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DEVISING MEASURES TO REDUCE MULTI-FREQUENCY NOISE LOAD ON EMPLOYEES IN MACHINING AREA

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The object of this study is the process of determining and managing the risks of noise exposure (NE) for employees at the mechanical department when machining metals on a drilling machine (DM).

The problem relates to the increase in the risk of an employee receiving an industrial injury because of NE at the workplace of a machine tool. The impact of noise on the human body depends on the duration of exposure, the level of sound pressure, and its intensity. An important characteristic of noise is its frequency composition, as it can affect the perception of sounds and the human body. Prolonged exposure to noise can damage various systems in the human body or cause pain. Therefore, it is important to understand the impact of NE on workers and devise measures to reduce the negative impact on their health and work productivity. The research is based on real-time noise measurements followed by their decomposition into octave frequencies and modeling of noise propagation in the room with and without the use of various types and designs of soundproof barriers (SB). In the course of the study of NE propagation during drilling on the machine, an excess of noise levels at medium and high frequencies near the noise source was found. An employee who works on DM is exposed to high-frequency noise that exceeds the established normative indicators. Therefore, it is necessary to use personal protective equipment for the machine operator and install safety equipment to protect other workplaces. The use of the latter makes it possible to significantly reduce the impact of NE on workers, in particular, at low frequencies by 20.8 %, at medium frequencies by 15.6 %, and at high frequencies by 17.3 %

Keywords: occupational safety, noise source, working area, noise load, soundproof barrier

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1. Introduction

Modern production consists of a large number of elements that function as a single unit and are aimed at producing finished products for the needs of society. But, regardless of the result, every production is characterized by dangerous and harmful factors that negatively affect the health of workers or reduce their work capacity. One of the main negative factors in production is noise, which is characterized by unwanted or harmful sound vibrations [1]. These fluctuations extend into and beyond the work area and can lead to an increased risk of personal injury because of reduced attention to warning signals. The source of noise in production can be any technological process. The latter is accompanied by a change in sound pressure due to mechanical vibrations generated during the operation of machines, engines, pumps, compressors, hand tools, and other equipment with moving parts [2, 3].

The issue of hearing loss is so global that studies [4] indicate that about 1.57 billion people or 20.3 % of the world's population are hearing impaired. This is mostly related to production processes and age-related aging of the human body.

Therefore, studies aimed at designing an apparatus for assessing the production load are relevant as they contribute to reducing the risk of encountering industrial injuries associated with hearing loss by employees at mechanical departments.

2. Literature review and problem statement

Mechanical production processes are characterized by the appearance of noise and are their direct sources. A large body of current research is aimed at determining the amount of noise and reducing its levels. Thus, in work [2], attention was paid to the nature of the occurrence and propagation of noise from production machines and mechanisms. In addition, the process of modeling noise propagation on the surface of the machine is considered, which consists of many factors, namely the operation of electric drives, the cutting process, and the operation of rotating and moving parts of the machine. To this end, a whole network of microphones should be used. But the authors do not consider the decomposition of noise into octane frequencies, which can affect both individual human organs and the human body as a whole. In work [3], the milling machine is directly considered as a source of noise and its propagation. At the same time, the size of the noise is affected by the diameter of the cutting tool, its speed of rotation, and feeding on the tooth. In addition, it is recommended to install a silent casing. But the authors do not consider the decomposition of noise into octane frequencies. In [5], comparative noise indicators from milling, turning, and drilling machines are given. It was determined that the greatest noise is observed during the operation of drilling machines. The degree of impact of noise on the human body may depend on many factors, among which the following should be highlighted: duration of action, logarithmic level of sound pressure and intensity [6, 7]. In addition, one should not forget about the individual psychophysiological characteristics of each person. According to literary sources, the authors of works [8–10] pay attention to the creation of universal protective screens that can protect workers from electromagnetic radiation and noise. Thus, in [8], the dependence of the risk of occupational injury for workers in the mining industry is considered. And in work [9], the authors focus their attention on the operation of electronic devices and computer equipment. This equipment is characterized by electromagnetic radiation and certain noise, which when superimposed on each other can lead to deviations in the work of organs, systems, or the human body as a whole. In work [10], authors propose a universal protective screen against noise and electromagnetic radiation. But just like the previous works, the issue of noise decomposition by octane bands is sidestepped. The reason for this neglect is that all the cited works are based on the consideration of exceeding the equivalent noise level at the workplace without reference to octane frequencies.

The human ear perceives sounds in a wide range of intensities (from the lower hearing threshold to the upper pain threshold) and does not respond equally to all frequencies. An important characteristic of noise is its frequency composition [6]. According to the sound frequency, noise can be classified as low-frequency up to 300 Hz, medium-frequency 300–800 Hz, and high-frequency noise above 800 Hz. In works [11, 12] it was established that low-frequency noise with an intensity of up to 100 dB does not cause a noticeable adverse effect on the hearing organs; for medium-frequency noise – 85–90 dB; for high-frequency – 75–85 dB. The most unfavorable subjective sensations and effects on the human body are caused by high-frequency noise. Studies by OSHA and the National Institute for Occupational Safety and Health (NIOSH) have determined that the permissible noise limit, which is 100 % of the daily noise dose, is 85 dBA for NIOSH and 90 dBA for OSHA. Exceeding these indicators leads to the appearance of hearing defects [13, 14].

According to the results from our review of literary sources, it was established that noise from production equipment leads to hearing loss for employees in the mechanical engineering industry. At the same time, the studies do not consider the impact of noise at octane frequencies, which is important in combination with the introduction of special protective screens. Therefore, the task of reducing the noise load and creating a safe working environment arises.

3. The aim and objectives of the study

The purpose of our study is to devise measures to reduce the noise load on the worker at metal machining. This will provide an opportunity to assess the level of noise at the workplace or site, identify possible health consequences, and suggest proposals for protective measures; improve working conditions:

Therefore, the research will contribute to increasing the safety and health of workers, as well as improving their working conditions.

To achieve the goal, the following tasks were solved:

– to determine the level of noise load at the workplace of the machine tool;

– to define the mathematical dependence between the noise level and frequency depending on the mode of operation of the drilling machine;

– to choose protective screens to protect the machine worker from noise;

– to assess the risk of impact of noise load on the employee's health.

4. The study materials and methods

The object of our study is the working environment at the machining center, including equipment, tools, work processes, and the workers who are in this environment. The research is aimed at studying the noise load to which workers are exposed and devising measures to reduce this load and improve working conditions.

The main hypothesis of the study assumes that the noise load caused by machining processes has a significant impact on the health and productivity of workers in the machining department. This hypothesis assumes that there is a direct relationship between the level of noise to which workers in the machining area are exposed and their health and productivity. The research is aimed at confirming this hypothesis by objectively assessing the level of noise, studying its impact on workers, and developing measures to reduce this impact and improve working conditions.

One of the operations in the processing of metal parts or structures is drilling. Drilling machines have the greatest noise impact compared to other metal cutting machines. Therefore, it was proposed to investigate the operation of the 2L53U radial drilling machine [5].

The assessment of the noise load on the worker from the drilling process was carried out using a testo 816-1 noise meter and computer equipment with a microphone. During the research, the noise level was recorded directly in the cutting area and near the worker (distance 0.6 m). The testo 816-1 sound level meter has a calibration certificate No. UA/22/23124/000083 dated 01/24/2023, valid until 01/24/2024, the device's measurement accuracy is ±1.4 dB. As a result of the testo 816-1 measurements, the equivalent sound level at the workplace was calculated, which exceeds by 12.8 dBA the permissible value, regulated by the State Sanitary Standards of Ukraine 3.3.6.037-99, and is equal to 92.8 dBA, about which the protocol was received. However, the results of the calculation and analysis of the experimental data recorded using computer technology showed a deviation of ±1 % from the results obtained using the testo 816-1 sound level meter.

Field studies of the noise load from the metal drilling process were carried out for three modes of operation of the drilling machine:

– idle time;
– drilling with constant feed;
– drilling with cyclic feed.

During the study, we assume that the cutting tool is ideal, neglecting the diameter of the cutting tool, the change in the rotation speed of the drill, and the cutting speed.

To obtain a spectral analysis of sound, the interactive software package Sound Forge Pro is used, followed by the mathematical package CurveExpert to derive approximate expressions with the possibility of comparing experimental data and approximate dependences in the Microsoft Office Excel program. The calculation of the risk of receiving an industrial injury depending on the level of noise load on the worker is carried out in the mathematical package Mathcad [15].

5. Results of studying the risk of noise load

5. 1. Determining sound pressure levels during of drilling machine operation

At the first stage of the research, the calculation and visualization of noise levels [5] at the workplace of a metalworker were carried out using the Sound Forge Pro software. This program makes it possible to acquire a spectral analysis of the sound signal and sound pressure levels obtained during drilling machine operation under different modes. Sound Forge Pro makes it possible to decompose the received noise sound into its components using the windowed function of signal decomposition, namely rectangular transformation. The spectral analysis of sound was carried out in the range of frequencies from 0 to 22050 Hz and the number of points 65536. The result of digital data processing is the studied values for three modes of operation of the drilling machine in the form of sonograms, histograms, and linear plots. Fig. 1 shows the corresponding plots for the case in which the highest noise load is observed, namely, for drilling with a constant feed.

So, it is possible to establish the dependence of the spectral density of the noise power on time, that is, how long the sound of one or another frequency lasts and what the density between neighboring frequencies is. Under all three modes, the levels of permissible sound pressure and sound intensity are exceeded, this is especially characteristic when researching in the frequency ranges from 0 to 8199 Hz. Noises that exceed the permissible sound level are indicated in red. Linear plots and histograms visualize the variation in noise level with frequency over the entire frequency range from 0 to 22050 Hz.

Based on the histograms built, the sound pressure levels in the octave frequency bands immediately near the noise source were determined and summarized in Table 1. Fig. 2 shows a comparison of sound pressure levels from octane frequency bands near the noise source. Green color indicated a safe noise level, and red – a dangerous noise level.

Table 1

Sound pressure levels in octave frequency bands near the noise source

Operation mode	Sound pressure levels, dB, in octane frequency bands, Hz											Sound power level, dB
	31.5	63	125	250	500	1,000	2,000	4,000	8,000	16,000	22,500	
Idle run	78	76	80	83	81	81	84	85	84	71	60	91.5
Continuous feed drilling	79	77	97	91	92	92	86	85	83	70	59	100.2
Drilling with cyclic feed	79	83	92	88	86	85	91	89	83	75	52	97.3

The plot (Fig. 2) demonstrates that exceeding the permissible noise level occurs mostly at medium and high frequencies for all operating modes of the drilling machine.

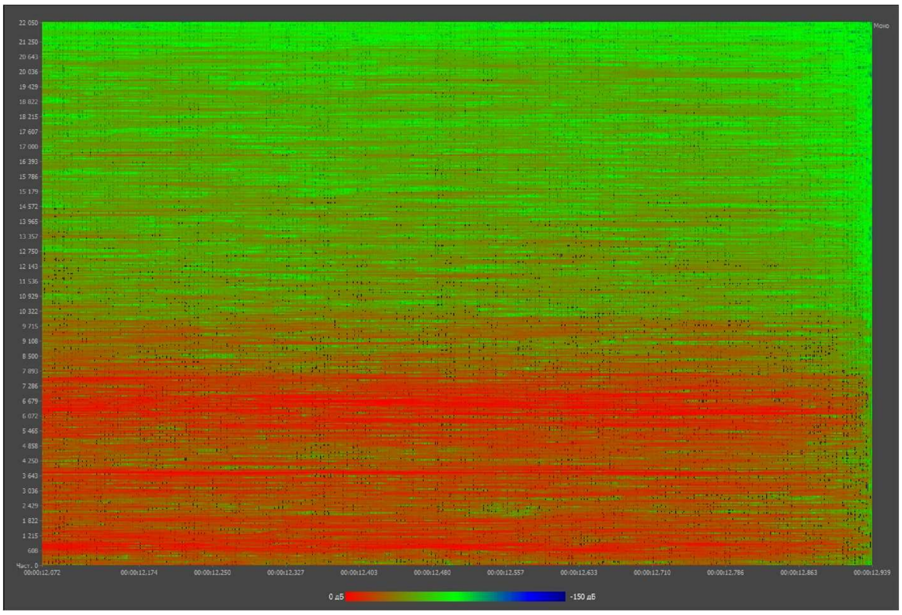
In order to determine the mathematical dependence between noise level and frequency, approximation was performed using mathematical packages. To this end, a series of points with a frequency step of 500 Hz in the range from 0 to 22 kHz was added to the octane frequencies (Table 1). For the specified operating modes of the drilling machine, a fifth-order polynomial dependence was derived in the form:

$$y(f)=a_0+a_1f+a_2f^2+a_3f^3+a_4f^4+a_5f^5, \quad (1)$$

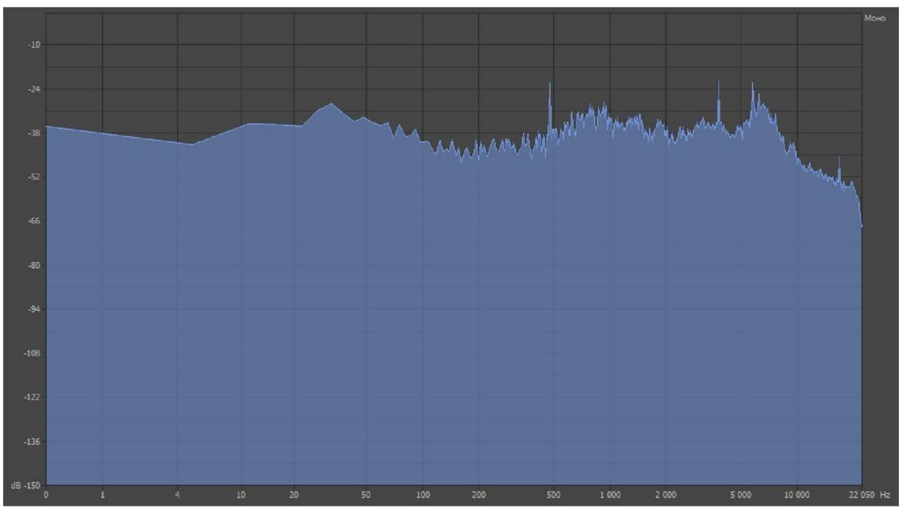
where f is frequency, Hz; a_0–a_5 are coefficients of the equation.

The coefficients of determination, correlation, and coefficients of the equation for the derived dependences, taking into account the mode of operation of the metal-cutting machine, are summarized in Table 2. Comparative plots of data obtained during the experiment and the approximated functions are shown in Fig. 3.

The above plots (Fig. 3) show a high correlation of the approximated functions in comparison with the experimental data.



a



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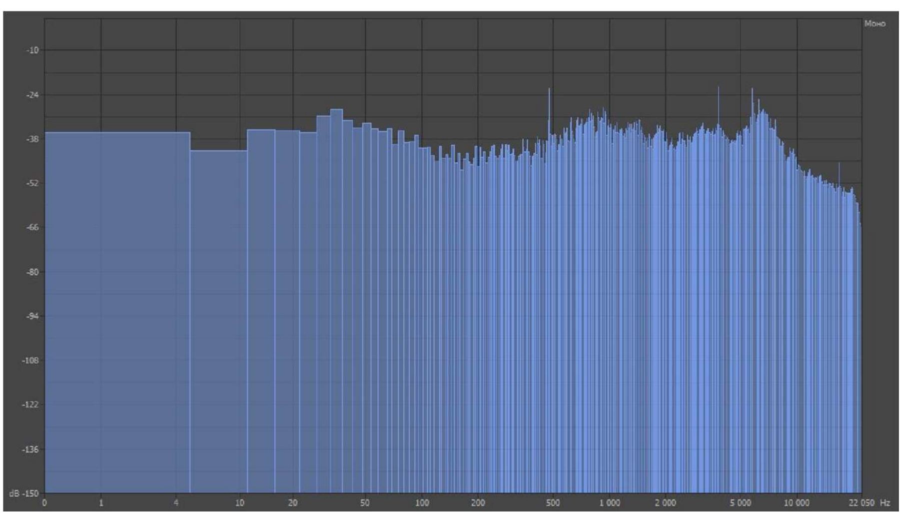

c

Fig. 1. Drilling on a metal cutting machine with constant feed: *a* – sonogram; *b* – linear plot; *c* – historgama

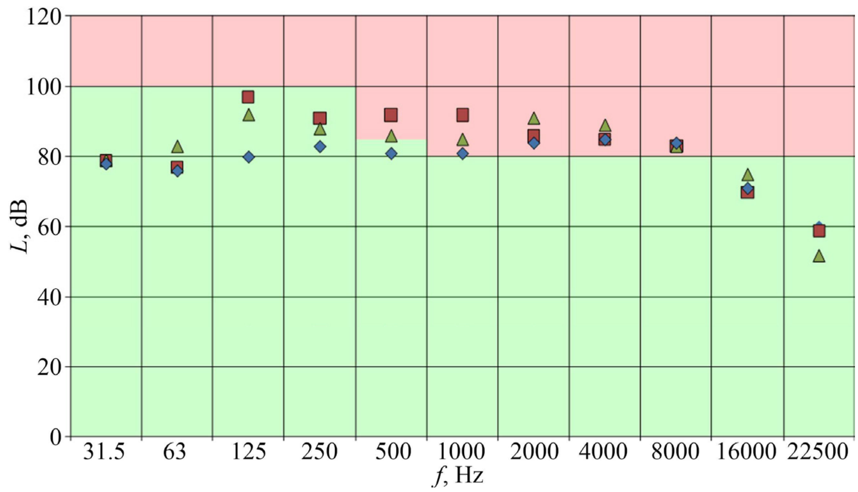

Fig. 2. Change in the sound pressure level by octane frequency bands for three modes of drilling machine operation near the noise source: ◆ – idle mode; ■ – drilling with constant feed; ▲ – drilling with cyclic feed

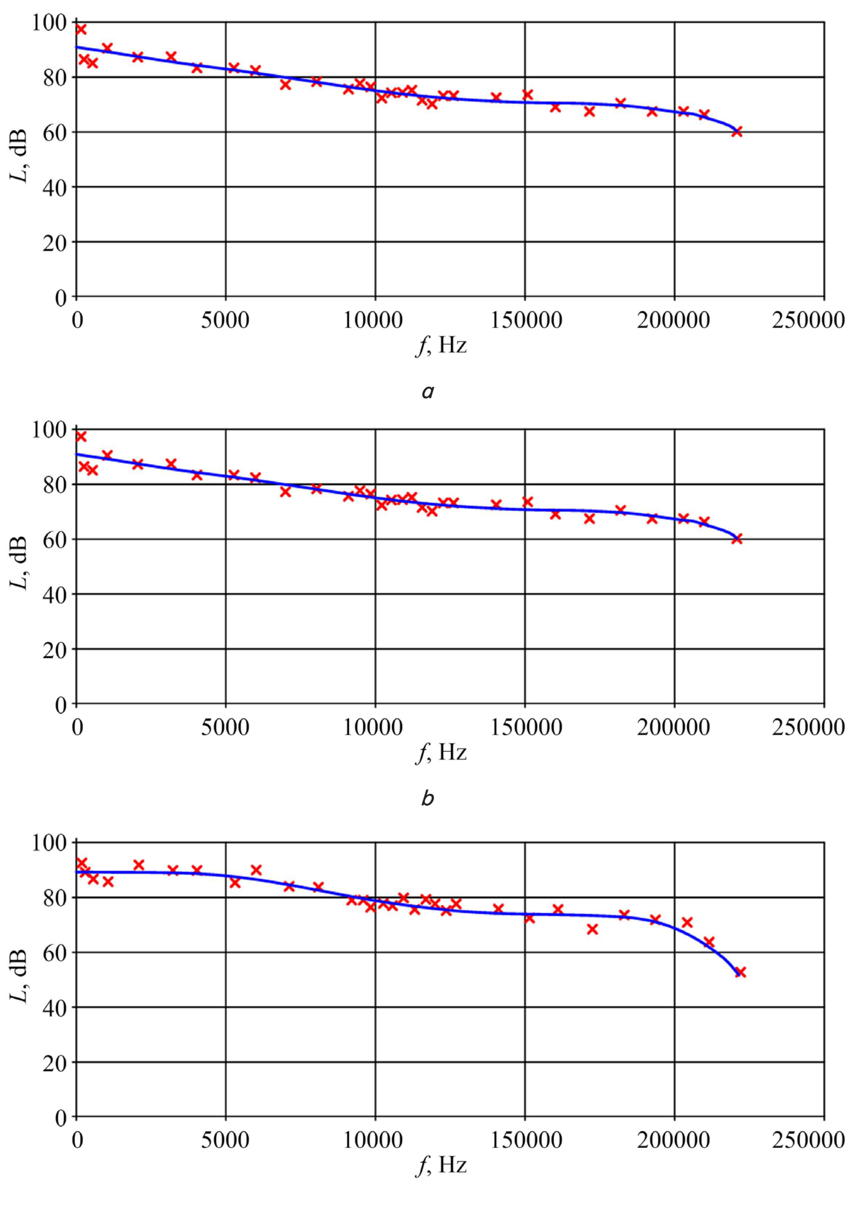

Fig. 3. Comparative plots of experimental data and approximation functions: *a* – idle run; *b* – drilling with constant feed; *c* – drilling with cyclic feed; ✕ – experimental data; ―― – plot of the approximation function

Table 2

Components and accuracy indicators of polynomial dependences

Drilling machine operation mode	Coefficients of the equation						Coefficient of determination	Correlation coefficient
	a_0	a_1	a_2	a_3	a_4	a_5		
Idle run	80.19	$2.44\cdot10^{-3}$	$1.27\cdot10^{-7}$	$-1.04\cdot10^{-10}$	$8.22\cdot10^{-15}$	$-1.84\cdot10^{-19}$	0.9	0.95
Continuous feed drilling	90.51	$-1.86\cdot10^{-3}$	$1.34\cdot10^{-7}$	$-2.58\cdot10^{-11}$	$1.999\cdot10^{-15}$	$-4.78\cdot10^{-20}$	0.92	0.96
Drilling with cyclic feed	88.35	$1.1\cdot10^{-4}$	$1.48\cdot10^{-7}$	$-6.83\cdot10^{-11}$	$5.56\cdot10^{-15}$	$-1.33\cdot10^{-19}$	0.94	0.97

5. 2. Determining sound pressure levels at the driller's workplace

In a similar way, the value of the noise by the octane frequency bands and the resulting sound pressure level near the worker who works at the drilling machine and the power source were determined. In addition, the noise levels near the employee, whose workplace is in 3 meters, have been determined. The values for the three modes are given in Table 3.

Table 3

Sound pressure levels in octane frequency bands and resulting sound pressure levels near workers

Mode of operation	Sound pressure levels, dB, in octane frequency bands, Hz								Sound power level, dB(A)
	63	125	250	500	1,000	2,000	4,000	8,000	
Distance to the employee 0.3 m									
Idle run	75.4	79.4	82.4	80.4	80.4	83.4	84.4	83.4	90.9
Continuous feed drilling	76.4	96.4	90.4	91.4	91.4	85.4	84.4	82.4	99.6
Drilling with cyclic feed	82.4	91.4	87.4	85.4	84.4	90.4	88.4	82.4	96.7
Distance to the employee 3 m									
Idle run	61.5	65.5	68.5	66.4	66.4	69.4	70.4	69.2	76.9
Continuous feed drilling	62.5	82.5	76.5	77.4	77.4	71.4	70.4	68.2	85.6
Drilling with cyclic feed	68.5	77.5	73.5	71.4	70.4	76.4	74.4	68.2	82.7

Analysis of our results from Table 3 allows us to conclude that the worker who works at the drilling machine for a long time is in the zone of increased high-frequency noise, and therefore may feel pain from its influence. An employee who works at a distance of 3 m from the noise source is also affected by it, and as a result may feel pain. It should be noted that the study does not take into account the technical condition of the machine, the degree of sharpening of the drill, and other possible sources of noise.

5. 3. Selection and application of protective screens

In order to protect workers from the negative impact of noise, it is proposed to install protective screens, namely, the installation of the first screen between the source of noise and the worker working behind the machine, as well as outside his workplace in order to protect other workers. According to calculations using the Sound Propagation Level Calculator (Noise Tools), it is possible to propose the installation of 2 protective noise-absorbing screens. A schematic representation of the installation of the proposed noise-absorbing screens is shown in Fig. 4. According to the image, the noise source is chosen for the point "0" in height, at a distance of 0.3 m horizontally, the first protective screen is installed, the upper point of which is 0.4 meters above the noise source. This screen is intended to protect the worker who works at the drilling machine. Also, in the program window, you can choose and set the noise absorption coefficient, which will correspond to the real screen made of the appropriate material.

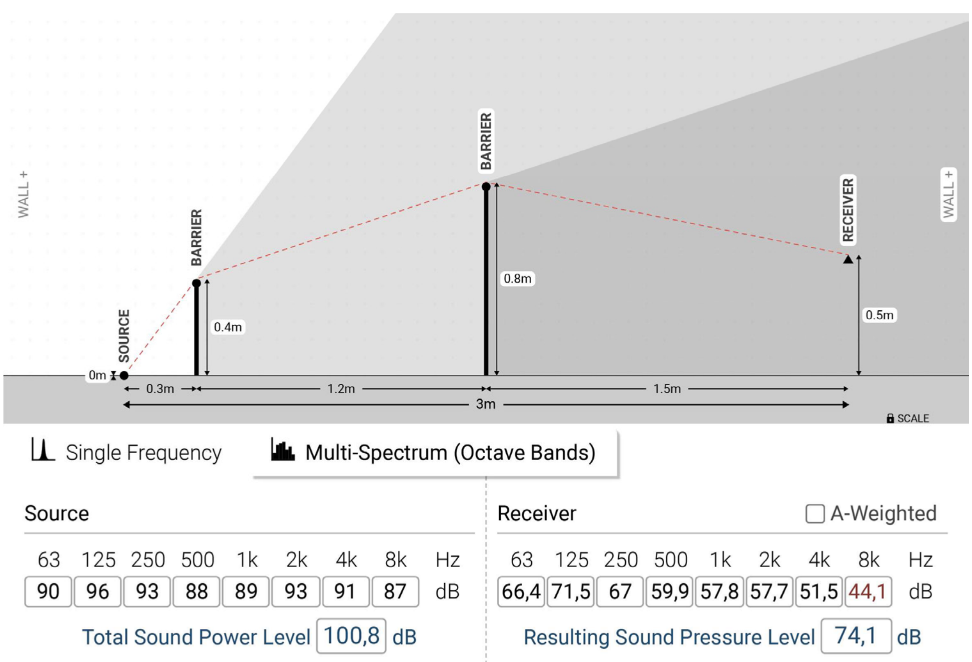

Fig. 4. Working window of Sound Propagation Level Calculator with the installation of noise-absorbing screens

At a distance of 1.5 m horizontally, a second barrier is installed, the upper point of which is higher than the noise source by 0.8 m. If we consider that the height of an employee working at a distance of 3 m is 1.8 m, then the point on scheme is at a height of 0.5 m. Table 4 summarizes data for all three modes of operation of the equipment and taking into account the installed screens for the relevant workers.

The data in Table 4 indicate a significant reduction in the noise level both for the worker who works at the machine and for the worker who works at a distance of 3 meters. Fig. 5 shows a comparison of sound pressure levels by octane frequency bands for three different operating modes of the drilling machine with and without installation of a protective barrier. The zone of safe noise level is marked in green, and the zone of dangerous noise level is marked in red. The plot demonstrates that the use of the screen makes it possible to significantly reduce the impact of noise, namely, in the area of low frequencies, noise can be reduced by 20.8 %, at medium frequencies by 15.6 %, and at high frequencies by 17.3 %.

Table 4

Sound pressure levels in octane frequency bands and resulting sound pressure levels near workers, taking into account the installation of appropriate protective screens

Mode of operation	Sound pressure levels, dB, in octane frequency bands, Hz								Sound power level, dB(A)
	63	125	250	500	1,000	2,000	4,000	8,000	
The distance to the employee is 0.6 m, one screen is installed									
Idle run	62.9	65.7	67	62.7	60.2	60.4	58.6	57.4	72
Continuous feed drilling	63.9	82.7	75	73.7	71.2	62.4	58.6	56.4	84.1
Drilling with cyclic feed	69.9	77.7	72	67.7	64.2	67.4	62.6	56.4	80
The distance to the employee is 3 m, two screens are installed									
Idle run	49.4	52.5	54	49.9	46.8	45.7	42.5	38.1	58.6
Continuous feed drilling	50.4	69.5	62	60.9	57.8	47.7	42.5	37.1	70.9
Drilling with cyclic feed	56.4	64.5	59	54.9	50.8	52.7	46.5	37.1	66.7

With the help of mathematical packages, sound pressure levels were approximated by octane frequency bands, taking into account the installation of appropriate protective screens. To this end, a number of points in the range from 0 to 22 kHz were added to the octane frequencies (Table 4). For the specified operating modes of the drilling machine, taking into account the installed screens, a fourth-order polynomial dependence was derived in the form:

$$d(f) = b_0 + b_1 f + b_2 f^2 + b_3 f^3 + b_4 f^4, \quad (2)$$

where f is frequency, Hz; b_0–b_5 are coefficients of the equation.

The coefficients of determination, correlations, and coefficients of the equation for the derived dependences taking into account the mode of operation of the metal cutting machine and the installation of protective screens are summarized in Table 5. Comparative plots of data obtained during the experiment and the approximated functions are shown in Fig. 6.

With the help of the interactive Noise mapping tool from Noise Tools, it is possible to get a picture of noise propagation from the source in real time and observe how the installation of a protective screen affects noise reduction. Modeling is performed for drilling under a cyclic mode as it is the most frequent during the work shift. To this end, in the window of the interactive tool, we set the geometry of the room, which corresponds to the actual dimensions of the production room of 5×10 m. In the corner of the room, a noise source is installed at a height of 1.3 m, as well as two workers who are at a distance of 0.6 and 3 m. Fig. 7, 8 show patterns of noise propagation in the case of workers working without a screen and installing two screens in accordance with the above.

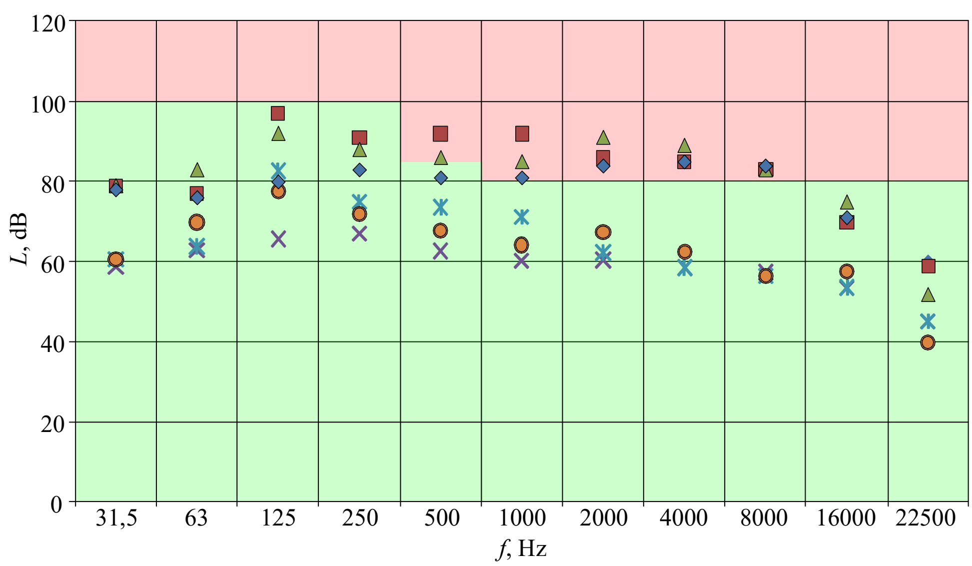

Fig. 5. Comparison of sound pressure levels from octane frequency bands for three different modes of drilling machine operation, taking into account the installation and without installation of a protective barrier in front of the worker at a distance of 0.3 m from the noise source: ◆ – idle operation of the machine without installation of a protective screen; ■ – drilling with constant feed without installation of a protective screen; ▲ – drilling with cyclic feed without installation of a protective screen; ✕ – non-working operation of the machine with the installation of a protective screen; ✱ – drilling with constant feed with the installation of a protective screen; ● – drilling with a cyclic feed with the installation of a protective screen

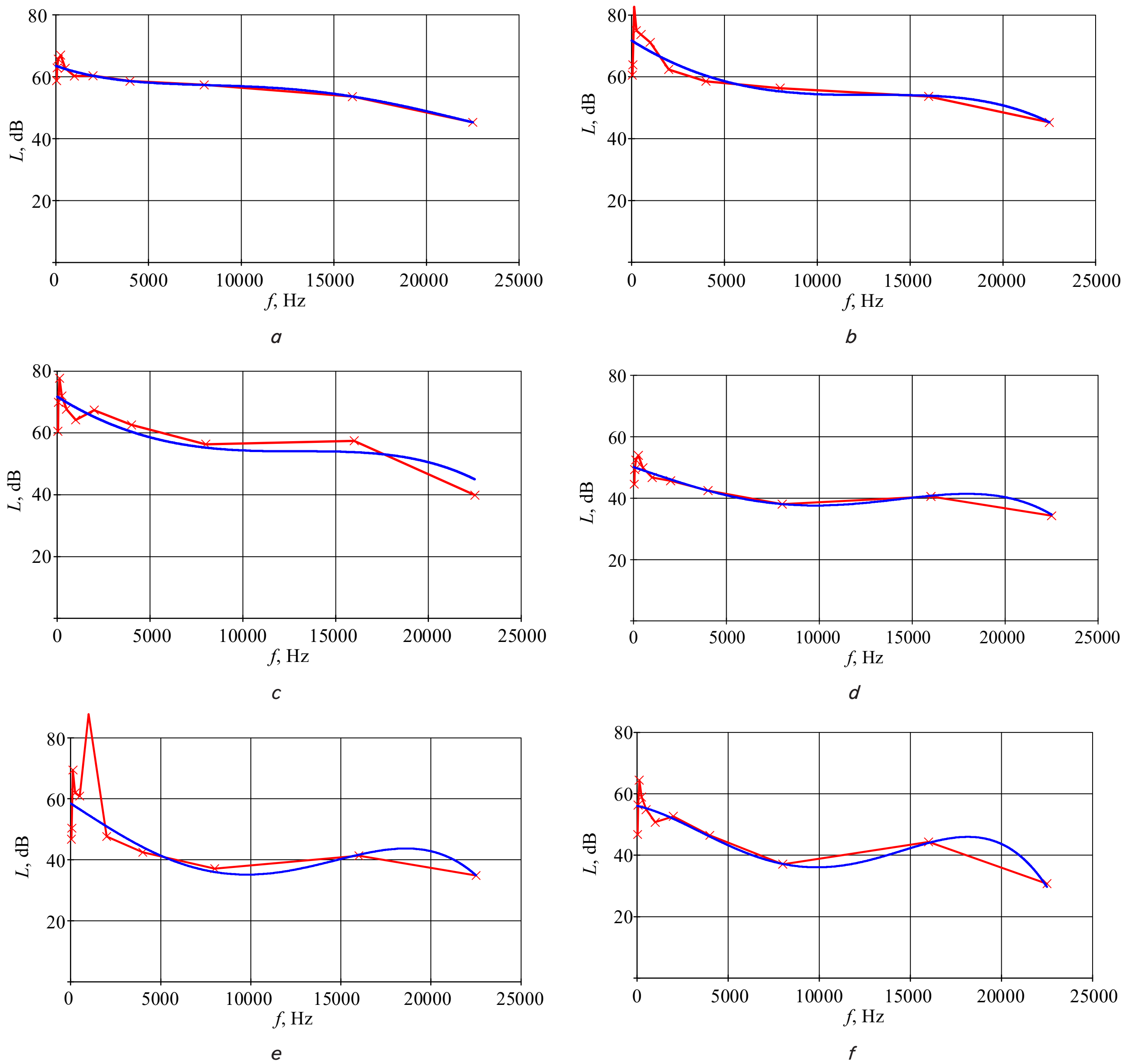

Fig. 6. Comparative plots of software-derived values and approximation functions with the installation of protective screens: — software-defined values; plot of the approximation function; *a* — no-load drilling with the installation of a protective screen at a distance of 0.3 m; *b* — drilling with constant feed with installation of a protective screen at a distance of 0.3 m; *c* — cyclic drilling with installation of a protective screen at a distance of 0.3 m; *d* — no-load drilling with the installation of two protective screens at a distance of 3 m; *d* — drilling with constant feed with installation of two protective screens at a distance of 3 m; *f* — cyclic drilling with the installation of two protective screens at a distance of 3 m

Table 5

Components and indicators of accuracy of polynomial dependences

Drilling machine operation mode	Coefficients of the equation					Coefficient of determination	Correlation coefficient
	a_0	a_1	a_2	a_3	a_4		
The distance to the employee is 0.6 m, one screen is installed							
Idle run	63.51	$-2.06*10^{-3}$	$2.64*10^{-7}$	$-1.48*10^{-11}$	$2.46*10^{-16}$	0.87	0.93
Continuous feed drilling	71.76	$-3.76*10^{-3}$	$2.45*10^{-7}$	$-2.99*10^{-12}$	$-1.24*10^{-16}$	0.81	0.9
Drilling with cyclic feed	71.75	$-3.76*10^{-3}$	$2.44*10^{-7}$	$-2.93*10^{-12}$	$-1.26*10^{-16}$	0.82	0.91
The distance to the employee is 3 m, two screens are installed							
Idle run	50.15	$-2*10^{-3}$	$-3.57*10^{-8}$	$1.66*10^{-11}$	$-5.52*10^{-16}$	0.84	0.92
Continuous feed drilling	58.48	$-3.77*10^{-3}$	$-5.1*10^{-8}$	$2.9*10^{-11}$	$-9.49*10^{-16}$	0.77	0.87
Drilling with cyclic feed	56.1	$-1.3*10^{-3}$	$-5.22*10^{-7}$	$6.26*10^{-11}$	$-1.74*10^{-15}$	0.79	0.89

Analysis of the noise distribution patterns indicates a reduction in the noise level for both workers but requires the installation of a protective screen or screens of complex structures (Fig. 9).

Modeling the spatial distribution of sound is absolutely necessary because it makes it possible to see the real picture of noise pollution in the room and choose the necessary sound barriers.

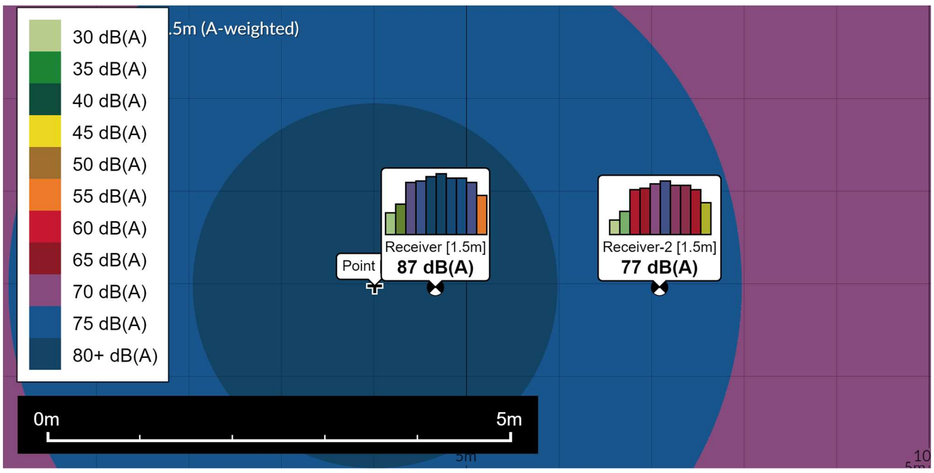

Fig. 7. Pattern of sound propagation in a room without the use of protective screens

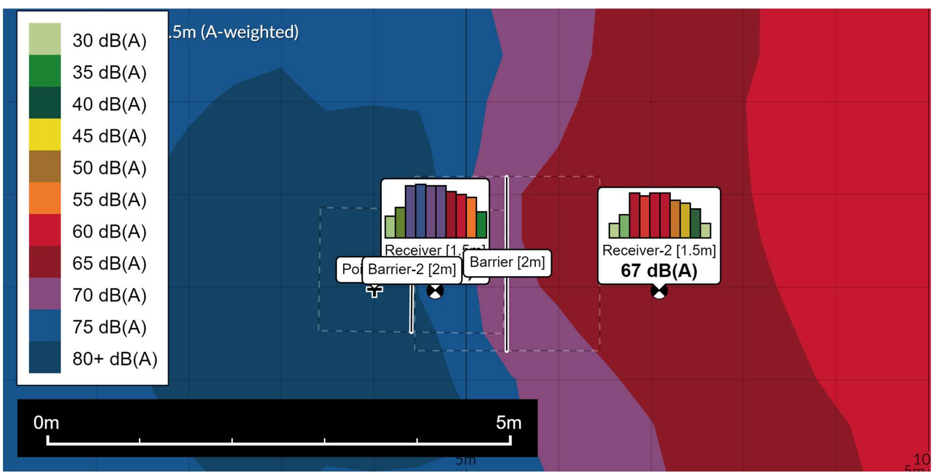

Fig. 8. Pattern of noise propagation in the room with the use of a protective screen

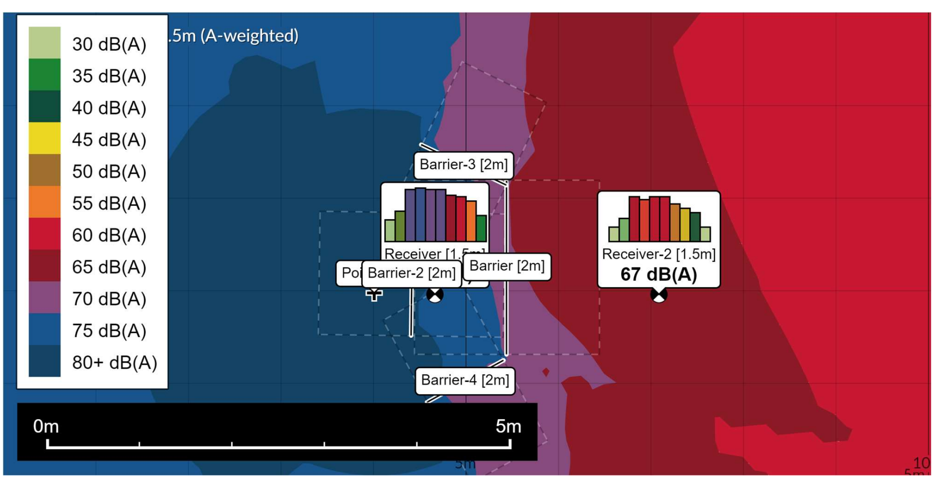

Fig. 9. Pattern of the spread of noise in a room using a protective screen of a complex design

5. 4. Determining the risk of occupational injury from noise exposure at the driller's workplace

According to our results, the risk of hearing loss due to noise load in the case of drilling operations was calculated in order to provide a recommendation on the use of individual hearing protection equipment for workers.

An indicator for assessing noise in the working environment is the A-weighted sound pressure level – L_{Aeq}, which is a measure of the time-averaged value of acoustic energy.

If the measurement time interval T_O is divided into smaller time intervals T_e, then the A-weighted sound pressure level, in dB, is calculated from the formula:

$$L_{A_{eq}} = 10\log\left[1/n\sum 10^{L_{Aeq,Te}/10}\right], \quad (3)$$

where $L_{Aeq,Te}$ is the A-weighted equivalent sound pressure level, adjusted for frequency characteristics, in the time interval T_e; n is the number of measurements.

The calculation according to (3) gives the results listed in Table 6.

Next, you should calculate the noise exposure level (dB) during an eight-hour working day using a mathematical expression:

$$L_{ex_{8h}} = L_{A_{eq}} + 10\log\frac{T_e}{T_o}, \quad (4)$$

where L_{Aeq} is the A-weighted sound pressure level; T_e is the exposure time, in minutes, during the working day, which is equal to 6 hours (360 minutes); T_o is a control time equal to 8 hours (480 minutes) or using a daily noise exposure calculator in a special spreadsheet.

The calculated level of noise exposure (dB) during an eight-hour working day according to the operating modes of the equipment and the distance from the noise source is summarized in Table 7.

According to [15], the risk of hearing loss from constant noise exposure is calculated as:

$$R_{ex,8h} = 10^{0.1*\left(L_{ex_{8h}} - L_{dop}\right)}, \quad (5)$$

where $L_{ex_{8h}}$ is the level of noise exposure (dB) during an 8-hour working day; L_{dop} – permissible noise level of 80 dB.

Table 6

A-weighted sound pressure level depending on the operating mode of the equipment and the distance from the noise source

No. of entry	Mode of operation	A-weighted equivalent sound pressure level
0.3 meters from the noise source		
1	Idle run	90.9
2	Continuous feed drilling	99.6
3	Drilling with cyclic feed	96.7
3 meters away from the source of the noise		
4	Idle run	76.9
5	Continuous feed drilling	85.6
6	Drilling with cyclic feed	82.7

Table 7

Calculated noise exposure level (dB) over an 8-hour working day

No. of entry	Mode of operation	A-weighted equivalent sound pressure level
0.3 meters from the noise source		
1	Idle run	89.7
2	Continuous feed drilling	98.7
3	Drilling with cyclic feed	95.5
3 meters away from the source of the noise		
4	Idle run	75.7
5	Continuous feed drilling	84.4
6	Drilling with cyclic feed	81.5

According to the NIOSH Sound Level Meter [15], the risk level indicators have the following ranges:

– small/minimal risk of hearing loss – $R_{ex,8h}$<0.5;

– average risk of hearing loss – 0.5≤$R_{ex,8h}$≤1.0;

– high risk of hearing loss – $R_{ex,8h}$>1.0.

The results of the calculations are summarized in Table 8.

Table 8

Levels of risk of hearing loss from noise exposure during drilling operations

No. of entry	Mode of operation	Estimated risk, $R_{ex,8h}$	Risk level
0.3 meters from the noise source			
1	Idle run	9.33	high
2	Continuous feed drilling	74.1	high
3	Drilling with cyclic feed	35.5	high
3 meters away from the source of the noise			
4	Idle run	0.37	minimal
5	Continuous feed drilling	2.75	high
6	Drilling with cyclic feed	1.41	high

Based on Table 8, we infer that almost all modes of drilling machine operation carry a high risk of the worker receiving an industrial injury because of hearing loss.

In a similar way, the risk of hearing loss was calculated in the case of installing two noise-absorbing screens. The calculation results are given in Table 9.

Therefore, the installation of noise-absorbing screens can significantly reduce the risk of hearing loss by workers in the machining area.

Table 9

Levels of risk of hearing loss because of noise load during drilling operations with the installation of two noise-absorbing screens

No. of entry	Mode of operation	Estimated risk, $R_{ex,8h}$	Risk level
0.3 meters from the noise source			
1	idle run	0.12	minimal
2	continuous feed drilling	1.93	high
3	drilling with cyclic feed	0.75	medium
3 meters away from the source of the noise			
4	idle run	0.01	minimal
5	continuous feed drilling	0.09	minimal
6	drilling with cyclic feed	0.04	minimal

6. Discussion of results of the risk assessment for hearing loss

As a result of our experimental study on the drilling machine operation, a number of sonograms were acquired during different modes of operation of the equipment. Based on the results of sonogram analysis (Fig. 1), noise load levels in octane frequency bands near the noise source were determined. Thus, there is an excess of the permissible value of noise at medium and high octane frequencies (Fig. 2), which can negatively affect the state of health of the employee of the machining department. Approximation of the relevant data (Fig. 3, Table 2) made it possible to derive mathematical expressions that have a high coefficient of determination and correlation.

In addition to determining the noise load in the immediate vicinity of the noise source, the noise levels in the worker's working area (0.6 m) and at a distance of 3 m from him/her were also determined. It was established that increasing the distance from noise sources has a negligible effect on the change in sound power level, which requires the installation of additional sound-absorbing protective screens. Depending on the mode of operation and the distance from the noise source, the sound power level decreases in the range of 0.6–0.7 % at a distance of 0.6 m and 15.6–16 % at a distance of 3 m.

Computer simulation of the pattern of sound propagation in a production room without the use of protective screens confirms previous experimental data. As a result, marks were defined where it is necessary to install noise-absorbing protective screens. Further computer simulations with installed screens at a distance of 0.3 m and 1.5 m showed a decrease in sound power in the range of 15.6–21 % at a distance of 0.6 m and 13.8–19.4 % at 3 m.

The calculation of the risks of hearing loss, taking into account the different operating modes of the drill and distances from the noise source, was carried out according to the NIOSH Sound Level Meter procedure. A comparative analysis of our results revealed that the use of noise-absorbing screens can reduce the level of risk from high to minimal (Tables 8, 9).

At the same time, the wear of the cutting tool, its geometric parameters and cutting speed, as well as the general technical condition of the machine, were not fully taken into account.

Prospects for further research focus on choosing the material for noise-absorbing screens, their thickness and design, which could make it possible to increase the protection of workers from the negative impact of noise load. A separate important aspect is also the introduction of global standards for creating a safe production environment, which have not yet become widely used in Ukraine among various business entities.

7. Conclusions

1. According to the acquired sonograms, the levels of noise load in the octane frequency bands in the immediate vicinity of the noise source under various modes of operation of the equipment were determined. Exceeding the permissible value of noise at medium and high octane frequencies in the range of 7.1–15.2 % was established.

2. It is shown that as the distance from the noise source to the measurement point increases, the sound power level decreases from 7–17 % (0.6 m) to 1 % at a distance of 3 m. Therefore, it is recommended, in order to protect workers, to install protective noise-absorbing screens, which make it possible to reduce noise in the area of low frequencies by 20.8 %, middle – 15.6 %, high – 17.3 %.

3. With the help of mathematical packages, a simulation of the distribution of the noise load of the workplace was carried out before and after the installation of noise-absorbing screens at a distance of 0.3 m and 1.5 m from the noise source. It has been established that such protective screens can reduce the noise level in the range of 15.6–21 % at a distance of 0.6 m and 13.8–19.4 % at a distance of 3 m.

4. Analysis of the risks of hearing loss, taking into account the operating modes of the drill and the distance from the noise source, was carried out according to the NIOSH Sound Level Meter procedure. According to it, a high risk remains for a driller working at a distance of 0.6 m from the noise source for the case of constant feed drilling. All other modes for both distances (0.6 and 3 m) are reduced to the minimum level.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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Data availability

The manuscript has associated data in the data warehouse.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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