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INNOVATIVE APPROACHES TO DESIGN OF PROTECTIVE NOISE CABINS BY APPLYING WALL MATERIALS

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Abstract*: The paper presents a practical solution for designing a protective noise cabin using wall materials and a mobile access application. Due to the current wide-spread demand for small-sized benchtop tools intended for domestic purposes, the development of group protective equipment for their upgrade, operation, and application becomes urgent. The presence of adjacent living rooms when organizing the working space at the stage of set-up works raises the issue of meeting the requirements of sanitary standards concerning noise. The concept of designing a cabin with a sufficient level of noise insulation is implemented by the example of the most unaffected soundproof cabin made of purest wall materials. Processing of results on the average value of sound pressure levels and indeterminacy of measurements is carried out using the developed mobile accessed application. It has been determined that the sound level (dBA) is increased with the increase of the rotational frequency. The achieved maximum level of the sound outside the protective noise cabin of 73.6 dBA at the standard mode of equipment operation is lower than the regulated value of 80 dBA, thus allowing to substantiate this approach as the express method for designing a protective noise cabin.*

Keywords: *wall materials, noise decreasing, protective noise cabins, workplace*

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1. INTRODUCTION

Since the market of small-size metalworking and wood-processing equipment is growing, noise reduction for such material becomes urgent. It is especially important in the case of the installation of such equipment in the vicinity of living areas. In this case, noise reduction of manufacturing equipment is not so essential for a worker as for the colleagues surrounding him. Following Health regulations SN 2.2.4/2.1.8.562-96 «Noise at workplaces, living and public places and residential areas» and also State Standard GOST 12.1.036-81 (ST SEV 2834-80) «Noise. Allowable levels in living and public buildings», the following maximum allowable levels of noise exposure are assigned, see Tabs. 1 and 2.

Sound pressure levels [dB] in octave bands with midband frequencies [Hz]									Sound levels and equivalent sound levels, [dBA]
31.5	63	125	250	500	1000	2000	4000	8000	
107	95	87	82	78	75	73	71	69	80

Tab. 1: Maximum allowable levels of noise exposure at permanent workplaces in manufacturing rooms and within industrial sites

Sound pressure levels [dB] in octave bands with midband frequencies [Hz]									Sound levels and equivalent sound levels [dBA]	Maximum sound levels $L_{Amax.}$ [dBA]
Living rooms in apartments	63	125	250	500	1000	2000	4000	8000		
In the daytime:	63	52	45	39	35	32	30	28	40	55

Tab. 2: Allowable levels of sound pressure, sound levels, equivalent, and maximum sound levels of penetrating noise in living and public buildings and noise levels in residential areas

2. REVIEW OF EXISTING SOLUTIONS

Issues of providing work safety concerning the reduction of noise exposure can be considered in terms of the noise level analysis as, for example, in [1] and group protective equipment development. If the equipment upgrade is impossible, one of the simplest ways of noise exposure reduction within a room and, therefore, in adjacent rooms is the installation of a protective noise cabin. Noise protective cabins are used at different conditions as applied to various objects, and layout features vary them. The main application areas for the principle of sound absorption and soundproofing using protective noise cabins are as follows:

1. reduction of noise from machine-tool equipment, for instance, CNC machine-tools [2, 3];
2. providing special noise protected conditions within audiometric tests in audiometric chambers [4];
3. noise protection of operators in cabins of building equipment (digging machines, lorries, elevator equipment) from penetrating the operating motor [5-8];
4. providing noiseless space in anechoic rooms intended for studying noise protective properties of materials [9];
5. designing the cockpits for aircraft, specifically helicopters [10].
6. manufacture and operation of phone booths [11].

The development of protective noise cabins depends on the type of desired equipment and layout features and elements that perform special functions. Therefore, solutions allowing to provide the necessary level of noise proofing are different. For instance, in [12], the main attention is focused on the application of guideways with passive insulation inserts, thus allowing to reduce the noise of an elevator cabin. Analysis of a soundproofing pack which is the key element in the design of ship dorm rooms is stated in [13]; proposals on application of the sound insulation factor of cars with the account of the type of road pavement, engine transmission, and vehicle performance are developed in [14]. Due to the recent development of rapid simulation and prototyping techniques, the level of achieving the necessary results can be analyzed visually on-screen. The numerical method in [15] is used to evaluate the noise from two manufacturing systems of heating, ventilation, and air conditioning mounted on a simplified structure of the vehicle cabin and real cabins of manufacturing vehicles. The results are further compared regarding the flow gas dynamics and generated noise, and then they are verified experimentally. Such a classical approach allows for evaluating further the mutual influence of operating modes of air motion and noise absorption by cabin lining concerning noise suppression within a wide frequency band. Along with wall materials used as the cabin lining, effective noise suppression methods are also applied, and their efficiency is numerically proved [16]. The combination of finite and boundary element methods within the research allows for evaluating the efficiency of noise suppression from blades of a turboprop engine in the cabin with a volume of 17 m3. It results in achieving the reduction of the sound pressure level by 7 dB at the application of six secondary noise sources (loudspeakers) and six error sensors (microphones).

There are also several key versions of the structural implementation of the researched means of group protection – the protective noise chamber. The complex approach to designing noise-absorbing cabins for audiometry has been implemented in the project [4]. Walls of a cabin that comprises a window and a noise-absorbing door are made of specialized noise protective panels with a thickness of 53 mm, and the floor is covered with antistatic coating.

Following [11], the version of a cabin implies the application of an all-welded metal frame made of a shaped tube with the consequent lining of the cabin by metal sheets with a thickness of 2 mm. The cabin is purposed for open--air application at ambient temperatures from - 40 to +50 °C, and it is protected from atmospheric precipitations. Noise insulation of the cabin by 28 dB following the State Standard GOST 31299-2005 is achieved by the application of glass units made of multilayer shock-resistant glass with a thickness of 25 mm. A special noise absorbing material is additionally applied in the cabin frame. The overall dimensions of the cabin are 1100×1100×2000 mm.

Some engineering solutions are intended for the simultaneous reduction of noise and vibration. This class of cabins includes, for example, the device made by the useful model patent [5]. Principles of sound insulation are used due to multilayer sound-absorbing materials, and vibration absorption by amortization devices is applied. The principle of sound insulation due to multilayer lining is also implemented in the useful model «Portable port crane cab» by the patent [6]. The device can be used as a trailer cabin for outside activities.

Certain layouts of cabins imply the application of innovative materials that results in the positive effect in combination with the known principles of sound insulation. For example, the material Celotex® is used in the elevator cabin made by the patent «Elevator car sound-insulating structure» [7]. The structure of the acoustic baffle applied in this device comprises three layers of the noise absorbing material Celotex®. The work described in [17] opens up the possibilities of applying acoustic materials in the design of car interiors. It is shown in [18] that the application of commercially available sound insulation materials with a high sound absorption factor and low heat conductivity offers the challenge of using the aluminum foam as the sound insulation material. In this connection, aluminum honeycomb structures suggested by scientists in [19] can significantly widen the areas of wall material application.

A small-sized acoustic chamber with a volume of 1.12 m^3 for testing samples with an area of 0.3 m^2 [9] can be considered the device designed and manufactured to solve tasks similar to the existing project. One of the tasks was to reduce the production and material costs by searching the chamber's optimal volume to receive reliable values of measured parameters in the chamber at high and mean frequencies. Comparative studies of measurements in the manufactured small-sized chamber and the standard-sized acoustic one showed the satisfactory repeatability of results.

The crux of the problem is to prevent the propagation of sound. Since the equipment emits noise in all directions, it must be located inside the noise protection booth. If we are designing a massive structure, then a good option is to use a brick or concrete fence, since the sound insulation of such a structure will be good. However, from a practical point of view, this is not always beneficial. The mass turns out to be excessive, and in addition, it is desirable to have a movable cabin. In this case, two possibilities are presented; the first one is to sacrifice part of the desired noise reducing or to make a single-layer wall from a lighter material. If the emphasis is only on the mass and availability of materials, then a sheet of mild steel with a thickness of about 1.6 mm or a board of pressed shavings with a thickness of 25 mm is a good option. However, in steel, the intrinsic damping is extremely small, since it is a rigid material with low internal friction. In addition, resonance phenomena are possible in steel sheets. It should also be noted that the surface of the machine is completely reflective. In this case, some additional elements that absorb sound are required. When using such elements, the following should be considered. A sound wave going from the source to the wall of the room partially passes outward and partially reflects back. The reflected wave hits the wall again, partially passes outward again, and is reflected again. In other words, the part of the wave that fails to penetrate the fence immediately is reflected and tries again. Therefore, if the walls reflect sound well from the inside, then more sound will pass outside than in the case when the walls are absorbing. This means that the walls of the fence must be covered from the inside with sound--absorbing material. If a massive fence cannot be realized, and a single-layer partition made of 1.6 mm steel sheet does not provide the necessary insulation, then the double partition principle can be applied. This, in particular, can be achieved by constructing the same second fence outside the first railing at a distance of about 150 mm and installing both rails on elastic microporous rubber supports.

However, due to the emergence of technologically advanced building materials, which, among other things, can be used as sound-absorbing materials, perhaps more advanced solutions. A sandwich construction of lighter partitions sandwiched between layers of mineral wool may be suitable. But it is better to use various other sound absorbers, such as neoprene or polyurethane foams, in which the sandwich principle is already implemented. Some of these materials, in particular isolon, do not require special fire protection. Such materials are found to be more cost effective.

Another aspect of the design of a soundproof cabin is the size of the enclosure. Size affects efficiency in two ways. First, the larger the dimensions of the corresponding wall, the greater the radiation in a given direction. Some mechanisms (for example, machine tools) have large, hard surfaces that reflect sound well. Since the average value of the absorption coefficient inside the fence is important, for the same mechanism and the same acoustic lining of the fence, the average absorption coefficient for a large fence will be higher than for a small one. Therefore, it is more advisable to make a larger fence, in particular, also because then it will be possible to install a door for passage inside during repairs.

3. IMPLEMENTATION

The present research work is carried out within the program to improve the working conditions of an operator of small-sized machine-tool equipment. It is focused on reducing its noise exposure to the environment of living places adjacent to the workshop. It should be noted that such work, in the most cases, requires serious preparatory work, both in terms of calculations and in terms of design. However, simple engineering solutions lead to unexpected results. The concept of sound insulation is implemented by the example of the simplest sound isolative cabin made of the Izolon® (isolon) material and Joker system. The task of the work was to choose materials for sound insulation and the frame of the whole layout to provide minimum costs within the limited budget. It was also necessary to achieve the required level of noise reduction within the octave frequency band that can be compared with values stated in sanitary regulations as the allowable ones. As a minimalistic version within the limited budget, noise reduction should be enough for the subjective sensation of the sufficiency of the taken actions.

It is known that isolon is mainly used for heat insulation. Its noise insulation properties are not so good as compared to, for instance, materials applied in cars to provide acoustic comfort. But in the specific case, this material can be the most suitable to achieve the goal. It is not dusting, and it does not expose harmful substances in concentrations that exceed the maximum allowable ones. Values of sound insulation coefficients for isolon (sound absorption of isolon (foaming ratio 30, the apparent density of 33 kg/m^3)) are given in [20].

The Joker system is the set of chromed tubes and fasteners that allow for designing and fast assembling strong frames. Such a system is successfully applied in the interiors of trade organizations. The frame with the overall dimensions of 1600 × 1600 × 2500 mm was assembled using the components, as shown in Tab. 3.

#	Name	Amount
1	Chromed pipe 0.7, D=25	18 m
2	Pipe plugs	4 pcs.
3	Angular joint for 3 tubes, Uno-04	8 pcs.
4	Foiled isolon, S = 10 mm	12 m

Tab. 3: Components for the assembly of the protective noise cabin

The fastening of isolon to the cabin frame was made using plastic cable ties.

The ready structure is shown in Figs.1 and 2 as applied to the equipment shown in Fig. 3.

Fig. 1: General view of the protective noise cabin

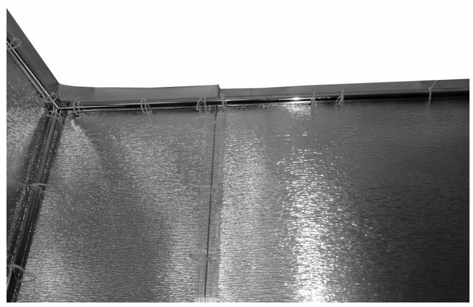

Fig. 2: Internal view of the angular part of the protective noise cabin

Fig. 3: Working place inside the protective noise cabin

The efficiency of noise insulation of the cabin can be evaluated by professional sound noise meters, for instance, two-channel SV 102, but the software SPL Meter was chosen as the most available means for pilot researches. Estimation of the difference of sound pressure levels in octave frequency bands was carried out at various rotational frequencies of the idling lathe chuck.

4. RESULT AND DISCUSSION

Fig. 4 shows the sound pressure levels in octave frequency bands at the engine rotational speed of 1600 rev/min – it is the standard rotational frequency of the spindle at metal machining. It is specified that the best sound insulation is achieved in octave frequency bands with geometric average values of 1000, 2000, 4000, 8000 Hz for all rotational frequencies.

It was found that the sound level (dBA) is increased with the increase of the engine rotational speed; however, the difference of sound pressures inside and outside the cabin remains practically the same – the geometric average value is 7.6 dBA. The average values of measured sound pressure levels have been determined using special software implemented as the mobile accessed application (Fig. 5).

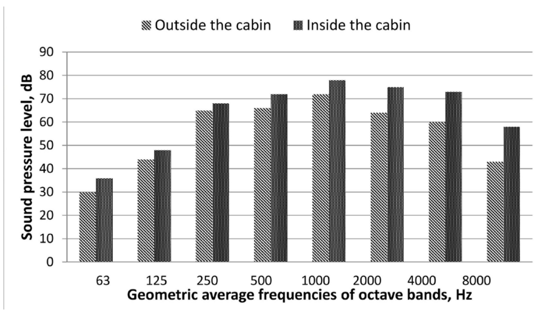

Fig. 4: Sound pressure levels outside and inside the cabin at the frequency of 1600 rev/min

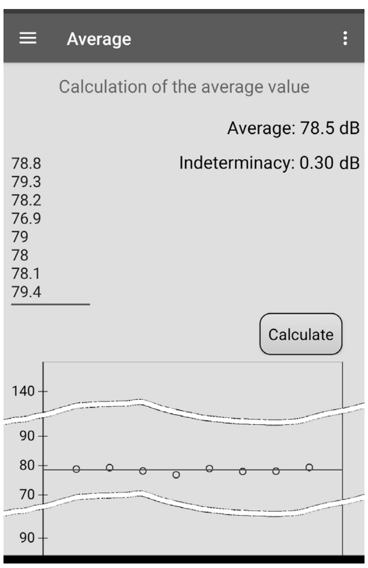

Fig. 5: Screen form of the software for evaluation of the average value of the sound level, where points and the average value are marked as the line break

The indeterminacy value accounts for measured data scattering related to measurement errors and the influence of environmental factors. The formula 1 calculates indeterminacy:

$$\boldsymbol{U_A} = \left(\frac{\sum_{i=1}^{n}\left(\boldsymbol{L_i} - \boldsymbol{\bar{L}_{Aeq}}\right)^2}{\boldsymbol{n(n-1)}}\right)^{\boldsymbol{1/2}}, dBA \qquad (1)$$

where

$\boldsymbol{L_i}$ is the sound pressure level (sound level) of the $\boldsymbol{i^{th}}$ measurement;

$\boldsymbol{n}$ is the number of measurements;

$\boldsymbol{\bar{L}_{Aeq}}$ it is the average value of sound pressure levels (sound level).

Tab. 4 presents the numerical values of measurements obtained within the implementation of the project.

Engine rotational speed [rev/min]	The sound pressure level in octave frequency bands [Hz] (inside and outside the cabin, correspondingly)								A-weighted decibels [dBA]
	63	125	250	500	1000	2000	4000	8000	
400	25	44	65	67	69	62	54	38	72
	25	41	60	58	63	54	48	35	65.7
600	30	44	67	67	77	68	64	47	75.7
	25	42	61	61	67	58	51	37	68.5
800	29	44	67	68	77	70	68	50	77.5
	25	41	62	60	67	60	54	38	69.2
1000	28	45	69	69	77	75	74	52	78.5
	24	41	62	62	68	61	56	38	70.4
1200	32	45	66	69	78	74	70	55	79.4
	26	43	63	63	70	62	59	40	71.6
1400	30	46	68	71	78	74	72	57	80.4
	29	44	62	62	70	64	59	41	72.2
1600	36	48	68	72	78	75	73	58	81
	30	44	65	66	72	64	60	43	73.5
1800	30	49	68	73	80	78	76	59	82.3
	29	48	66	66	72	66	61	46	74.3
2000	35	49	70	74	81	77	76	61	82.8
	30	48	68	69	73	66	62	46	75.6

Tab. 4: Sound pressure levels at various modes of equipment operation

5. CONCLUSION

The achieved maximum level of the sound outside the protective noise cabin of 73.6 dBA at the standard frequency of spindle rotation of 1600 rev/min is lower than the regulated value of 80 dBA. Subjectively, the reduction of the sound level in octave frequency bands for various rotational frequencies of the lathe chuck is sufficient to provide the acceptable level of "silence" in adjacent living rooms. Application of isolon as the noise insulation material allows for reducing the high-frequency noise above 1000 Hz. As a comparison, the achieved noisiness coincides with the level of noise for the operation of standard model household vacuum cleaners with their sound level within the range 75…80 dBA. It is necessary to note, that the reserve of 6.5 dBA is still available in case of a possible increase in the sound level at real processes of material working. The noise requirements stated by sanitary laws are met using more efficient and, therefore, more expensive noise protective materials. The mobile accessed application allows for obtaining the average values of noise levels in real-time mode and filters the values that can essentially influence the indeterminacy of measurements.

Development of the protective noise cabin made of available wall materials allows for organizing the working space to carry out the start-up and set-up works of the lathe equipment with its further upgrade, for example, to the computer numerical control machines. Widespread adoption of mathematical modeling approaches in engineering practice and scientific research in the field of acoustics promotes the transition to the qualitatively new level in engineering calculations and design of new types of noise protection structures as a collective protective equipment from the noise of machines and systems in the industry.

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