Method for Evaluating the Acoustic Efficiency of Anti-Noise

Sergej P. Dragan[1], Aleksej V. Bogomolov[2], Ajrat D. Kotlyar-Shapirov[3]
A.I.Burnasyan Federal Medical Biophysical Center
Moscow, Russia
[1]s.p.dragan@mail.ru, [2]a.v.bogomolov@gmail.com, [3] double9305@mail.ru

Evgenij V. Larkin
Tula State University
Tula, Russia
elarkin@mail.ru

Yekaterina A. Kondrateva
Skolkovo Institute of Science and Technology,
Moscow, Russia
kondratevakate@yandex.ru

Alexandra S. Konkina[1], Natalya N. Solovjeva[2]
South Ural State University
Chelyabinsk, Russia
[1]alexandra.konkina@yandex.ru, [2] nsolowjowa@mail.ru

Abstract— **The method for calculating the integral evaluation of the acoustic efficiency of individual noise protection means is presented, which allows to evaluate the acoustic efficiency of noise-protective headphones, a noise-protective helmet and their joint use in the interests of solving problems of aviation medicine, occupational medicine and hygiene.**

Keywords— protection from noise; acoustic efficiency; medical acoustics; occupational health.

I. Introduction

At workplaces where the organizational and technical measures do not manage to reduce the noise level to the normative values or this is impossible due to technical and operational considerations, in accordance with (GOST 12.1.003-83; GOST R 12.4.212-99), means should be used individual protection against noise, which, depending on the design, are divided into: antinoise headphones that cover the auricle from the outside; antinoise inserts, which are worn in the inner part of the ear canal or in the auricle; anti-noise helmets covering the auricle and part of the head [1, 2].

To date, a significant number of modifications of personal protective equipment have been developed, differing both in appearance and quality of manufacture, and in efficiency [3, 4]. It has been established that the amount of noise attenuation in the headphones cups at low frequencies depends most significantly on the characteristics of the sealing layer (ambushy), at medium frequencies on the characteristics of the filler and the features and design of the cup body, and at high frequencies on the characteristics of the material from which the cups of the headphones are made [5-7]. In accordance with this, work is underway to improve the samples of personal protective equipment. Essential value for effective carrying out of such works has use of a correct method of an estimation of acoustic efficiency (muffling ability) of means of individual defense, under which the noise reduction provided by means of individual protection, on researched octave frequencies or in the certain frequency range.

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II. Standardized Quantitative Characteristics of Acoustic Efficiency of Anti-Noise Headphones

At present, the acoustic efficiency of the anti-noise is evaluated by comparing the numerical values of the indices in each of the octave bands with frequencies from 63 Hz to 8 kHz. Such octave bands 8, different headphones can have high acoustic efficiency in some frequency bands and low acoustic efficiency – in other frequency bands. Therefore, in order to characterize the acoustic efficiency of the developed model of the personal protective equipment, an integral indicator is needed that combines the estimates of acoustic efficiency in each octave band [8, 9].

The current GOST R 12.4.212-99 (ISO 4869-2-94) defines three indicators characterizing the acoustic efficiency of noise-protective headphones for high, medium and low frequencies (H, M and L, respectively), as well as the SNR (Single Number Rating) Is a single noise absorption index. These indicators establish criteria for the selection or comparison of anti-noise, and also determine the requirements for a minimum acceptable noise absorption for the frequency range of 63 Hz ... 8 kHz, not allowing such an estimate for the frequency range below 63 Hz. It should be noted that the generally accepted (standardized) indicators of the acoustic efficiency of noise-proof helmets have not been developed to date.

III. Analysis of Sensitivity and Correctness of the Method of Calculation of Evaluation of a Single Absorption of Noise by Sound Protective Headphones

To study the sensitivity and correctness of the method for calculating SNR estimates, data on the acoustic efficiency of

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noise-protective headphones of leading foreign and domestic firms (enterprises) were used [8]:

1) Peltor Optime 2;

2) ATI / David Clark DCAT Flight Deck Cranial;

3) Headphones of JSC "NPO" Dinafors";

4) personal protective equipment, given as an example in GOST R 12.4.212-99;

5) personal protective equipment with equilibrium noise absorption values (under the equilibrium noise absorption value is meant a distribution of acoustic efficiencies in octave frequency bands, an increase of which by 10 dB in each band results in an equal increase in the SNR estimate (by 0.5 units)).

For each sample of noise-proof headphones, SNR values are calculated. Then, alternately at each frequency, the acoustic efficiency values were increased by 10 dB and new SNR estimates were calculated, i. E. The sensitivity of the method to the change in the acoustic efficiency of noise-proof headphones at different frequencies is determined, characterized by an estimate of the average value of acoustic efficiency (Mf) and the SNR score difference with an increase in the acoustic efficiency of the noise-protective headphones at each frequency by 10 dB (ΔSNR).

The Peltor Optime 2 headphones (sample 1) have such characteristics that increasing the acoustic efficiency by 10 dB at a frequency of 125 Hz leads to an increase in the estimate of the SNR of 2.5 dB, although an increase in efficiency at other frequencies will not result in such a significant increase in the SNR .

For David Clark headphones (sample 2), the change in SNR is different: there are two frequencies (250 and 4000 Hz) at which the increase in acoustic efficiency leads to the maximum change in SNR.

For headphones of JSC NPO "Dinafors" (sample 3), the maximum sensitivity of the SNR was recorded for a frequency of 125 Hz: an increase in acoustic efficiency by 10 dB leads to an increase in the SNR of 2.6 dB. On the other frequencies, an increase in the acoustic efficiency of headphones for SNR estimation does not have a significant effect.

For headphones, given as an example in GOST R 12.4.212-99 (sample 4), it is established that the SNR value is more influenced by the acoustic efficiency at 500 Hz (ΔSNR = 1.1 dB). At frequencies of 63 Hz, 4000 Hz, 8000 Hz, the increase in acoustic efficiency by the SNR value is practically unaffected.

For headphones with an equilibrium distribution of sound attenuation values (sample 5), an increase in acoustic efficiency by 10 dB at any frequency increases the SNR by 0.5 dB. Increasing the acoustic efficiency of personal protective equipment at all frequencies by 1 dB also increases the SNR by 1 dB.

Thus, the obtained results indicate that increasing the acoustic efficiency of headphones at different frequencies leads to different and unequal changes in SNR, which does not allow to judge objectively the acoustic efficiency of headphones in the entire frequency range, which is caused by the introduction of frequency A-correction of the sound pressure level. As a result, it is impossible to objectively compare headphones with different acoustic efficiency at different frequencies. To compare different types of personal protective equipment, it is necessary to take into account the form of the SNR incremental curve from the change in acoustic efficiency.

IV. General requirements to the method of complex research of acoustic efficiency of means of individual protection from noise

In order to correctly compare the protective properties of the newly developed personal protective equipment against noise and their comparison with existing samples, it is necessary to develop a method that takes into account the specific characteristics of aircraft noise throughout the normalized frequency range [10–12]. In addition, this method should combine not only the characteristics of the acoustic efficiency of the headphones used, but also the characteristics of the acoustic efficiency of noise-protective helmets defined in a helmet space.

The noise-protective helmet can be elastic (hard) and soft, and depending on this the characteristics of the headphones used in its composition can also be completely different. With the use of soft helmets, the acoustic efficiency of the headphones can be higher than that of headphones that are used in elastic helmets, because using soft helmets air conduction decreases much better than bone helmets, and using elastic helmets on the contrary: bone conduction decreases significantly better than air conduction. Therefore, the question of which helmet more effectively protects against noise in terms of both air and bone conduction is open.

In order to correctly compare the samples of headphones and helmets produced by enterprises (companies) of different countries, it is necessary to take into account that the data on the acoustic efficiency of the samples in Russia are represented in the range 2 Hz ... 8 kHz, and in Europe and America – 63 Hz (in some countries 125 Hz) ... 8 kHz. Therefore, the method must correctly take this into account.

V. Method of calculation of the integrated acoustic efficiency of means of individual protection from noise

The technique developed taking into account the above features is based on comparison of data on maximum noise levels in human places of residence with the requirements of sanitary norms for the adverse effect of noise [2, 4, 7, 8].

Undoubtedly, complete protection against noise with the use of personal protective equipment can be achieved when acoustic efficiency at each octave frequency provides protection from the highest noise values in both air and bone conduction [9]. But the values of the maximum acoustic efficiency for air conduction determine the acoustic efficiency of personal protective equipment.

In [8], for each normalized octave frequency, the values of the maximum permissible sound pressure levels, dB, and the maximum sound pressure levels recorded at the specialists workstations servicing aircraft are given.

It should be noted that at present there are no personal protective equipment in the world providing the necessary degree of protection against noise in both the lower and upper parts of its spectrum.

The coefficient of protection of the personal protective equipment ($k_з^1$) is defined as the logarithm of the ratio of the number of octave bands used to the sum of the acoustic efficiencies of the prototype of the personal protective equipment in each octave frequency band used (in dB):

$$k_з^1 = 20 \cdot \lg \frac{n_1}{\sum_{i=1}^{n_1} 10^{\Delta_i/20}} ,$$

where n_1 – is the number of octave bands used (in the current GOST, an octave band estimate of 125 Hz to 8 kHz is used, i.e., n_1=7, and taking into account the full range of effects, an estimate should be made in octave bands from 2 Hz to 8 kHz, i.e. n_1=13), Δ_i – is the difference between the maximum acoustic efficiency of the sample of the personal protective equipment and the experimentally recorded value of the acoustic efficiency of the developed personal protective equipment for each octave frequency (Δ_{1i}), calculated as follows:

$$\Delta_i = \Delta_{2i} - \Delta_{1i},$$

where Δ_2 – is the maximum acoustic efficiency for air conduction, dB.

Note that the index Δ_i is determined by the results of acoustic measurements in the sub-incipient space, i.e. takes into account the degree of protection for air conduction.

The weight coefficients of the components of the integral coefficient of protection of personal protective equipment for each octave frequency are taken into account by the maximum permissible levels. When the acoustic efficiency of the developed personal protective equipment reaches the required values for complete protection against maximum noise levels, the value of the protection factor will be 1, which corresponds to a value of 0 dB on a logarithmic scale. In the case where the acoustic efficiency of the personal protective equipment in any frequency band is higher than the maximum values, i.e.

$$\Delta_{2i} - \Delta_{1i} < 0,$$

then Δ_i=0, i.e. excessive security at one frequency does not lead to an increase in the protective properties at other frequencies and, accordingly, to an increase in the evaluation of the coefficient of protection of the personal protective equipment.

It can be noted that the protection factor of modern samples of individual noise protection equipment is in the range of –15 dB and below, i.e. no personal protective equipment is able to fully protect against noise having pronounced high- and low-frequency components.

Obviously, to protect against noise through the bone conduction it is necessary to use noise-protective helmets that protect the surface of the head from direct acoustic impact. To develop a method for calculating the protection rating of such helmets, it is necessary to take into account that the noise level transmitted by bone conduction is 20–30 dB less than the level perceived by the ear due to air conduction.

The protection coefficient for helmets (elastic or soft) can be estimated in a similar way, but instead of the data on the maximum efficiency for air conduction, bone conduction data, which are 20 dB lower, should be used. The maximum values for bone conduction are given in [8], and for frequencies 2, 4 and 32 Hz, when the maximum acoustic efficiency for air conduction is less than 20 dB, these values are 0. In this case, the summation in the denominator of the formula is carried out only for 10 frequencies (n_2=10), that is, the evaluation of the helmet's protection factor ($k_з^2$) from measurements of acoustic efficiency in a helmet space is calculated by the formula:

$$k_з^2 = 20 \cdot \lg \frac{n_2}{\sum_{i=1}^{n_2} 10^{\Delta_{3i}/20}} ,$$

where n_2 – is the number of octave bands used to evaluate the efficiency, Δ_{3i} – is the difference between the maximum bone conductivity efficiency and the experimentally recorded acoustic efficiency value of the personal protective equipment being developed in the helix space at each corresponding octave frequency (Δ_{4i}) is calculated as follows:

$$\Delta_{5i} = \Delta_{5maxi} - \Delta_{4i}.$$

In this case, you should also use the condition:

$$\text{if } \Delta_{5maxi} - \Delta_{4i} < 0,\text{, then } \Delta_{5i} = 0$$

That is, excessive security at one frequency does not lead to an increase in the protective properties of the helmet over the entire frequency range.

If the acoustic efficiency of the developed personal protective equipment (helmets) reaches the required values to protect against maximum noise levels, the value of the protection factor will be 1, which on a logarithmic scale corresponds to a value of 0 dB.

So, based on the formulas for calculating the headphone and helmet protection rating, the expression for calculating the integrated (integral) evaluation of the protective properties of the helmet with headphones (k) looks like:

$$k = 20 \cdot \lg \frac{n_1 + n_2}{\sum_{i=1}^{n_1} 10^{\Delta_i/20} + \sum_{i=1}^{n_2} 10^{\Delta_{3i}/20}} .$$

VI. Conclusion

Thus, the developed method for calculating the integral evaluation of the acoustic efficiency of individual noise protection facilities supplements standardized methods and allows an adequate assessment of acoustic efficiency over the entire frequency range specified by the sanitary norms (2 Hz ... 8 kHz). In addition, the method allows to give an objective quantitative description of the acoustic efficiency of separate helmets (by measurements in the helmet space), as well as helmets complete with headphones. The proposed methodology can also be used to analyze the acoustic efficiency of the entire set of protective equipment (headphones, helmets, vibro suits) from the acoustic effect in the entire frequency range.

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