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Occupational noise protection in workshops with operating equipment

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Abstract. The industrial environment of production workshops encompasses a range of harmful and hazardous factors that negatively impact workers' health and performance. Among these, high levels of noise generated by operating equipment during technological processes are particularly significant. Prolonged exposure of workers to elevated noise levels, exceeding 80 dB, without collective and individual protective equipment, leads to occupational hearing diseases and disruption of other bodily systems. The purpose of this study was to develop protective measures against industrial noise in workshops with operating equipment, thereby improving working conditions. The research employed scientific generalisation and analysis of existing literature on the harmful effects of industrial noise, along with regulatory documents concerning permissible noise parameters in workshops. Permissible noise parameters in the working areas of industrial premises have been substantiated. Based on applicable regulatory acts, scientific recommendations were proposed for the design of a noise-insulating panel to reduce broadband and low-frequency noise using soundproofing and sound-absorbing materials. It has been established that the use of a sound-insulating panel increases the effectiveness of noise reduction in working areas of premises to the level of sanitary standards. The practical significance of the obtained results lies in reducing noise levels in industrial premises through the summary localisation of sound waves and their subsequent absorption within the sound-insulating panel. This allows for the improvement of working conditions in industrial workshops with operating equipment and a reduction in occupational morbidity among industrial workers

Keywords: sound level; sound insulation; sound wave; sound-absorbing layer; mineral packing; sound-insulating panel

Introduction

The relevance of this research lies in the fact that industrial production in the mining is linked to the extraction and processing of raw materials using crushing, dressing and transportation equipment, all of which produce high levels of noise. Metallurgical production also employs various types of equipment, the operation of

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which is accompanied by intense noise, contributing to the deterioration of working conditions. The increasing power and productivity of dressing and metallurgical equipment, along with the use of transport equipment, leads to an increase in industrial noise in workshops. Infrasound and ultrasound generated during equipment operation also negatively impact the human body.

The study by A. Mehrotra *et al*. (2024) examined the complex impact of noise on workers, encompassing hearing loss, tinnitus and sleep disturbances, in addition to non-auditory problems such as irritability, cognitive impairment and psychological stress linked to cardiovascular disorders. The study by D. Hillesheim *et al*. (2024) focused on the relationship between the occurrence of dizziness among Brazilian workers due to industrial noise exposure. Studies have shown that nearly a quarter of workers who suffer occupational hearing loss experience episodes of dizziness.

The results of C. Krittanawong *et al*. (2023) demonstrated the progressive effects of noise on workers, indicating that noise-induced psychological stress and mental health disorders, such as depression and anxiety, negatively impact the progression and severity of cardiovascular disease. Reduced sleep quality and duration increase sympathetic nervous system activity, which may contribute to the development of diseases such as hypertension and diabetes. Noise exposure also disrupts the hypothalamic-pituitary axis, increasing the risk of cardiovascular diseases. The authors concluded that noise is the second main factor for disease development in Europe after air pollution.

The evidence outlined above confirms the ongoing problem of excessive noise levels from operating equipment in mining and metallurgical facilities, which not only affect workers' well-being but can also lead to hearing loss and increase the risk of workplace injury. Considering the morally and physically outdated equipment that has exceeded its operational lifespan, is not regularly inspected, and remains in use without timely replacement or modernisation in accordance with legal requirements, the issue of noise reduction in production workshops requires urgent resolution. The study by M. Yaman *et al*. (2024) addressed the need for a comprehensive approach to industrial noise control and reduction. The authors emphasised that noise should be reduced at its source, along its transmission path, and at the worker's location. Depending on the origin, noise can be classified as aerodynamic, mechanical (vibrational), electromagnetic, or hydrodynamic.

The research conducted by D. Rieznik *et al*. (2024) regarding the negative impact of noise on workers in industrial premises with operating equipment primarily focused on preventive recommendations for reducing its level or developing the measures: modifying technologies to reduce equipment-generated noise; isolating noise sources; absorbing noise; using personal protective equipment; developing hygiene regulations; organising regular medical examinations for workers in noisy workshops.

The study by O. Levchenko *et al*. (2023) presented typical technical measures for reducing industrial noise in workshops: replacing stamping machines with pressing machines; high-precision manufacturing of equipment components; improving the fastening of vibrating equipment components; substituting metal components with plastic ones; using centrifugal fans instead of axial ones, etc. However, the authors noted that reinforcing moving components does not completely eliminate their oscillations or the associated noise.

C. Singh & S. Deswal (2025) propose reducing noise directly at its source. To limit spatial propagation, they recommend using acoustic glass materials to enclose noisy equipment. To reduce the transmission of aerodynamic, electromagnetic, and partially mechanical noise between workshops, recommendations by S. Sorin *et al*. (2020) regarding the rational selection of building materials can be employed to improve the sound-insulating properties of building structures.

A. Arjunan *et al*. (2024) proposed equipping recreation areas for workers, dispatch rooms, observation rooms, control rooms, offices, laboratories, and other premises with sound-insulating walls, partitions, etc., lined with sound-absorbing materials. M.J. Crocker & J.P. Arenas (2020) noted that an effective means of noise reduction in buildings is the use of sound-absorbing materials, such as fibreglass, foam, perforated cardboard, felt, cotton, etc.

Therefore, a promising direction for research is the integrated use of sound-insulating and sound-absorbing materials, which increases the effectiveness of noise reduction. The purpose of this article was to develop effective means of protection against industrial noise, such as the sound-insulating panel, which will improve the working conditions of workers in workshops with operating equipment.

Materials and Methods

The study analysed existing measures and means of protection against industrial noise and recommendations for their implementation, which allowed for the identification of ways to increase their effectiveness. The physical characteristic of industrial noise is that mechanical vibrations of solid and gaseous substances in the air produce sounds across different frequency ranges; that is, noise consists of a collection of sounds with varying frequencies. Industrial noise generated within industrial premises is characterised by several parameters: amplitude and frequency of oscillation, sound pressure, sound intensity, and the speed of sound wave propagation.

To develop effective protective means against industrial noise, it is essential to understand its physical parameters, which were described in the work by O. Lapshyn *et al*. (2023):

1. Amplitude of sound oscillations (*A*, mm) – the extent to which pressure deviates from the equilibrium position; the greater the amplitude, the higher the sound pressure and the louder the sound.

2. Frequency of oscillations (*f*, Hz) – the number of acoustic oscillations per second.

3. Sound pressure (*P*, Pa) – the difference between the pressure generated during sound production and the ambient pressure in the absence of noise (P_0).

4. Sound intensity (*I*, W/m^2) – the average sound energy flow per unit surface area.

The speed of acoustic oscillation propagation depends on the elastic properties, temperature, and density of the medium in which they travel.

To measure noise levels, specialised instruments known as sound level meters are used (e.g. VShV-003, ISHV-1, and devices from Testo, PCE, Tenmars, etc.). These typically consist of a microphone, frequency-weighting filters, detector, integrator and indicator. Since the human ear's sensitivity varies with both sound frequency and intensity, sound level meters are equipped with several filters that correspond to different noise intensity levels. These filters simulate the ear's amplitude-frequency response at specific sound intensity levels and are labelled A, B, C, and D. Filter "A" approximates the response of the "average ear" under low noise conditions, "B" corresponds to high noise levels, "C" is used for peak level assessment, and "D" was developed for evaluating aircraft noise. According to DSN 3.3.6.037-99 "Sanitary Norms of Industrial Noise, Ultrasound, and Infrasound" filter "A" is used for norming noise (Resolution of the Ministry of Health of Ukraine No. 37, 1999). The permissible sound pressure levels in octave frequency bands, sound levels, and equivalent noise levels at workplaces for broadband continuous and non-continuous (excluding impulse) noise were provided in Table 1.

Table 1. Sound pressure levels and noise levels at workplaces

Type of labour activity	Sound pressure levels (dB) in octave bands with frequencies, Hz									Noise level, dBA
	31,5	63	125	250	500	1,000	2,000	4,000	8,000	
Creative activity	86	71	61	54	49	45	42	40	38	50
Highly skilled work	93	79	70	68	58	55	52	50	49	60
Operator work	96	83	74	68	63	60	57	55	54	65
Workplaces at control panels	103	91	83	77	73	70	68	66	64	75
Workplaces in industrial premises	107	95	87	82	78	75	73	71	69	80

Source: developed by the authors based on Resolution of the Ministry of Health of Ukraine No. 37 (1999)

Given that most industrial equipment generates noise in the 1,000-5,000 Hz range, healthy working conditions in production workshops require that sound pressure levels not exceed 70-75 dBA. For research on the development of a sound-insulating panel, the Tenmars ST-109R sound level meter from Tenmars Electronics (Taiwan) was used, which allows for measuring noise in the range from 30 to 130 dB with a frequency range from 20 Hz to 16 kHz. The selection of the panel's structural parameters and sound-absorbing material was conducted by measuring the noise level behind a barrier (panel). Noise level measurements were taken at least three times.

Results and Discussion

The maximum permissible noise levels at permanent workplaces within premises and across enterprise territories must not exceed 80 dBA. The impact of various noise levels on the human body leads to the following sensations: 30-55 dB – does not disturb tranquillity; 60-85 dB – stress on the central nervous system, prolonged exposure causes neurosis; 90-120 dB – prolonged exposure results in hearing loss; 120-150 dB – pain threshold, eardrum rupture; above 160 dB – death. Depending on the type of work activity, noise levels at workplaces range from 60 to 130 dB (Table 2).

Table 2. Noise levels of some sources in workshops

Noise source	Noise level, dB	Note
Medium loudness conversation	60	At a distance of 1 m
Metal-cutting machines	80-95	At the workplace
Jackhammers	90-110	At the workplace
Woodworking machines	100-120	At the workplace
Forging and stamping equipment	110-115	At the workplace
Pneumatic drills	110-130	At the workplace

Source: developed by authors

According to DSTU 2867-94 (1994), at mining and metallurgical enterprises, noise control is carried out through the use of collective and individual means. Preference is given to collective means, which include: means of noise reduction at its source, and those that block sound waves during their propagation. While reducing noise at its source is the most effective solution, this often depends on the equipment's design, which can only be altered by the manufacturer. Consequently, enterprises are typically left with less effective methods, such as sound insulation and sound absorption.

The principal noise control strategies in industrial settings include:

Replacing noisy technological processes or mechanisms with less noisy alternatives. For example, substituting pneumatic drilling hammers with electrically powered devices or using centrifugal fans, which operate more quietly than axial ones.

Considering permissible sound pressure levels during equipment design, as outlined in Table 1. These norms aim to prevent occupational hearing disorders. It is important to note that the auditory system is more sensitive to higher-frequency sounds. Accordingly, as frequency increases, so does the harmful impact of sound, necessitating lower permissible sound pressure levels.

To mitigate noise at the source, the following measures are recommended: where possible, replacing metal components of mechanisms with non-metal components; reducing clearance gaps in component joints; using sound-absorbing gaskets; better balancing of rotating components; replacing impact mechanisms with impact-free, and reciprocating motions with rotary motions. Where it is not feasible to reduce noise through structural changes, devices should be installed to inhibit its propagation. For example, gear reducers and similar components should be enclosed in sound-insulating housings or filled with lubricants to dampen noise.

Aerodynamic noise produced by turbulence or air/gas exhaust (e.g. fans, pneumatic machinery and tools) can be mitigated using built-in or attached mufflers, as discussed in the studies by C. Gaonkar & T.N. Sreenivasa (2024), W. Yang *et al.* (2025), and B. Liu *et al.* (2025). Aerodynamic noise mufflers can be active and reactive. The operation of active mufflers is based on the principle of absorbing sound energy and converting it into heat. In this case, porous sound-absorbing materials play a main role, as emphasised by X. Tang & X. Yan (2017). The simplest active muffler attached to an exhaust outlet is a piece of pipe or hose, the inner surface of which is lined with felt. In a reactive muffler, noise attenuation is achieved by incorporating expanding chambers into the air duct. Reactive mufflers that effectively dampen air pulsations are used in compressor and pneumatic installations.

For example, to reduce the noise produced by a hammer drill during blasthole drilling in quarries and mines, a rubber muffler is fitted, as illustrated in Figure 1. The muffler operates by permitting exhaust air from port 5 to enter the muffler chamber 4, where it loses energy through expansion, and exits gradually through port 6. The noise level of the hammer drill, which is 111-124 dBA, is reduced to 85-90 dBA. The reduction of aerodynamic noise generated by stationary fan units used to ventilate mine workings is 25-30 dBA when using a PGS (plate muffler wall) muffler (Fig. 2).

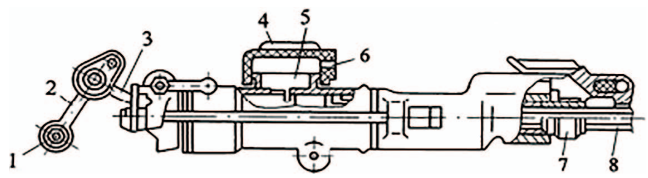

Figure 1. Schematic diagram of muffler placement on hammer drill PR-25MV

Notes: 1 – flexible handle; 2 – crossbar; 3 – bracket; 4 – muffler; 5 – exhaust port; 6 – muffler window; 7 – rubber-metal holder; 8 – drill bit

Source: O. Lapshyn *et al.* (2023)

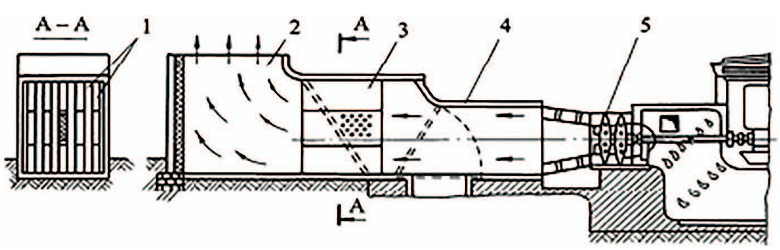

Figure 2. Schematic diagram of a muffler for stationary fan units

Notes: 1 – PGS muffler section; 2 – vertical bend, lined with fibreglass material; 3 – PGS plate muffler; 4 – reinforced concrete diffuser; 5 – fan

Source: O. Lapshyn *et al.* (2023)

According to Figure 2, the plate-type silencer 3 is installed in the outlet duct before the diffuser 4 and consists of six to eight parallel vertical partitions (made of reinforced concrete plates or porous slag blocks) arranged 300-400 mm apart along the channel. To reduce noise transmitted through the metal casing and ring diffuser of the fan, a removable enclosure constructed from sheet metal, wooden boards, felt, and leatherboard is used. The annular gaps in the fan casing are filled with sand or slag.

Timely maintenance is a well-known and effective means of noise control. As research M. Kalifa *et al.* (2025) demonstrated that loose or poorly adjusted machines, tools, and pipelines significantly increase noise and vibration levels.

Where technical solutions are not sufficient to reduce noise at the workplace, the use of personal hearing protection is required.

Personal hearing protectors must comply with the relevant DSTU standards that are harmonised with European regulations. As of 2025, Ukraine recognises at least 10 such standards. These standards delineate safety and performance requirements, testing protocols, and selection criteria (Table 3).

Table 3. Ukrainian requirements and standards for personal hearing protection devices

Standard	Responsibility
DSTU EN 352-1:2018 (2018)	Defines requirements for earmuffs
DSTU EN 352-2:2018 (2018)	Defines requirements for earplugs
DSTU EN 352-3:2018 (2018)	Defines requirements for earmuffs attached to safety helmets
DSTU EN 352-5:2015 (2015)	Defines additional requirements for earmuffs with active noise reduction systems
DSTU EN 13819-1:2005 (2005) and DSTU EN 13819-2:2005 (2005)	Defines the test method common to all types of hearing protective devices
DSTU EN 352-4:2014 (2014)	Defines additional safety requirements and associated testing procedures for level-dependent earmuffs
DSTU EN 352-6:2005 (2005)	Defines additional requirements for earmuffs with electrical audio input circuits
DSTU EN 352-7:2005 (2005)	Defines additional requirements for level-dependent earplugs
DSTU EN 458:2005 (2005)	Applies to the selection, use, care, and maintenance of hearing protective devices

Source: developed by the authors

Earplugs (DSTU EN 352-2:2018, 2018) are personal hearing protection devices worn either inside the ear canal (aural) or positioned just outside it (semi-aural). Earplugs may be disposable, reusable, custom-moulded, or headband-supported. Earmuffs (DSTU EN 352-1:2018, 2018) are personal hearing protection devices consisting of independent sound-insulating shells that are pressed against the ears or surrounding head area. These shells are held in place using a headband positioned over the head, behind it, or under the chin. The clamping force must not exceed 14 N. The sound-insulating shells of earmuffs are hollow components mounted on a clamping device. Sealing cushions are attached to these shells to enhance comfort and their fit to the head, along with a sound absorber designed to improve the acoustic performance of the earmuffs at specific frequencies. The minimum acoustic attenuation performance of earplugs and earmuffs must not be less than the values specified in Table 4.

Table 4. Requirements for acoustic attenuation performance of earplugs and earmuffs

Noise frequency, Hz	125	250	500	1,000	2,000	4,000	8,000
Noise reduction, dB	5	8	10	12	12	12	12

Source: developed by the authors based on Table 3

Manufacturers of personal hearing protection devices have developed earmuffs equipped with electronic systems that provide active noise cancellation by phase-shifting the incoming sound field by 180°. This achieves a reduction of 10-15 dB in the low-frequency range (50-300 Hz), where conventional hearing protection is least effective. Some earmuffs also feature communication systems or playback of functional background music. The need for personal hearing protective equipment can be determined using the methodology proposed by M. Romas & O. Tsybulska (2015), which accounts for risk management approaches to worker health damage and the fundamental requirements of current occupational safety legislation.

Given the diversity of industrial equipment in use, all types of noise, including ultrasound, are typically present, with levels varying across production sites and often exceeding 100 dB. Sources of ultrasound in industry include ultrasonic equipment used for technological or research purposes, as well as equipment where ultrasound generation is a concomitant phenomenon. Workers may be exposed to ultrasonic vibrations either through direct contact with tools, fluids, or components, or indirectly by being within the ultrasonic field. Other environmental factors, such as high humidity and vibration, can intensify the negative effects of ultrasound, especially when accompanied by high-frequency noise. The soundproofing method used to counteract this includes the use of protective enclosures with air gaps between the housing and the equipment, or isolating noisy devices in dedicated chambers.

A disadvantage of existing noise protection devices is that they are primarily utilised for reducing high-frequency sound levels through screening, which diminishes their effectiveness in protecting against low-frequency noise, such as mechanical and aerodynamic noise. A more effective solution is the sound-insulating panel proposed by Utility Model Patent No. UA 59305 (2011), which incorporated a housing with a sound-absorbing lining. The disadvantage of this panel lies in its limited applicability, as it cannot effectively reduce the overall noise level generated by both low- and high-frequency sounds. For example, in small volume premises, numerous reflections of sound waves from enclosing structures create a non-uniform (diffuse) field, where the maximum noise level may occur outside the sound-insulating device. To enhance the effectiveness of industrial noise protection, a novel design for a sound-insulating panel was proposed, which shown in Figure 3. This panel is capable of reducing noise to normative levels through the summary absorption of sound waves across a broad frequency spectrum.

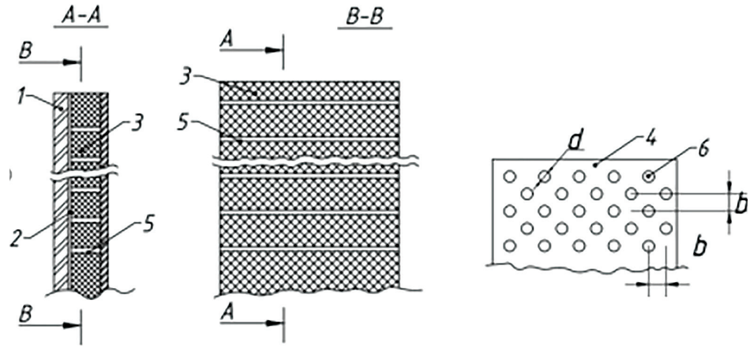

Figure 3. Noise-insulating panel

Notes: 1 – soundproof base; 2 – metal foil; 3 – mineral wool; 4 – flexible sheath; 5 – support shelves; 6 – perforation holes
Source: developed by the authors

The sound-insulating panel was designed as a combined arrangement of sound-impervious and sound-absorbing layers. Specifically, the sound-impervious layer was constructed as a flat, sturdy base to which a sheet of metallic foil is rigidly affixed. The sound-absorbing layer comprised a packing of mineral wool encased in a perforated flexible casing. The perforations on the casing were arranged in a staggered pattern, and the mineral wool is supported by horizontal support shelves positioned along the height of the panel. The operational principle of this panel is that industrial noise sound waves enter the sound-absorbing layer 3 through the perforation holes 6 in the sheath 4 and are absorbed by the fibres of the mineral wool, which is packed onto the support shelves 5. During this process, the absorption of sound waves by the mineral wool fibres is accompanied by the conversion of sound energy into thermal energy. The sound waves that penetrate the mineral wool fibres then impinge upon the sheet of metal foil 2, rigidly secured to the flat sound-impervious base 1. These waves are reflected from the foil and return to layer 3, where they are finally absorbed by the mineral wool fibres occurs.

The advantage of utilising this sound-insulating panel lies in its ability to reduce overall noise level across various frequency spectra, owing to the reflection and absorption of sound waves generated by operating equipment. While the use of specialised sound-insulating enclosures is an effective measure, it proves challenging and costly to implement, especially when dealing with much equipment within a workshop due to complex machinery configurations. Consequently, the widespread adoption of sound-insulating barriers or cabins, lined with sound-absorbing materials or panels, has been observed.

The study conducted by P. Deuszkiewicz (2021) demonstrated that the use of multi-layered constructions can enhance noise reduction effectiveness within the frequency range of 8 Hz to 8 kHz. However, it is essential to consider the frequency characteristics of the sound source when modifying the design of multi-layered sound insulation panels. J. Nurzyński (2021) investigated the sound insulation effectiveness of partition panels, which consisted of a core made of polyurethane foam and mineral wool, with metallic surfaces attached to both sides. The weighted sound reduction index for models of varying configurations, with a thickness of 50 mm, ranged from 31 dB to 45 dB.

To reduce low-frequency noise (up to 2,000 Hz), M.A. Elkasaby *et al.* (2020) proposed creating sound-insulating barriers from nanofibre composites made from polymer materials (polyvinyl alcohol, polystyrene, and polyvinyl chloride), further modified by the addition of fillers such as carbon nanotubes, graphene, wollastonite, and fibreglass, to improve their sound insulation properties. Additionally, to reduce the volume of accumulated industrial waste, some researchers suggested its utilisation for noise protection. For example, A. Železnik *et al.* (2025) proposed using recycled plastic as a sound-absorbing material, which would additionally address plastic waste disposal issues. D.G.K. Dissanayake *et al.* (2021) recommended the development of sound-insulating materials from textile waste, such as cotton and polyester fabric remnants.

Consequently, the conducted analysis of existing measures and means for protecting against industrial noise and recommendations for their implementation has shown that introducing measures to alter technological processes, equipment, or individual equipment components can achieve a noise level reduction, on average, of 5-12 dBA. For example, replacing stamping machines with pressing machines avoids impact actions, yet the noise level is only reduced by 5-6 dBA. This reduction is insufficient to significantly improve working conditions in premises where much equipment is operating.

Conclusions

The equipment used in mineral processing facilities generates high levels of noise, the prolonged exposure to which may cause partial or complete hearing loss among workers, as well as disruptions to other bodily systems. Noise attenuation is achieved through modification of process technology (e.g., replacing impact actions with non-impact ones; reciprocating movements of mechanisms with rotary ones); substitution of structural equipment components (e.g., rolling bearings with plain bearings, metal components with plastic components, reducing the mass and surface area of impacting components); relocating noise-generating equipment outside the production workshop.

Among the noise protection measures, the most widely adopted include: the use of sound-insulating casings and gaskets; lining impacting components with sound-absorbing materials; using sound-insulating cabins for personnel; employing sound-reflecting screens; utilising active and reactive mufflers; applying personal protective equipment. To mitigate the harmful effects of industrial noise in production premises, this paper proposed a novel design of a sound-insulating panel capable of absorbing broad-spectrum sound waves emanating from operating equipment. Future research aims to substantiate the technical parameters of a wide range of sound-screening and sound-absorbing substances, and to develop effective methods and means for reducing noise generated by operating equipment.

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Conflict of Interest

None.

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Захист від виробничого шуму в цеху з працюючим обладнанням

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Анотація. Виробниче середовище промислових цехів являє собою комплекс шкідливих та небезпечних чинників, які негативно впливають на здоров'я та працездатність працівників. Серед них можна виділити високий рівень шуму, який генерує працююче обладнання під час виконання операцій технологічних процесів. Перебування працівників у середовищі підвищеного рівня шуму – більше 80 дБ – без засобів колективного та індивідуального захисту, викликає у них професійне захворювання органів слуху та порушення нормальної роботи інших систем організму. Метою цього дослідження була розробка засобів захисту від виробничого шуму в цехах з працюючим обладнанням для покращення умов праці. У дослідженні були застосовані наукове узагальнення і аналіз літературних джерел зі шкідливості виробничого шуму, а також використані нормативні акти і положення з регламентації параметрів шуму у виробничих приміщеннях. Обґрунтовано допустимі параметри шуму в робочих зонах виробничих приміщень. На підставі нормативних актів та положень запропоновано наукові рекомендації з розробки звукоізолюючої панелі для зниження рівня шуму широкосмугових і низьких частот звуконепроникним і поглинальним матеріалами. Встановлено, що використання звукоізолюючої панелі підвищує ефективність зниження рівня шуму в робочих зонах приміщень до рівня санітарних норм. Практичне значення отриманих результатів полягає у зниженні рівня шуму в промислових приміщеннях за рахунок сумарної локалізації звукових хвиль і наступного поглинання їх в межах звукоізолюючої панелі, що дозволяє поліпшити умови праці в промислових цехах з працюючим обладнанням та зменшити професійну захворюваність працівників у промисловості

Ключові слова: рівень звуку; звукоізоляція; звукова хвиля; звукопоглинальний шар; мінеральна упаковка; звукоізолююча панель