical mechanisms.

Carrying out a preliminary assessment of the type and magnitude of the possible fault allows you to identify the most dangerous defects to continue operation and decide on the decommissioning of the mechanism. In other cases, you can continue to operate the mechanism with reduced intervals between measurements to clarify the rate of further deterioration with a forecast of residual life or for professional diagnosis, which will significantly reduce the number of unreasonable conclusions of the mechanisms for repair.

This requires a constant increase in the requirements for the accuracy of measuring control points of equipment and methods of technical control, as part of technological processes.

Appropriate means of measuring, analyzing and transmitting information are an integral part of any information and measurement system for monitoring equipment based on any of the signal processing methods. Therefore, one of the urgent tasks is to increase the accuracy of measurement results during vibration control, which is considered a powerful tool for equipment diagnostics. Therefore, in order to obtain complete information and relate the accelerometer measurement data to the actual conditions and consequences, it is necessary to consider the methods of mounting the transducer.

## 1. Analysis of recent research and publications

Detection of faults that have not yet led to catastrophic consequences, determining the degree of development of the defect and its signs are possible only on the basis of a detailed study of the structure of vibration signals. Many studies have been devoted to the issue of vibration control of machinery [1–3, 5–13]. The work is devoted to research on the methods of signal analysis [1, 2, 7–9, 13], specializing in solving diagnostic problems, such as the method of shock pulses [2, 7] and the method of envelope [8, 9], which allow to solve a number of diagnostic tasks on one-time measurements of vibration or noise, and also methods of diagnosis on the basis of narrowband spectral analysis of signals [1, 13].

The work is devoted to numerous studies to study the effect of different types of defects [11, 12] on the operation of machines and diagnostic signals [6]. The results of these studies have shown that the greatest diagnostic information has a vibration signal, and many other types of signals almost duplicate one or another information contained in the vibration signal. In addition, it has become apparent that defects begin to develop long before emergencies occur. And almost immediately the defects begin to affect the vibrations and noise disturbed by these nodes. Therefore, the task of measuring and monitoring changes in the signals of the object and their parameters over time becomes relevant.

## 2. The purpose of the article

The aim of the article is to increase the accuracy of measurement results when controlling equipment for vibration signals, for this purpose we investigated the methods of mounting measuring transducers in the equipment monitoring system, which can affect the accuracy of vibration measurement results and the technical condition of equipment.

## 3. Presentation of the main material

Vibration control [4] of operating mechanisms is a measurement of the level of vibration in the standard frequency band at all control points of the mechanism, comparing the obtained values with the established ones and deciding on the compliance of vibration with the norms.

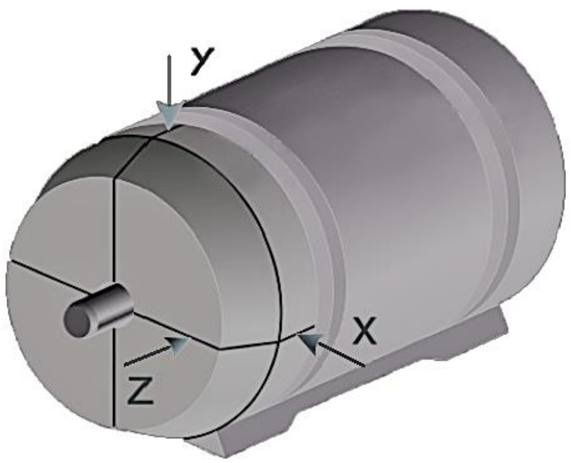
Therefore, increased vibration in machines can cause serious damage. Stresses caused by vibration contribute to the accumulation of damage in materials, cracks and damage. Such problems can be detected at the beginning using vibration measurement methods. Thus, there is a great necessity to measure, evaluate and control the vibration signals of industrial equipment.

The main requirement for the choice of vibration control points of nodes of controlled mechanisms is the identity of points, and for vibration and measurement directions of identical mechanisms, which allows to compare measurement results and build thresholds "by group" usually from ten identical control objects (their group thresholds for each point and control directions). For mechanisms that do not have "groups", thresholds are built "historically" after the accumulation of periodic measurement data for a time or about ten percent of the typical resource or, more commonly, at least a thousand hours of operation.

The main points of control of vibration of mechanisms by the simplest monitoring system are selected according to the current ISO standards in the direction of "Monitoring of a condition and diagnostics of cars", on the case of support of rotation. The main temperature control points for machine assemblies are also the fixed surfaces of the rotating assemblies.

Vibration at the main control points, in accordance with the recommendations of the current standards for vibration control of machines and mechanisms, should be measured in three mutually perpendicular directions, in particular, for horizontal mechanisms - vertical, horizontal and axial, as shown in figure 1.

Taking into account the direction of measurement, at least low-frequency vibration, often provides additional information to identify the condition of the mechanism. Vibration at medium and high frequencies to monitor the condition of mechanisms with a horizontal rotor is usually sufficient to measure in the vertical direction (in the direction of static load on the rotary bearings).




*X – horizontal, Y – vertical, Z – axial*

*Fig. 1. Recommended directions of vibration measurement on support of rotation of mechanisms*

In some cases, it is recommended to use additional vibration control points of the mechanisms for additional information. First of all, this is the point on the outer surface of the housing of the flow-converting mechanisms, where the flow rate is maximum. Measurements of high-frequency vibration at this point reveal problems with the formation of the flow of liquid (gas), and the comparison of the results of these measurements with the results of similar measurements on bearing assemblies – to separate the faults of bearings and impellers.

Another group of additional vibration control points is used to measure the vibration on the housing of some machines in the direction of rotation of the rotor (low-frequency tangential vibration) caused by pulsating torque components that act on the rotating parts and the housing. The points of control of such vibration must have a direction tangential to the body and be as far as possible from the axis of rotation and the points of attachment of the mechanism to the foundation. The most effective results are measured by tangential vibration in the case of elastic (on vibration isolators) fastening of the unit to the foundation.

All thresholds for the values of the measured vibration parameters that separate the sets of states of the controlled object are counted from the "base line" passing according to the statistical average obtained from the results of periodic measurements of the values of this parameter of a defect-free object, Fig. 2.

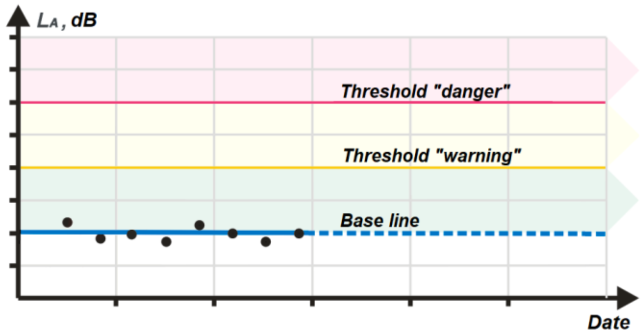



*Fig. 2. Setting thresholds relative to baseline*

When determining the "base line" values of the vibration level in the standard frequency band (general level), linear units are used (mm / s or microns for the general level of low-frequency vibration), for the components of the one-third octave spectrum of vibration acceleration - logarithmic units (dBA). The base line for RMS and Ultrasonic Vibration Peak can be plotted from measurements in both linear units (m / s$^2$ or g, in logarithmic scale) and in logarithmic units (dBA, in linear scale).

The base line for each parameter is determined by its periodic measurements in the nominal operating mode of the mechanism for a long time, during which several stops are performed for its periodic maintenance. In single-mode mechanisms, at least a high-quality control of the mode is necessary (control of the mechanism's output to a steady-state mode of operation). For multi-mode mechanisms, control should be quantitative (in terms of speed and, if necessary, in terms of load). A large statistical scatter of data when plotting the baseline of the controlled parameter indicates the ineffectiveness of the parameter used for monitoring the condition or the need for more accurate control of the operating mode of the mechanism.

The presence of a statistically significant slope at the base line (or on its statistically significant segment) indicates an ongoing change in state in the process of running-in (decline) or defect development (rise). In the first case, the base line needs to be refined after statistically significant stabilization of the measurement results; in the second, the residual resource can be predicted (until the "dangerous" threshold is reached, measured from the "base line" value determined at the beginning of the "base line" slope).

An analogue of the "base line" in the form of a statistical mean value of the monitored parameter (baseline value) can also be used to set thresholds for a significant (usually from ten) group of identical mechanisms. A feature of such a construction of the average value for the group is the possibility of getting into the used group of mechanisms with different operating time, including those with developing defects. In order to minimize the influence of such mechanisms on the results of assessing the average value for the group of defect-free mechanisms, it is recommended to carry out an additional assessment of the results obtained.

At present, the standard thresholds for vibration monitoring of the condition of mechanisms are determined only for the general level of low-frequency vibration. There are also generally accepted recommendations for setting state thresholds by the temperature of nodes or by vibration parameters, measured from the baseline (according to history) or from its analogue (according to a group of mechanisms). However, such recommendations can be used only for the initial period of operation of the simplest monitoring system. In the future, these thresholds should be specified for each type of mechanism.

In total, it is recommended to set up to 4 thresholds for the value of each vibration parameter:

- the lower threshold, determined by the lower boundary of the zone of permissible values of the controlled parameter of the operating mechanism,
- threshold "warning", which determines the upper limit of the zone of permissible values of the controlled parameter of the mechanism operating without restrictions,
- threshold "danger", which determines the upper zone of short-term admissible values of the parameter at the time of decision-making.
- "stop" threshold, exceeding which requires an urgent stop of the mechanism.

In many cases, for the most important of the monitored parameters, the last two thresholds are combined into one.

Typical recommendations for setting the thresholds "warning" (+ 10 dB) and "danger" (+ 20 dB) above the statistical average value can be used as thresholds for individual components of the one-third-octave vibration spectrum (when making decisions on a group of mechanisms).

When making decisions about the state of exceeding the values of the parameter over the baseline, one should take into account the significantly smaller scatter of the results of periodic measurements of the parameters of one mechanism in comparison with a group of mechanisms, especially in the low-frequency components of the vibration spectrum. Accordingly, the recommended thresholds for monitoring the state "by history" depend on the frequency of the spectrum component.

When determining the condition of the mechanism for the growth of RMS and the Peak of ultrasonic vibration, the thresholds for the RMS and the Peak are determined from the base line ("base line" when constructing thresholds for a group of mechanisms) for the RMS and are, respectively, 10 dB and 20 dB for the "warning" threshold, as well as 20 dB and 30 dB for the threshold is "dangerous". When controlling the geometric mean from RMS and Peak, the same thresholds are usually maintained as for RMS.

With the accumulation of data on false alarms (premature withdrawal of control objects for maintenance or repair), omission of dangerous situations and the results of independent defect detection of objects coming for repair (based on the results of condition monitoring), the thresholds in the monitoring system can be adjusted both in large and in the smaller side. After the accumulation of practical experience, it is possible to determine the thresholds for the urgent "shutdown" of mechanisms in the pre-emergency state. Until these thresholds are determined, it is recommended to use the "danger" threshold for the accelerated withdrawal of the mechanism for current repair.

When making decisions about the state of the temperature rise of the nodes of the mechanism, it is recommended to set any thresholds only after constructing a baseline and evaluating the RMS of the results obtained.

The simplest means of vibration control includes: a measuring transducer, an analyzer (actually a vibrometer), as well as an external program for collecting and analyzing measurements.

It is recommended to use an accelerometer with a natural resonance frequency of more than 25 kHz as a measuring transducer in the monitoring system. However, the method of attaching the accelerometer to the object can significantly affect the allowable frequency range of vibration measurements.

The best way to attach the accelerometer to the object is threaded, in which the resonant frequency of the accelerometer is practically not reduced (Fig. 3). However, this method involves the preparation of threaded holes for the stud at the control points of the mechanism, and when taking measurements requires additional time to twist / unscrew the sensor with the measuring cable. This is considered a disadvantage and therefore this method is not suitable for frequent use in periodic vibration measurements by portable monitoring systems.

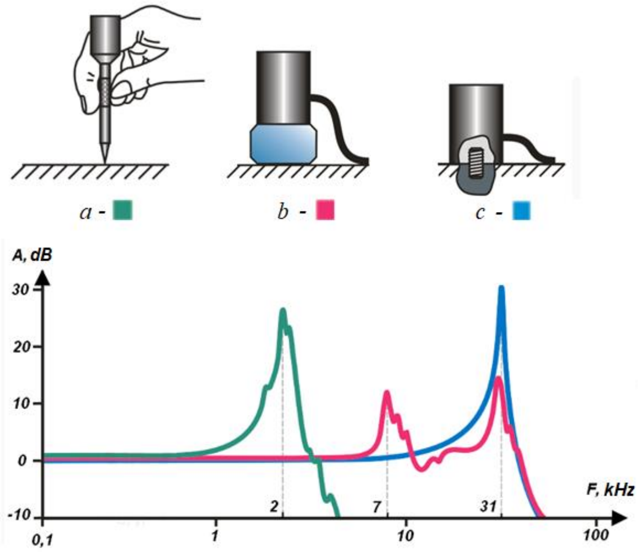



*Fig. 3. Ways of fastening of accelerometers: and - by means of a manual probe of a standard design; b - mounting on a magnet; in - fastening on a hairpin*

When mounted on a magnet, the resonance of the sensor depends on the strength of the magnet and the state of the contact surface, and it is usually in the range of 4–10 kHz. Despite such a low resonance in the problems of vibration monitoring with such mounting, it is possible to make relative measurements of vibration after resonance on the magnet. Moreover, relative measurements can be performed on the resonance of the magnetic mount, the quality factor of which is limited (Fig. 3), and when lubricating the surface of the object at the point of installation of the magnet, the quality factor of this resonance is further reduced. It should be noted that often only with the help of a magnet it is possible to measure vibrations in the tangential direction (when diagnosing electric motors) without any preparation of the object of control (installation on the body of corners, ledges).

If the surface is made of non-magnetized materials, the use of a manual probe is allowed, but the standard design of such a probe minimizes the resonant frequency (Fig. 3). This problem can be solved by introducing into the design of the probe an elastic element through which the accelerometer will be pressed by the probe to the object, and which will thus regulate the force of the pressure. In this case, as in the case of threaded mounting, the resonance of the accelerometer may not decrease. But the vibration sensor can be affected by vibration guidance from the hand with which the probe is pressed against the object. To reduce these movements, it is necessary to eliminate the rigid connection of the probe and the accelerometer, as well as installing an elastic element between them.

To simplify the proposed design as much as possible, it is recommended to make the probe entirely of elastic material with the installation of an elastic gasket between the probe and the sensor (Fig. 4). It is also important to provide a mechanical isolation of the accelerometer cable with an elastic element and a probe, otherwise the guidance by hand will be transmitted through the cable.

In some cases, it is necessary to measure the vibration of the nodes of the object of control, the surface of which has a high temperature. When installing a magnet on such a surface, the heat flux is well transferred directly to the sensor housing, which distorts the results of vibration measurements (temperature jumps and the resulting thermal expansion, the sensor perceives for a long time as vibration, mostly low frequency, and until the sensor and the object of control are establish thermal equilibrium).

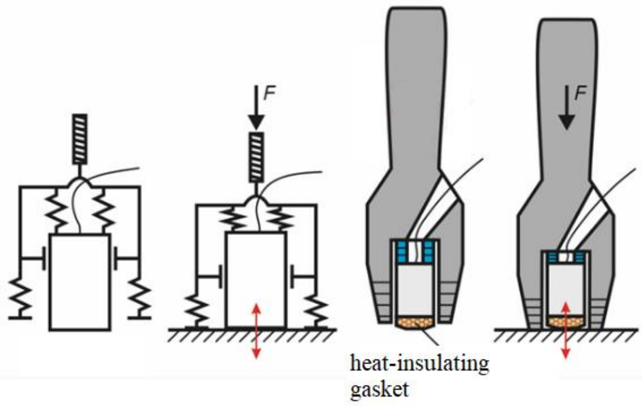



*Fig. 4. Special probe design*

In such cases, it is desirable to attach a rigid heat-insulating gasket, for example made of textolite, to the contact surface of the sensor built into the probe for short-term measurements.

## 4. Conclusion

The current state of technologies of control of machine equipment with measurement of vibration parameters is considered and analyzed in the work. All work to ensure optimal operating modes of the mechanism for monitoring, to install sensors and carry out measurements should be carried out in full compliance with the current norms and rules to ensure the safety of the work being carried out.

The recommendations for optimization of vibration control points in natural conditions of operation and after short-term operation of the mechanism in dangerous modes are formed. The methods of mounting the measuring transducer in the equipment monitoring system are considered. It is shown that in order to obtain complete information, in order to link the accelerometer measurement data with the real conditions and consequences, it is necessary to take into account the methods of mounting the measuring transducer.

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