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Training simulator for evaluating the effectiveness of personal noise protection equipment

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Abstract. A description of the laboratory simulator created at Murom Institute for the study of personal hearing protection equipmnent against acoustic noise is presented. General issues of assessing the effectiveness of such equipment are considered. It is shown that in the conditions of the educational process it is sufficient to use a laboratory simulator in the form of a human head manikin, equipped with the hearing organs' simulators and microphones. The simulator includes a manikin head with a built-in microphone and the internal cavity filled with noise-absorbing material. The microphone is installed so that its center line coincides with the center line of the auricle auditory canal and its working surface (membrane location area) completely covers the hole cross-section in the holder, excluding the sound wave penetration into the area behind the microphone.The second microphone is placed in a special holder near the manikin and provides the noise sound pressure level monitoring in the area where the manikin is installed. Processing of the generated signals is carried out using a program for analyzing spaced acoustic noise based on LabView. Several pairs of electret microphone capsules for general use, type wm61, were selected for the simulator. The first measurements, showing the fundamental possibility of using the simulator in the educational process in the “Technosphere Safety” field of study, were carried out. It is shown that in the octave ranges, measurement accuracy can be ensured at a level of +3 ÷ -0.5 dB, which corresponds to the “Type 2” class in the ANSI system adopted in the USA.

1 Introduction

Statistical and supervisory authorities of the Russian Federation note that up to a third of workers function in conditions that do not meet sanitary and hygienic requirements in terms of external influences. Thus, in 2011, up to 46% of occupational diseases were associated with exposure to external physical factors. In 2022, more than 24.5 thousand complaints, regarding the adverse effects of physical factors, were registered.

The presence of such physical factors in the industrial and domestic environment is one of the causes of both general and occupational diseases. Moreover, of all the physical

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factors, excesses of hygienic standards recorded at industrial enterprises in 2022, the maximum share belongs to noise exposure (24.4%) [1] Also, from the State Report "On the state and protection of the Russian Federation environment of in 2021" it follows that the noise factor continues to remain significant in the urban environment: the share of noise measurements in residential buildings that do not meet sanitary standards in 2021 amounted to 17.0% (in 2020 - 15.7%).

It is obvious that noise protection is one of the priority for the development of modern society.

From the point of view of industrial safety in conditions of acoustic noise, personal protective equipment (PPE), which primarily includes noise-protective headphones and earplugs, are considered quite effective [2].

Basic requirements for personal protective equipment are established by regulatory documents in force in different countries. For example, in the Russian Federation, from January 1, 2024, the GOST ISO 4869-2-2022 standard was introduced, establishing three calculation methods (octave band calculation method, HML and SNR method) of the A-corrected noise sound pressure level affecting an employee wearing hearing PPE. The EU Noise Directive 2003/10/EC [3] also establishes three types of standard values for noise exposure in the workplace, which should provide the possibility of adapting the PPE use in different conditions.

However, according to various sources, in many cases the PPE actual effectiveness is significantly lower than that declared by manufacturers [4-7]. This state of affairs requires either preliminary or periodic monitoring of the personal protective equipment condition, ensuring the noise level effective reduction along its path from the source to the human auditory system.

Usually they talk about two main types of PPE effectiveness monitoring - objective and subjective [8]. Objective methods require the use of test chambers, often with a significant working volume. Subjective methods involve analyzing the subject's feelings. Both methods are associated with significant difficulties and financial costs.

Simpler methods involve measurements using a miniature microphone placed in the ear canal, or using a human head manikin, equipped with hearing simulators and microphones.

The use of manikins to assess noise exposure levels and the noise protection effectiveness is also of interest from the point of view of organizing training of specialists of technospheric safety field. Studying the characteristics of noise sources and personal protective equipment is mandatory in the process of training occupational safety specialists.

This article is devoted to the problem of creating simple laboratory tools to assess the PPE effectiveness against noise.

2 Laboratory simulator for assessing the noise-reducing headphones' effectiveness

Simulators used to assess the noise-protective headphones' effectiveness are known. For example, [9] describes the GRAS 45CA device, designed to test the performance of hearing protection devices such as earmolds and headphones. The device has high accuracy rates and can be used for precision measurements, but the cost of such equipment is quite high, which does not allow the device to be widely used in the educational process.

A measuring bench for testing headphones is quite simple. It has got a device made in the form of a simulator of the middle part of the head of an adult, a personal computer with software for recording test results, a test signal source, and an omnidirectional sound source [10]. To monitor the signal, condenser microphones with a flat frequency response in the frequency range 30 – 10000 Hz are used. The test signal is pink noise, measurements are carried out in one-third octave frequency bands in the range of 63-8000 Hz. The device has

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high metrological characteristics, however, even in this case, the cost limits the widespread use of this stand in the educational process of most educational institutions.

Murom Institute has developed a simulator to evaluate personal protective equipment (noise-protective headphones and earplugs). A standard manikin with a built-in measuring microphone was used as the basis for the head model basis. The internal cavity was filled with noise-absorbing material. The manikin is shown in Fig. 1. [11].

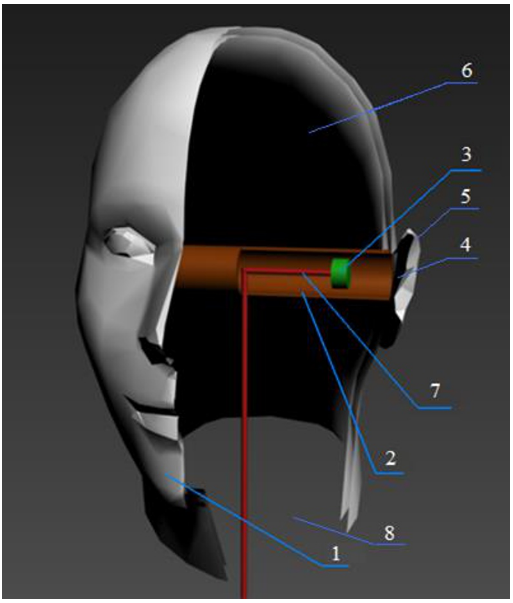

Fig. 1. 3D manikin model.

The basis of the simulator is a head manikin 1. On its inner surface, on the auricle side, the microphone 3 holder 2 is installed. The microphone 3 is placed so that its center line coincides with the center line of the auricle 5 auditory canal 4, and their working surface (the area of the sensitive element - membrane) completely blocks the hole cross-section in the holder 2, excluding the sound wave penetration into the area behind the microphone. The internal cavity 6 is filled with sound-absorbing material.

The microphone 3 is connected to the sound pressure level meter using the cable 7, which goes out into the external environment through the hole 8 in the manikin base.

The structure is installed on a rigid base through a vibration-isolating gasket. A view of the manikin with noise-reducing headphones is shown in Fig. 2.

The second microphone, which provides simultaneous sound pressure level control in the space where the manikin is located, is placed in a special holder near the manikin. Both microphones are connected to a personal computer using external ADCs. Processing is carried out using a program for analyzing spaced acoustic noise [12,13], also developed at Murom Institute.

The program for simultaneous analysis of the spectra of 2 audio signals uses the graphical programming language G of the LabView environment. The measured implementation of the audio signal in the form of 40,000 16-bit binary numbers is processed using a fast Fourier transform (FFT). The result is a discrete spectrum of the audio signal in the range from 0 to 20 kHz in 1 Hz steps. At the end of each cycle of measurements, the corresponding spectrum of the audio signal, averaged over a given analysis time, is calculated. The average difference spectrum is calculated separately.

Fig. 2. Simulator with noise-reducing headphones.

The generated arrays are saved in files in the form of spreadsheets with the xls extension. Values are stored in octave or one-third octave range mode, fixed relative to the geometric mean frequency.

General purpose capsules of wm61 types, etc., widely used in computer audio equipment, are used as microphones. The quality of such microphones cannot match the precision technology level. Even a simple selection of a pair of capsules with the same characteristics is a complex issue. To select capsules that matched their characteristics, more than 30 specimens were analyzed. The measurements were carried out in a laboratory anechoic acoustic chamber, providing a sound insulation level of up to 51 dB at a frequency of 1000 Hz [14].

Based on the measurement results, pairs, that were most consistent with each other in terms of amplitude-frequency response (AFC), were selected. Then, using the analysis program, the difference in the frequency response of the selected pairs was estimated when the microphones were exposed to acoustic noise.

3 Measuring accuracy assessment

A comparison of the signal spectra shows that there is no need to talk about complete correspondence of the frequency response of the microphones, since the nature of the change in the center line is different in all cases. The analysis of deviations in the frequency response of the spectra difference shows that in all cases there is a noticeable difference, in the case of, for example, capsules No. 13 and No. 14, reaching up to 30 dB at certain frequencies, which does not allow us to talk about the use of such capsules for constructing a precision measuring system.

At the same time, it should be taken into account that the current methods for measuring acoustic noise provide for the analysis of signals at weighted average frequencies of octave or sub-octave ranges [3]. Since the developed system ensures the storage of data in the form of a database built on recording the sound pressure level (SPL) precisely at weighted average frequencies with the ability to select ranges, we will use the data from recording these measurements and present the difference changes in SPL in one-third octave and octave ranges (Fig. 3, 4 and 5) in the form of graphs.

From the analysis of these frequency response characteristics it is clear that in the first case (capsules No. 13 and No. 14) the differences in the frequency response reach +10 dB,

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while in the second case (capsules No. 27 and No. 28) we are talking about +7 ÷ - 5 dB deviations in the one-third octave range and +6 ÷ -5 dB in the octave range.

As for the third case (capsules No. 31 and No. 32), the deviations in the one-third octave range are +6.5 ÷ -6 dB, which generally coincides with the second case, but in the octave range the deviations are at +3 ÷ -0, 5 dB level, which is significantly less than other cases.

It should be noted that in the one-third octave ranges the weighted average frequencies were taken into account from 25 to 16000 Hz, and in the octave ranges - from 63 to 8000 Hz. The measurements were carried out in the form of five series with the average value being found in accordance with the current methodology [15].

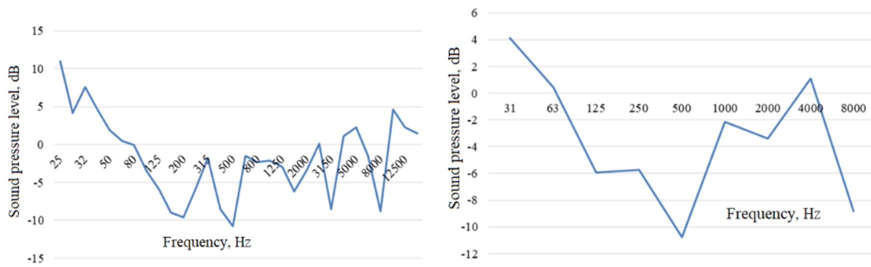

Fig. 3. Results of signal spectrum monitoring using capsules No. 13 and No. 14 in one-third octave and octave ranges.

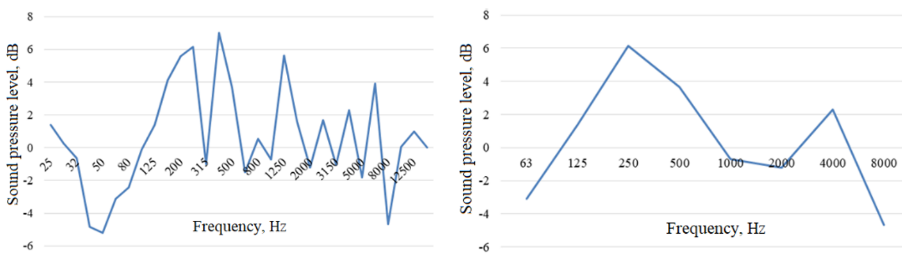

Fig. 4. Results of signal spectrum monitoring using capsules No. 27 and No. 28 in one-third octave and octave ranges.

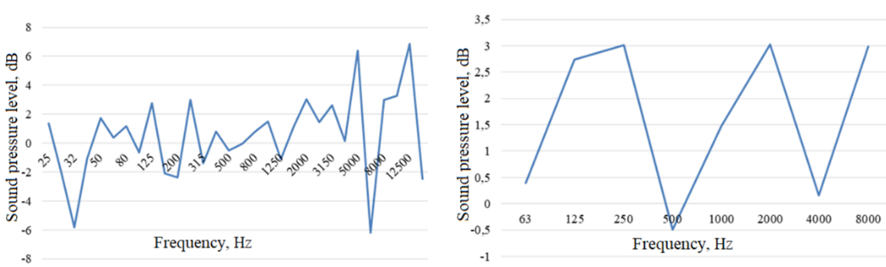

Fig. 5. Results of signal spectrum monitoring using capsules No. 31 and No. 32 in one-third octave and octave ranges.

The latter result generally corresponds to the “Type 2” class in the ANSI (American National Standards Institute) classification system for noise control measuring instruments adopted in the USA [16]. For instruments of this type, the required measurement accuracy is about ±2 dB. Such sound level meters are used for general purpose measurements: street noise, night noise, car noise, kitchen appliances, etc.

Such accuracy will also ensure the analysis of the noise-protective PPE effectiveness in the context of technosphere safety study issues (occupational safety) within the framework of the educational process.

4 Conclusion

The analysis of the research results shows that the use of the simplest microphone electret capsules to carry out precision measurements to assess any change in sound pressure level is not possible due to large differences in the individual frequency response of microphones.

However, their use in systems for qualitative assessment of changes in ultrasound, where measurements can be carried out with some error, is quite possible. For example, the use of such a system with a pair of microphones No. 31 and No. 32 is quite possible in the educational process when analyzing the quality of personal protective equipment (noise-protective headphones or earplugs), when assessing the quality of protection from acoustic noise using noise-protective acoustic screens, analyzing noise attenuation by propagation path (at short distances), etc.

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