Vibration analysis as an auxiliary tool for monitoring the safety and viability of production equipment in mechanical engineering

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Abstract. The paper considers the influence of dynamic loads that occur in industrial equipment of machine-building production on the conditions of its safe operation and viability, as well as on humans.

1. Introduction
In works [1-4] it was noted that the most dangerous for structures and various industrial equipment, as well as for humans, is the vibration load, so the development of measures to exclude the impact of this impact is relevant. The reasons for the need to take special measures are explained by the fact that the vibration effect in some cases can lead to negative effects [1], reducing the strength and performance of the structure and not only with resonance [4]. Since the variable stresses arising from the vibration effect lead to the accumulation of damage in the material in the form of cracks and eventually to destruction [2].

In works [1, 3] it is noted that vibrations at which accelerations do not exceed 0.03 g can only be attributed to vibrations that do not affect the state of structures and equipment.

In addition, both external and created by the equipment, vibration effects, without causing destruction of the object, can lead to a violation of its normal functioning. They also have a significant impact on the accuracy of various instruments and equipment.

A failure of an object that is not associated with destruction or other irreversible changes is called a failure

In other words, mechanical impacts can cause both structural damage and failures of machines, devices and apparatuses.

Thus, the purpose of creating vibration protection of production facilities and equipment is to ensure their vibration strength and vibration stability [5]. Acceptable values of frequencies and amplitudes under dynamic effects are given in both domestic and foreign regulatory documents.

2. Formulation of the problem
The peculiarity of vibration exposure is also the fact that it negatively affects people who are near the source of vibration [6] or in direct contact with it [7], so two main directions have been formed to solve this problem:
- first, ways to reduce the level of fluctuations in production equipment with all installed units and elements [1, 6];
- second, reducing the amount of vibrations transmitted through the equipment: cabs, operator seats [7], handles or control levers [8, 9], but in any of the options, the object itself, the source and nature of vibrations and dynamic effects will be determined differently.

As noted [1, 4], structures that work on dynamic effects are determined by their reliability and durability, not only by the nature and magnitude of the load, but also by the properties of the structure itself and the materials from which they are made.

Thus, since the physiological reactions of a human operator to external dynamic influences depend on the mechanical properties of the body, their study will be the initial stage of research to assess the impact of dynamic loads on the human body.

Therefore, the ultimate goal of research is to establish the relationship between external dynamic influences and the physiological changes that occur under their influence in the human operator [6, 7].

Of all external dynamic influences, vibration has the greatest harmful effect on both workers using manual mechanized tools [9] and personnel servicing transport and technological machines [7, 8]. The effect of vibration is usually experienced by personnel associated with the operation of machines and mechanisms containing unbalanced moving elements, as well as with the operation of all types of vehicles.

Therefore, one of the most important technical and socio-economic tasks of modern production is to study the impact of vibration processes on the human body in order to develop effective methods and means of complex and individual vibration protection (Figure 1).

Exposure to vibration for a long period of time leads to violations of the normal state of a person, has an impact on his production activities, and most importantly, on his health. Such persistent harmful physiological changes are called vibration disease, the symptoms of which are headache, numbness of the fingers, pain in the hands and forearm, the occurrence of convulsions, the appearance of insomnia, etc. [8].
Permissible human dynamic effects are regulated by sanitary standards. The norms take into account the peculiarities of the working posture and the ways of transmitting vibrations to the human body. Painful sensations from vibration are already manifested at accelerations that make up 5% of the acceleration of gravity, i.e. at \( w = 0.05 \text{ g} = 0.5 \text{ m/s}^2 \). Sensitivity to vibrations depends on both amplitudes and frequencies. At high frequencies, the amplitudes are significantly limited by the norms. Vibrations with frequencies close to the frequencies of natural vibrations of parts of the human body are especially harmful (table 1), most of which are located in the region of 6...30 Hz [9].

| Table 1. Diagram of the frequency range of vibrations that have a harmful effect on humans. |
|---|---|---|---|---|---|---|---|
| Symptoms of actions vibrations | Frequency, Hz |
| | | \(10^{-1}\) | \(10^0\) | \(10^1\) | \(10^2\) | \(10^3\) | \(10^4\) |
| Motion sickness | | | | | | | |
| Resonant vibrations of the body | | | | | | | |
| Difficulty breathing | | | | | | | |
| Effect on vision | | | | | | | |
| Effect on the cardiovascular system | | | | | | | |
| Poor hand coordination and foot support | | | | | | | |
| Deterioration in the quality of human operator work | | | | | | | |
| The heating of tissue, the destruction of the cells | | | | | | | |

Consequently, vibrations with different frequency characteristics have different effects on the human body (table 1).

As can be seen from table 1, harmonic low-frequency vibration (1...2 Hz) that causes a sleepy state leads to one of the most common forms of occupational diseases, vibration disease, which occurs as a result of the proximity of natural frequencies of vibrations of solid and elastic parts of the human body.

Thus, it is necessary to introduce restrictions on the impact of vibration on the human body.

3. Theory and results of experiments

When setting the tasks of providing vibration protection, the studied mechanical system is usually divided into two subsystems [10] (Figure 2), which have mutual connections "With". The "I" subsystem includes that part of the mechanical a system in which the physical processes that cause vibrations directly occur; this subsystem is called the source of vibrations. Subsystem "O" is that part of the mechanical system whose vibrations need to be reduced - called the object of vibration protection. Forces that occur in the system and cause vibrations of the object are called dynamic effects.

![Figure 2. Flow diagram of the source-object system.](image)

The main changes in the operator's body that occur under the influence of vibration are related to the amount of vibration energy absorbed by the human body. At the same time, the most important and subject to regulation are the spectral composition and values of the vibration speed in certain frequency ranges, as a result of which physiological functions can change, and with intense and prolonged exposure to vibrations, transient or pathological changes occur, and the effect on mental functions is manifested.

The mathematical model plays a dual role: first, it is an idealization of the description of any complex system, and second, it is a representation of various phenomena and dynamic processes that occur in it.

The current state of development of theory and practice allows us to distinguish a certain structure of models by their complexity, each level of which can be used depending on the goals of the study in a fairly narrow range.
Thus, the structural diagram of the human body can be represented by [11, 12] multi-mass model (Figure 3) with elastic bonds, and dissipative losses by damping elements.

![Diagram of the human body](image)

**Figure 3.** Biomechanical model of the human body in a sitting position: 1-head; 2-eyeball; 3-lungs; 4-forearm; 5-vertebral column; 6-closed hand; 7-legs; 8-abdominal cavity; 9-forearm and hand; 10-chest; 11-shoulder girdle.

As follows from the diagram (Figure 3), the resonance of different parts of the body occurs at different frequencies (table 2).

| Position in Fig. 2 | Part of the human body                        | Resonant frequency, Hz |
|-------------------|-----------------------------------------------|-------------------------|
| 1                 | Head                                          | 25                      |
| 2                 | Eyeball                                       | 30…80                  |
| 3                 | lungs                                         |                         |
| 4                 | Shoulder                                      | 16…30                  |
| 5                 | Vertebral column, longitudinal loading        | 10…12                  |
| 6                 | Closed brush                                  | 50…200                 |
| 7                 | Legs                                          |                         |
|                   | With bent knee joints                        | 2                      |
|                   | With straightened strained legs               | 20                     |
| 8                 | Abdominal cavity                              | 4…8                    |
| 9                 | Forearm and hand                              | 16…50                  |
| 10                | Chest                                         | 60                      |
| 11                | Shoulder girdle                               | 4…5                    |

With vertical vibration, the resonance of the abdominal organs is observed at frequencies of 4…8 Hz, the resonance of the head can occur at a frequency of about 25 Hz. At higher frequencies of the order of 30…80 Hz, the eyeball resonates. For example, during the first flights of American ships, vibration at a frequency of 50 Hz led to the fact that the astronauts could not read the instrument readings due to resonant eye vibration. The subjective feeling was that the eye was covered with a veil. Internal organs included in the resonance often cause painful sensations associated with stretching of the connective tissues that support the vibrating organ.

For the purpose of hygienic assessment, vibration is classified according to the following criteria. According to the method of transmission per person:
- the General vibration transmitted through the support surfaces to the body of a sitting or standing person;
- local vibration transmitted through the hands of a person; local vibration also includes vibration transmitted to the feet of a sitting person, and to the forearms in contact with the vibrating surfaces of work desks.
Typical cases of transmission of vibration to humans are shown in Fig. 4.

![Figure 4](image)

Figure 4. Examples of vibration transmission to the human body.

The General vibration is transmitted to the person through the seat 1 from road irregularities 2 and unbalance of the engine 3 (Figure 4, a); through the seat of the control cabin 1, tower crane 5 due to the vibration of the crane when lifting or lowering the load 4 (Figure 4, b). Also, the total vibration is transmitted through the floor of 6 workplace from the vibration of the test stand 7 (Figure 4, c); through the floor of 8 workplace located on the forming unit of the concrete paver 9 (Figure 4, d).

In the direction of action of the vibration divided in accordance with the direction of the axes of the orthogonal coordinate system (Figure 5): local vibration is divided into the current along the axes of the axes of the orthogonal coordinate system X, Y, Z, where the X-axis parallel to the axis of coverage space of the vibration source (arm, cradle, steering wheel, control lever held in the hands of a workpiece, etc.), the Y-axis perpendicular to the palm, and the Z axis lies in the plane formed by the X axis and the direction of feed or application of force (or the axis of the forearm, when power is not applied); the General vibration is divided into acting along the axes of the orthogonal coordinate system X, Y, Z, where X (from the back to the chest) and Y (from the right shoulder to the left) horizontal axes directed parallel to the support surfaces; Z-vertical axis perpendicular to the support surfaces of the body in places of its contact with the seat, floor, etc. For local vibration, the direction of the axes and their connection with the human hand are shown in Figure 6 and Figure 7.

![Figure 5](image)

Figure 5. The direction of the coordinate axes when the vibration affects a person (General vibration – a - standing and b - sitting positions)

The frequency composition of the forcing vibration determines the extent of its spread through the body and physiological reactions is described with consideration of the adopted dynamic model of the human body as a combination of mass and elastic elements. The threshold for vibration perception corresponds to an oscillatory speed of 10-4 m/s, and at a speed of 1 m / s there is a painful sensation.
Local vibration can be transmitted through the hands to the torso of a person (especially if the hands are tense) and cause general effects such as headaches, nausea, etc. The pathophysiological effect of vibration can lead to the development of vibration disease. The symptoms of vibrational disease are diverse. But most often it manifests itself in a sudden violation of blood circulation of the fingers of the hand, which causes their whiteness, sensitivity, numbness, tingling, all this can lead to partial paraplegia of the hands. When analyzing local vibration, the human hand can be represented as a model by the concentrated parameters [12] of Figure 8.

![Figure 8. Two-Mass model of the hand.](image)

4. Conclusions and conclusion
The analysis allows you to directly proceed to the study of such systems for effective use in assessing the technical condition of a particular equipment or group of equipment based on the results of measurements.

Thus, vibration measurements are carried out for sanitary and hygienic assessment of working conditions and for determining the vibration standards of machinery and equipment. In the first case, measurements of the normalized vibration parameters are performed at the workplace, in the second, the vibration characteristics (kinematic or dynamic parameters) are measured, which must be included in the normative and technical documentation for specific equipment or for groups of equipment.

Therefore, the use of a simple compact portable vibration analyzer, powered by a battery or network, which can work as a set-top box in conjunction with vibration monitoring equipment used for continuous monitoring of the viability of machines. This makes it possible to carry out on-site measurements of current or emergency diagnostics, respectively, of normal or abnormal vibration phenomena and establish the probable cause of the observed level of vibration, as well as predict the possible result of the impact of this level on the operation of equipment and human exposure.

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