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NOISE AS ERGONOMIC FACTOR OF THE PRODUCTION PROCESS

In the conditions of the sophisticated technical equipment, complex mechanization and automation of production, informatization of the society, when the labor productivity depends first all on the skillful use of machines there appears urgent need in the combination of labor with production tools, implementation of such forms and methods of machines maintenance which provide their efficient application on conditions of maintaining the staff health and high productivity.

Some production processes are accompanied by great noise. The sources of the intensive noise on the production site are machines and mechanisms with the unbalanced rotating masses as well as technological units and installations, where the motion of gases and fluids occurs at great speed and is of pulsating character.

The given research applies to the determination of the operation staff safety under the impact of one of the most dangerous factors-noise.

It has been determined that noise as any other factor of the environment, exercises impact on human organism. Studies of biological impact of noise on human organism showed that this impact depends on physical parameters of the sound. It should be noted that this impact depends not only on the spectrum of acoustic frequencies, amplitude and loudness but on the sequence of their emergence and how human can get used to them.

It has been established that as a result of long term impact of noise on human organism normal functioning of cardiac-vascular and nervous system, digestive and hematopoietic organs can be disrupted, professional deafness develops its further progressing may cause complete hearing loss.

Key words: *noise, sound, loudness, frequency, intensity, impact, safety, production process, human health, disease.*

Introduction

Human organism is influenced by numerous material factors of the industrial environment. Certain production factors act in a special manner, inherent only to them, influencing certain systems, organs and cause functional changes or diseases. For instance, factors, connected with vibration processes – noise and vibration often have one source of generation, they practically always act jointly on human organism but the character of their impact differs. Under the impact of noise such functional disorders may occur, for instance, adaption or hearing fatigue. In some cases noise may cause professional weakening of hearing or complete hearing loss. However, besides specific impact on separate systems and human organs, any work, performed in corresponding material state may lead to the emergence of numerous phenomena and processes, assessment of which makes conclusion about the complex action of the production state on human organism. In each production environment numerous physical and chemical factors can develop, they may level and mutually compensate each other from the point of view of physiology or vice versa – overlap each other and reinforce each other. That is why, one of the principles of ergonomics is the consideration of human organism as organic whole, which is in inseparable connection with the production environment. According to the definition of International organization of ergonomics, which was adopted at the congress in 2010: «Ergonomics is scientific discipline that studies the interaction of man and other elements of the system, as well as, sphere of activity, regarding the application of theory, principles, data and methods of this science to provide human well-being and optimization of general performance of the system [1, 2]. In accordance with this definition, ergonomics must realize the following tasks:

– carry out research, aimed at the adaption of the elements of «man – production process» system to natural physical and psychological abilities of the employee;

– provision of the maximum labor performance;

– prevent all possible threats for human health;

– optimization of the biological resources consumption in the work process.

Relevance of the research

Consideration of the production environment as an integral whole does not exclude the need of studying its separate elements. At first sight, in this contradiction the same interconnections appear as in the contradiction between part and whole in the process of analysis and synthesis. Studying of separate factors of the production environment requires their clear classification. In case of general classification, these factors can be divided into two groups, which basically differ from one another, namely, physical and chemical factors. One of the subgroups of physical factors is vibration and as a consequence, noise. In its turn, this subgroup comprises the acoustic vibrations, that is, noise, and mechanical vibrations (general and local vibrations). Main task of labor protection (and, naturally, ergonomics) is to provide for the staff healthy and safe labor conditions, which minimize cases of professional injuries and diseases. For this purpose it is necessary to study the internal connections in «man-machine» system , character of their reaction on the external disturbances. It is quite natural, that the study of the sources of production noise generation, ways of its propagation, characteristic features of its impact on human organism and protection against harmful impacts is relevant problem.

However, nowadays there is no clear system of theoretical and experimental studies, regarding the sources of noise generation, its types, consequences of its impact on human organism, measures and means to fight noise. In the given study an attempt is made to systematize the available material, outline ways for further research.

Objective of the research

Objective of the research is the reduction of the negative impact of production noise on the employees by generalizing the investigations, regarding the impact of the noise on human organism, determination of the directions, aimed at enhancement of the efficiency of the collective and individual noise protection.

Main part

Mechanical vibrations of the material particles of any elastic environment create noise. During its penetration into the space it is in the state of physical balance and mechanical vibrations cause local changes of density and pressure. Difference between the excessive pressure, originating as a result of acoustic wave propagation and pressure of the environment (for instance, air) is called acoustic pressure, it is measured in microbars (1 bar = 10^5 Pa = 10^5 n/m^2). Normal atmospheric pressure (760 mm of mercury column) in these units is 1.013×10^6 microbar.

In theory and practice of the science of noise sounds are distinguished – simple and complex. The source of simple sounds are bodies which perform vibrations by their mass, material base of complex sounds is vibration both of the whole body and its separate parts. Unlike simple sounds, in complex sounds not only basic but additional tones are distinguished. Both simple and complex sounds have constant values of the amplitude and frequency of vibrations and in case of noise, which consists of different tones, these parameters turn out to be variable and non-periodic. Complex sounds are distinguished by the pitch, tone, volume and pitch of the sound depends on the frequency, volume – on the amplitude of the vibrations and tone – on the additional tones.

Sound analyzer of a man enables to perceive sounds with the frequency of 16 to 20000 Hz, if the excessive pressure, originated under the action of the acoustic vibrations, exceeds certain limiting value, called sensitivity threshold. Sounds of the frequency less than 16 Hz are called infrasound and with the frequency of more than 20000 Hz – ultrasound. Acoustic pressure of the sound with the frequency of 1000 Hz, which corresponds to the sensitive threshold is 2×10^{-4} μbar. Sound perception occurs when the acoustic pressure is within the range of 2×10^{-4} to 5×10^2 μbar.

However, these parameters are not sufficient for objective, more over for subjective (i. e., based on our

feelings) assessment of the sound and noise intensity. Energy units turned out to be more convenient for this purpose. That is why, sound intensity is usually measured by the amount of sound energy, passing during one second across the surface of the perpendicular direction of sound wave motion. As a rule, acoustic energy is measured in microwatts (μW). Objective force of the sound is measured in microwatts per square centimeter, 1 μW/cm^2 corresponds to the pressure of 20 μbars. Thus, sensitivity threshold corresponds sound intensity of 10^{-10} μW/cm^2.

Sensitivity threshold corresponds to the low boundary of the objective scale of the acoustic sound intensity and its upper boundary corresponds sound intensity (also at the frequency of 1000 Hz), which causes painful sensations. For people with sensitive hearing this value is $10^2 \ldots 10^3$ μW/cm^2 (200 μbar). Thus, the range of the acoustic scale turns out to be rather wide: it covers 10^6 units of the acoustic pressure or 10^{12} units of acoustic energy. That is why, the application in this case of the linear scale seems to be not very convenient. Logarithmic scale is much more convenient, each tenfold change of the sound intensity (or twentyfold increase of its pressure) corresponds to one unit of measure. This can be presented in the form of dependence:

$$L = \lg \frac{I}{I_0} = 2 \lg \frac{P}{P_0}, \quad (1)$$

where $I_0 = 10^{-16}$ $\mu W/cm^2$, and $P_0 = 2 \times 10^{-4}$ μbar.

Hence, if $I = I_0$, the intensity $L = \lg 1 = 0$; if $I = 10 \times I_0$, $L = \lg 10 = 1$; if $I = 100 \times I_0$, $L = \lg 100 = 2$ etc.

Computation can be performed, using the unit of the acoustic pressure.

This logarithmic unit is called Bell (in honor of A. G. Bell, the inventor of the telephone). In practice, the value, ten times smaller, called decibel, (dB), is used. Increase of the sound intensity per 1 dB corresponds to the increase of sound volume on 26 %, and sound pressure – 12 %.

Usage of the logarithmic scale for the assessment of the sound intensity and acoustic pressure is connected with the fact that according to Weber-Fekhner law [3] there exist logarithmic dependence between subjective feeling and objective irritant. This dependence can be presented in the form of the formula:

$$L = C \frac{\Delta E}{E}, \quad (2)$$

where ΔE – is the substantial increase of the irritant force; E – is the irritant force, acted before; C – is constant coefficient.

If we assume that the values of the successive increments of the sound force are equal, we obtain after the transformations the following equation:

$$L = const \times \lg E, \quad (3)$$

where L – is sensible sound force (subjective value); E – is real sound force (objective value).

Weber-Fechner law sometimes is considered to be universal psychophysical law and any changes of feelings, caused by different physical irritants (acoustic and mechanical vibrations, smells, temperature, etc) fall under this law. It should be noted that such point of view does not correspond to the results of numerous experimental research. It can be stated that Weber-Fechner law reflects real dependence between the force of the irritant and intensity of feelings only in limited interval of the irritant action and the action of very strong or very weak irritants does not correspond to this law. Nowadays more and more arguments are made in favor of the statement that the dependence between the force of the irritant and level of feelings is not a logarithmic but exponential dependence (so called Stevens law) [3, 4].

Existence of the difference between the intensity of the irritant and level of feeling led to creation of not only objective but subjective scale. This is explained by the fact that the level of feeling depends not only of the sound force but also on the frequency. That is why, for the creation of the objective scale only the sounds of the determined (1000 Hz) frequency were used. Subjective scale, unlike the objective scale cover the complete interval of frequencies which man can hear. It is so called «background» scale of the sound force, developed on the base of the experimental studies. As a result of these studies it was established that two different sounds with different frequency but with the same objective force cause different subjective feelings in human hearing organs. Besides, these studies show that increasing or decreasing the intensity of

one and the same sound, the feeling, equivalent to the feeling, occurring in case of the actions of the sounds of different intensity (in spite of the difference in frequency). So called curves of equal noticeble loudness (isosonic curves) were constructed [5, 6]. Fig. 1 shows these curves of equal loudness of pure tones.

Subjectively sound force is measured in phons, in case of the sound action of 1000 Hz, one phon corresponds to 1 dB and in case of sound vibrations with other frequencies, these values will be different as far as the difference between this value and reference frequencies increase, these differences grow. But as it can be seen on the graph in Fig. 1, in the range of 400 – 500 Hz up to 4000 – 5000 Hz the given difference turns out to be insignificant that is why, in practice this difference can be neglected.

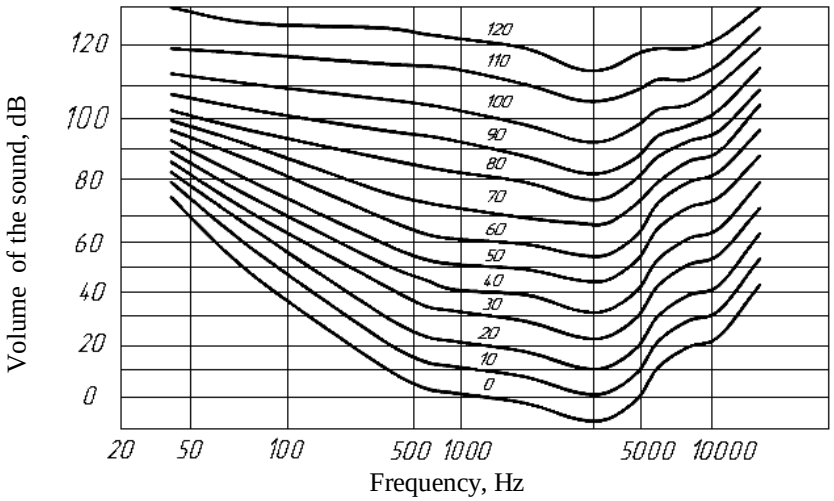

Fig. 1. Equal volume curves of pure tones

Noise as any other factor of the environment, exercises the impact on human organism. Studies of the biological impact of noise on human showed that this impact depends on physical parameters of the sound. But it should be noted that this impact depends not only of the spectrum of acoustic frequencies, amplitude and volume but the sequence of their emergence and human addiction to them. It is known, that in some cases the intensive but rhythmic sounds, creating simple melody, are perceived as pleasant music. Moreover, the notion of music melody and feelings, caused by this complex gamma of sounds (which form its material base), change in time and are stipulated by psychological, social and other individual factors.

Notion «noise» must be defined by the subjective criteria, first of all of psychological character. Noise can be called such acoustic phenomena (both audible and inaudible), which in this place and at this time are unpleasant or harmful for health. Although this definition is not very accurate, it rather exactly reflects real state of the problem. Evaluating noise both from physical and biological points of view, it is necessary to take into account not only the volume of sounds but their spectrum, i. e., distribution of the sounds according to separate frequencies. Sounds of high frequency cause more harmful impact than the sounds of low frequency. From this it follows that the danger of noise increases at the displacement of the largest levels of volume in the side of high frequencies. Noise, manifested in the form of discrete pulses, turns out to be more harmful than constant sound and the noise, which emerged suddenly, leads to greater psychophysiological disorders, than «normal» noise of this premise.

Biological impact of noise has been the subject of scientific research for a long time. Published results of the studies consider the impact, exercised by the noise on human hearing organs, for which any acoustic impact is adequate irritant [7]. Thus, a number of papers, devoted to the impact of noise on other organs and systems of human organism are published [7, 8]. Underling the difference between the adequate and inadequate impact of noise certain authors call the impact of noise on the functions of the internal organs as well as on autonomic and central nervous systems nonspecific [9, 10]. They think that consequences of nonspecific impact affect the human hearing organs earlier than specific impact.

Influence of the noise on hearing organs can be active (acoustic loss of hearing) or passive (reversible and irreversible decrease of hearing acuity). Functional changes of human hearing organs under the action of noise, first of all are manifested by the increase of hearing threshold. This increase (which is expressed in the emerging of the difference of hearing thresholds of one and the same person after the action of noise and

prior to such action) can change within the limits from several dB to several tens dB and depends on numerous factors (frequency of the sound, individual peculiarities of the human organism, exposure to noise). Some authors proved that the increase of the hearing threshold emerges first of all under the impact of the sounds of 250 – 4100 Hz [11, 12]. At the same time the authors [11, 13] revealed that human hearing organs have the highest sensitivity to the sounds of 800 Hz and in the range of 1000 – 3000 Hz.

Increase of the hearing threshold is physiological phenomena, accompanying the processes of functional adaptation of hearing organs. It can be admitted that the reason of adaptation is protective reaction of central nervous system. Shift of the hearing threshold (change of hearing acuity) presents the intensity of braking processes.

During the impact on human organism of complex by its spectral composition noise, which consists of the sounds of different frequency, the phenomenon of the so -call masking or muffling of one sound by another may occur. In this case masking sound leads to the increase of the hearing threshold of the sounds which it masks. Important masking effect create sounds with the frequency of 200 – 400 Hz which muffle the sounds of the range, following them (more than 400 Hz). According to various hypotheses masking phenomenon can be explained as a result of the irradiation of the excitation in the centers of the cortex or as one of the manifestations of hearing organs adaptation.

Three phases or forms of hearing organs reaction on noise are distinguished: adaptation, hearing fatigue and dysfunction. State of adaptation is reversible and increase of the hearing threshold, observed during adaptation as a rule, decreases in 3…5 minutes of rest in the conditions of the relative silence. Speed of emergence and efficiency of the adaptation as well as the interval of the sound spectrum, relatively which hearing threshold is observed, depend on the intensity and duration of the acoustic irritant action. Intensity of adaptation in the section higher than 2000 Hz is 10 dB, and in the section of the spectrum lower than 1000 Hz – 15 dB [12]. Shift of the hearing threshold can be detected by means of audiometric investigation (Fig. 2).

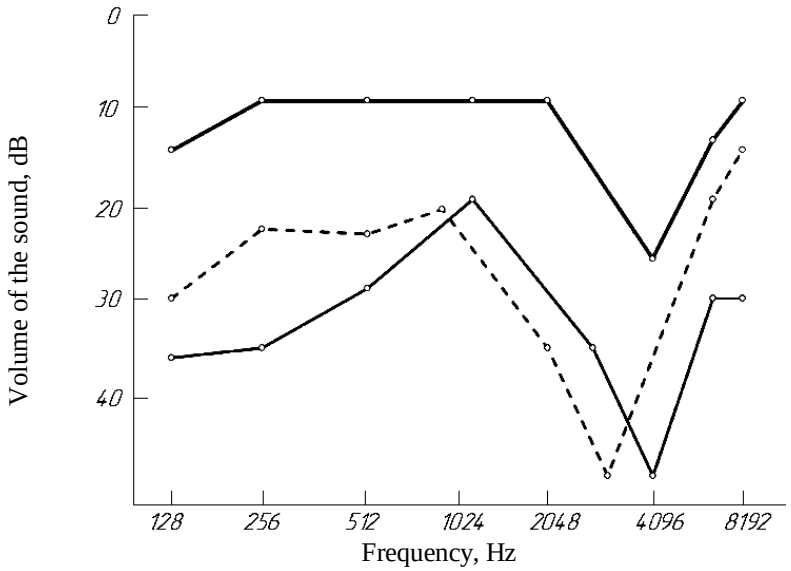

Fig. 2. Increase of the hearing threshold during the work in noisy conditions:
1 – results of audiometric investigations before the work; 2 – results of audiometric investigations after the first hour of work; 3 – results of audiometric investigations after the working day

In the state of fatigue, which develops under the action of too long or very intensive acoustic irritation, long-lasting increase of hearing threshold is observed, it disappears only in several hours or even tens of hours of rest, and in separate cases – in several days or weeks. In some cases the fatigue of the hearing organs may become irreversible (passive acoustic disorder of hearing organs functioning). Irreversible changes as a result of the acoustic injury (passive or acute) take place as a result of mechanical injury of the eardrum or Corti`s organ, located in the inner ear. Unlike the acoustic injury, reversible changes of hearing organs occur as a result of the reflect compression of the middle ear and due to functional disorders in the central nervous system, caused by the excessive amount of pulses, reaching the cortex.

Fatigue of the hearing system is also explained by the disturbance of the biochemical processes, taking place in hearing organs. In the state of fatigue the decrease of oxygen consumption is observed as well as the decrease of the activity of succinic acid dehydrogenation (ferment, contained in the inner hair cells), this is connected with the reduction of the protein content and nucleic acids in the cells of serpentine curls. Return of the concentration of these substances to the normal level lasts almost one day but it takes place slower (up to 3…8 weeks). At the same period the fatigue of the hearing organs is observed.

Than thought that for audibility 120…130 dB there exists constant pain threshold. New studies [11 – 13] showed that volume of the sounds, which correspond to the pain threshold, depends on the frequency spectrum and change in rather wide range. Researchers made a conclusion that the level of harmful influence of noise depends on numerous factors, including volume level, frequency range, time and character of the noise impact during the working day, on the length of work in the conditions of increased noise and individual features of the organism.

Among different forms of negative impact of noise on human organism its influence on mental functions and state of cardiovascular system has been examined in details. In particular in [14] it is noted that in the sphere of subjective perception noise leads to the emergence of unpleasant feelings, anxiety, illness, state of fear, oppression, suffering, alarm. In the conditions of noise the ability to concentrate attention decreases, the execution of the accurate work, which require the involvement of the central nervous system, becomes difficult. Under the impact of noise, the downtime and complex reaction lengthens (especially time of selection). It means that noise interferes with qualitive performance of the work, connected with receiving and transmission of information, different kinds of creative activity. Besides, noise interferes with verbal exchange of the information. Spectrum of frequencies of ordinary human speech is within the range of 200 to 2000 Hz, and its volume (at the distance of 300…360 cm) is 30…70 dB. Reception of the conversation is possible in case if the acoustic volume of the background at least by 10 dB is lower than the volume of the conversation. Thus, if the intensity of noise is 70 dB verbal exchange of the information is complicated and the intensity of the sound signals must be increased.

Practically, all the studies confirm the fact that in the conditions of high level of noise labor productivity decreases. Employees who are constantly under the impact of noise complain of a headache, fainting, poor sleep and appetite, they can react incorrectly to temperature change, visual impairment, disturbance of small and taste. Such workers are in the state of great excitement, they experience disturbed nervous psychological balance, they suffer from diseases, connected with the disorders of the nervous system and, first of all, from neuroses. Under the impact of noise the change of bioelectrical activity of the cortex is observed.

Noise influences differently on functioning of cardio-vascular system. It was determined that noise does not influence the pulse frequency but increases blood pressure. Cardiac output first increases then drops. Change of the functions of cardio-vascular system becomes more obvious when noise spectrum moves in the direction of higher frequencies. In general, the conclusion can be made that the degree of the noise impact on the organism of the worker greatly depends on the parameters of the sound and, naturally, on individual characteristics of the organism.

It should be noted that noise effects not only physical conditions of human but his mental abilities. In [15] it is noted that under the impact of noise productivity of labor drops , as it requires constant participation of visual organs , and the exposition of the clear vision of the objects decreases as compared with normal almost two times, depending on the noise intensity. Noise also causes the disorders of the processes of the visual organs adaptation in the darkness. The impact of noise increases the threshold of vision in the darkness, sensitivity of vision to infra-red radiation reduces, increases sensitivity to blue-green part of spectrum. These data are of great practical value and they should be used in the process of the alarm and signaling systems design.

Assessment of the negative impact of noise on human organism will be incomplete, if the problem of noise impact of energy processes is not mentioned. Studies [16] determined that energy expenditures of human organism increase in the process of execution of work in noisy conditions. In other words: any work, executed in the presence of noise turns out to be more difficult as compared with the same work, performed in the conditions of the relative silence.

All round assessment of the negative impact of noise must take into account its intensity (level of volume), level of the sources of background noise, spectrum of noise, being investigated and spectrum of the background noise, noise change in time, and in separate parts of spectrum during the working day, as well as individual characteristics of people, who work in the conditions of noise impact.

Struggle with harmful impact of noise is performed applying various methods. First of all, it is necessary to try to reduce the noise intensity, this can be achieved, using measures which change the direction of sounds propagation from the sources, jamming of the resonance oscillations, reduction of the number of the vibrating elements, attenuation of the waves, reflecting from the surface or installation of the soundproofing screens.

For individual protection of hearing organs special ear plugs (antiphons) or protective helmets are used. Application of antiphons is contraindicated in cases when along with the noise general vibration is available, because in case of blocking of the external auditory canal the removal of the sound wave is difficult, this causes the enhancement of the harmful impact off the mechanical oscillations. Antiphons must be manufactured from soft materials and filled with harmless substances.

Modern anti-noi se headphones may have the function of automatic regulation of the volume level of the external sounds, provide efficient reduction of the noise to 25 dB, enable to hear and better recognize the external sounds, warning signals, sounds of the equipment, conversations, etc. Greater part of them allow to regulate the level of the external sound perception, have several levels of volume, digital regulation of the noise level, etc.

In spite of great variety of the protective devices against the action of the noise, it is necessary to adhere to the norms of the noise level, depending on the category of the production premises, type of production and other factors. Table 1 contains maximum permissible noise levels depending on its source and parameters as well as type of the premises.

Table 1

Maximum permissible noise levels (dB)

Type of noise	Geometric mean value of octave range limits, Hz							
	63	125	250	500	1000	2000	4000	8000
Noise, penetrating from outside into the premises, located on the territory of industrial enterprise:								
a) design bureau, laboratories without own sources of noise;	71	61	54	49	45	42	40	38
b) administrative buildings of the enterprises, ambulant clinics, etc.	79	70	63	58	55	52	50	49
Noise, emerging in the premises and penetrate in the room, located on the territory of the industrial enterprises:								
a) precision assembly hall;	79	70	63	58	55	52	50	49
b) laboratories, monitoring and control cabins;	94	87	82	78	75	78	71	70
c) work places in the workshops and on the territory of industrial enterprises.	103	96	91	88	85	83	81	80

In spite of the availability of a great number of efficient technical facilities for the protection of the workers against the impact of noise, numerous measures, in particular, medical-preventive are used for this purpose. Besides active and passive protection against the impact of noise, permanent medical monitoring of human health and detailed selection of the staff for the work in the conditions of noise production premises is needed.

Only organic combination of various technical facilities and organizational preventive measures will enable to protect efficiently the workers aganist negative action of noise, protect their health and work performance at the satisfactory level.

Conclusions

1. Ergonomic drawbacks in the organization of the working places may become factors of risk of the production process. These drawbacks may cause the development of functional disorders, provoke the reduction of labor productivity, emergence of the professional diseases.

2. One of the most dangerous production factors, threatening human health is noise. Characteristic features of the production noise impact, character, depth and direction of the physiological changes of various systems of human organism depend on the level and frequency composition of the acoustic oscillations, their direction and physiological features of the human body.

3. For the numerical assessment of noise impact on the human organism it is expedient to use the relative logarithmic scale of the sound feelings. Such unit is called Bell, in practice, the unit 10 times less is used, that is dB.

4. Struggle with harmful impact of noise in greater part of cases is reduced to following to the available norms and rules as well as application of various technical facilities, which reduce the parameters of the vibration impact and medical-preventive measures to avoid the generation and development of the negative consequences of the noise action.

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