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MODELING OF THE SOUND ABSORPTION COEFFICIENT OF SOUND-PROOF LIGHTWEIGHT STRUCTURED PANELS (SLSP)

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ABSTRACT

This article describes an effective sound-proof panel. The ratio of acoustic characteristics and surface density of this panel outperforms many modern sound-proof and sound-absorbing materials and constructions. This article is devoted to the modeling of sound absorption coefficient for a new sound-proof panel. The formulas for determining the sound absorption coefficient are shown.

Keywords: sound absorption, damping, noise, noise protection, intensity of sound fluxes.

1. INTRODUCTION

The suppression of negative sound flux - noise has become an actual problem of our time. Noise, affecting people, in terms of the degree of negativity, is comparable to the destruction of ozone layer, industrial emissions, acid rain, etc. [1].

At present, there are many soundproof materials and constructions. This creates the impression, that their parameters cover a wide range of changes in such values as sound insulation, sound absorption coefficient, surface density. It seems that you can find a soundproof panel with any combination of design and acoustic characteristics. However, the analysis of the parameters of soundproof materials and constructions shows, that at present there are no soundproof panels with a rigid frame and soft filler, and panels with a rigid structure, whose surface density does not exceed 2 kg/m². This is clearly shown in the article [2].

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One of the directions for creation the light weight sound-proof panels can be the organization of sound fluxes inside the panel, aimed at mutual suppression. This can be achieved, if the panel design is developed, taking into account the laws of the damping process, and the laws of propagation of sound fluxes.

2. SOUND-PROOF LIGHTWEIGHT STRUCTURED PANEL (SLSP-3)

The authors developed a sound-proof lightweight structured panel (SLSP-3) [3, 4] (Figure 1). Its surface density does not exceed 2 kg/m² (0.909 kg/m²). This panel was used to reduce aerodynamic noise in air-cushion transport equipment - pneumatic conveyors, in office buildings of design organizations in Voronezh, with the aim to create comfortable working conditions, at the enterprise OAO HC "MebelChernozemiya" (Voronezh) to screen the noise of operating equipment.

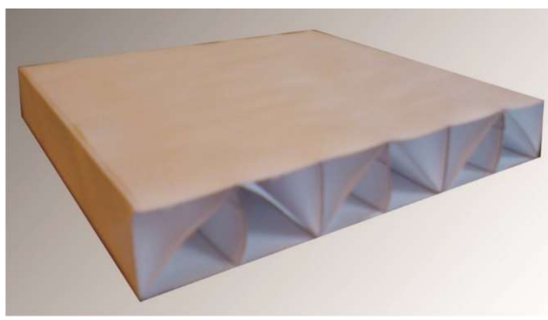


Fig.1. The element of panel SLSP-3.

The panel SLSP-3 has pronounced properties of sound insulation and sound absorption, due to the features of its design. The suppression of the intensity of sound waves is carried out by two physical processes: by damping [5] the vibrations of flat elements of SLSP-3, with the help of surrounding air, and by creation of counter sound fluxes with antiphaseinsideSLSP-3 [6], thatresults in the absorption of the sound flux energy. Due to this, the panel SLSP-3 has good sound absorption properties.

3. MATHEMATICAL MODELING OF THE SOUND ABSORPTION COEFFICIENT

The sound absorption coefficient is defined from the ratio of the intensities of sound waves: incident (J_1), transmitted (J_5), reflected (J_2), and absorbed ($J_{n1}+J_{n2}+J_{n3}$) (Figure 2):

$$\alpha = \frac{\left(J_{n1} + J_{n1} + J_{n1}\right)}{J_1} = \frac{J_1 - \left(J_2 + J_5\right)}{J_1} = 1 - \frac{J_2 + J_5}{J_1}. \quad (1)$$

The definition of the sound absorption coefficient, in accordance with (1), refers more to isotropic materials, devoid of a pronounced structure. For materials, having a regular structure, consisting of separate elements, a more detailed approach is needed to determine the flux of sound energy absorbed, either reflected, or transmitted through the entire structure.

Using the approach, presented in the article [6], we can obtain the necessary ratios of the sound fluxes intensities. The ratios for the energy flows, passing through the isotropic layer, are obtained, as shown in [6], from the representation of the sound wave passage through a thin plate, which is in oscillatory motion. This movement is damped by the surrounding air. The energy of dissipation irretrievably passes into the thermal energy of the environment. The magnitude of this energy can be determined on the basis of a coefficient, taking into account the losses throughout the panel structure. The sound-proof panel has the loss factor and the diffuse sound transmission coefficient, which were determined in the article [5]

$$\varepsilon_1 = \frac{1}{\sqrt{1 + \frac{1}{\left(\frac{4}{3}\alpha_1 + \frac{2}{3}Q\right)^2}}}, \quad (2)$$

$$\tau_1 = \frac{\ln\left(1 + Q^2\right)}{Q^2}, \quad (3)$$

Where $Q = \frac{m_p f}{\rho c}$ is the dimensionless complex; α_1, - is the sound absorption coefficient, m_p - is the surface density of sheet material, from which the elements of SLSP-3 panel are made; *f*- frequency; ρ- density of air; *c*- speed of sound in the air.

Figure 2 shows a simplified scheme of SLSP-3 panel, with the description of three basic layers of sheet materials.

The sound absorption coefficient is defined as the ratio of the absorbed or scattered energy of the flow to the energy of the incident sound flux.

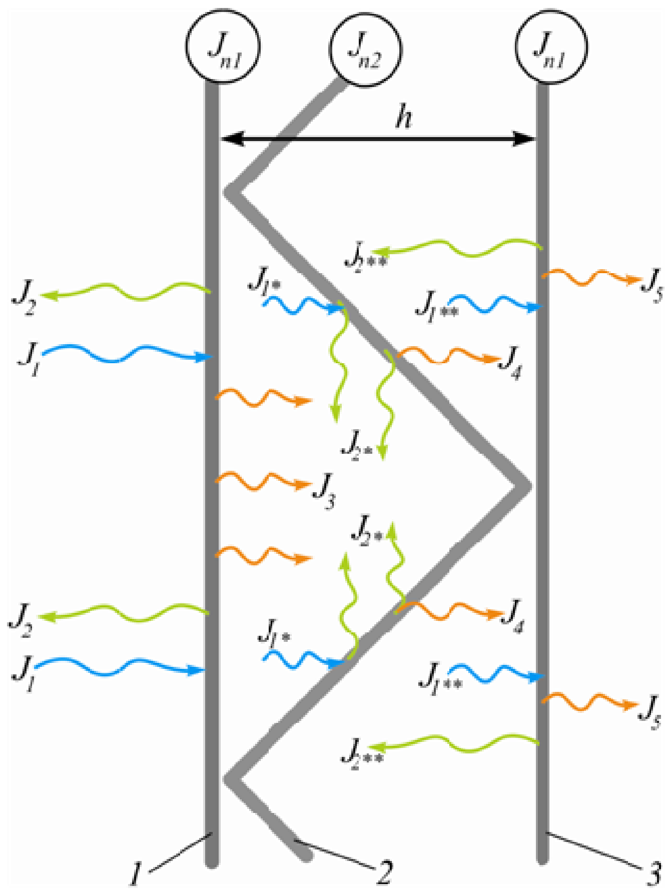


Fig.2. SLSP-3 panel. Sound fluxes in the structure of sound-proof lightweight structured panel: 1 - sheet, perceiving an incident sound wave; 2 - internal sheet; 3 – sheet, through which the sound wave moves out; J_1– main flux, falling on sheet 1; J_2–flux, reflected from the sheet 1; J_3 –flux, transmitted through the sheet 1; J_{1*} - main flux, falling on the sheet 2; J_4- flux, transmitted through the sheet 2; J_{2*}- flux, reflected from the sheet 2; J_{1**}- flux, falling on the sheet 3; J_{2**}- flux, reflected from the sheet 3; J_5- flux, transmitted through the sheet 3; J_{n1}, J_{n2}, J_{n3}- losses of energy for damping by surrounding air, respectively, by the sheets 1, 2 and 3;*h* - thickness of SLSP -3.

The hypothesis is made, that the damping energy of vibrational motion of sheets 1, 2, 3 is absorbed by air. Also, the reflected sound wave from the sheets 2 and 3, due to antiphase components in a diffuse sound flux, will be almost completely canceled. Therefore, the total absorbed energy in the structure of SLSP panel will be the following:

$$J_{n\Sigma} = J_{n1} + J_{n2} + J_{n3} + J_{2*} + J_{2**}\text{, or}$$

$$J_{n\Sigma} = J_1\left[\tau_1\varepsilon_1 + \tau_1^2(1-\varepsilon_1)\varepsilon_1 + \tau_1^3(1-\varepsilon_1)^2\varepsilon_1 + \tau_1(1-\varepsilon_1)(1-\tau_1) + \tau_1^2(1-\varepsilon_1)^2(1-\tau_1)\right].$$

The sound absorption coefficient of SLSP-3,inwhole, is determined as follows:

$$\alpha = \frac{J_{n\Sigma}}{J_1} = 3\tau_1^3\varepsilon_1 - 3\tau_1^3\varepsilon_1^2 + \tau_1^3\varepsilon_1^3 + \tau_1 - \tau_1^3 = \tau_1^3\left(3\varepsilon_1 - 3\varepsilon_1^2 + \varepsilon_1^3 - 1\right) + \tau_1 . \quad (4)$$

Finally, (4) can be represented in the form:

$$\alpha = \left(\frac{\ln\left(1+Q^2\right)}{Q^2}\right)^3\left(3\varepsilon_1 - 3\varepsilon_1^2 + \varepsilon_1^3 - 1\right) + \frac{\ln\left(1+Q^2\right)}{Q^2}, \quad (5)$$

4. EXPERIMENTAL CHECK OF THE SOUND ABSORPTION COEFFICIENT MODEL

The verification of the convergence of theoretical and experimental values of the sound absorption coefficient was carried out using the experimental facility, the scheme of which was presented in Figure 3.

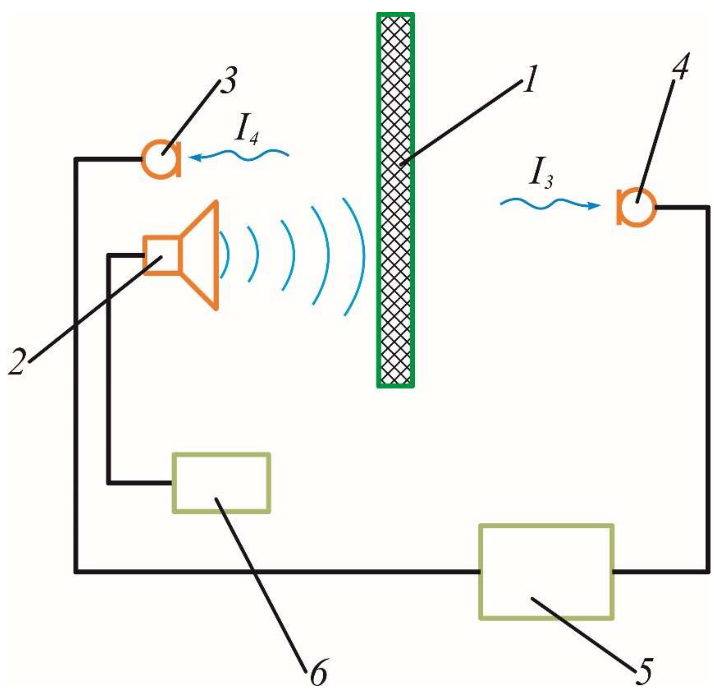
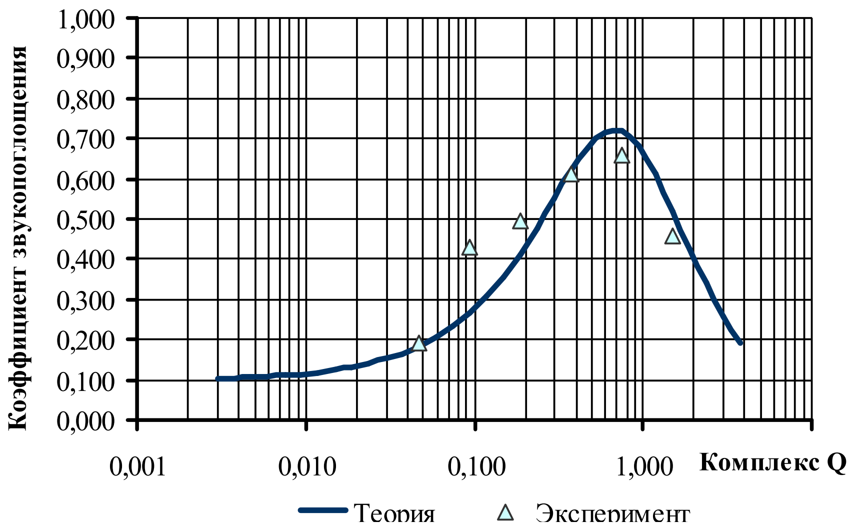


Fig.3. Scheme for measuring the sound absorption coefficient: 1 - panel, 2 - sound source, 3 - microphone for the reflected sound wave, 4 - microphone for the transmitted sound wave, 5 - two-channel sound level meter, 6 - white noise generator.

The experimental facility was located in the open space, with an average sound level of 28 dBA, and was used to measure the sound absorption coefficient, by estimating the intensities of the incident, transmitted and reflected sound waves, through the studied panel SLSP-3. The sound pressure was perceived by two microphones 3, 4, connected with the sound level meter 5. The investigated structure 1 was installed perpendicular to the horizontal plane. The distance between its lower edge and the floor was 0.5 m. The speaker and the microphone were located at the same level relative to the floor, so that an imaginary horizontal line, connecting their centers, passed through the center of the studied construction.

The results of measurements and theoretical values are shown in the graph (Figure 4) in the form of a curve, and in the Table.



Коэффициент звукопоглощения	Sound absorption coefficient
Комплекс Q	Complex Q
Теория	Theory
Эксперимент	Experiment

Fig.4. Theoretical and experimental values of the sound absorption coefficient of SLSP-3; the main characteristics of SLSP-3: $m_p = 0.08$ kg/m²; $h = 0.015$ m; $M_P = 0.909$ kg/m².

The efficiency checking of the sound-proof panel SLSP-3, in comparison with the existing soundproof materials with a rigid structure, was carried out using the sound absorption efficiency coefficient [2]. It is the ratio of the average sound absorption coefficient of the panel to its surface density:

$$K_{\alpha} = \frac{N_{rc}}{M_P}, \tag{6}$$

where M_P is the surface density of the panel, *kg/m²*. N_{rc} - is the average sound absorption coefficient, which can be determined using the normative document ATSM 423-90a (USA), according to which the arithmetical average of the sound absorption coefficients for the voice frequencies are the following: 250, 500, 1000 and 2000 Hz.

Table 1. Average sound absorption coefficient for materials, used in construction industry

Material, thickness of material	M_P, surface density, *kg/m²*	Voice range, *Hz*				N_{rc}	K_{α}
		250	500	1000	2000		
Wood-fibre boards (WFB), 12 *mm*	10.8	0.3	0.34	0.32	0.41	0.34	0.031
Particleboard, 15 *mm*	11.72	0.24	0.08	0.07	0.1	0.12	0.010
Gypsumboard, 10 *mm*	110	0.28	0.15	0.06	0.05	0.13	0.001
Plywood, 12 *mm*	9.53	0.08	0.17	0.16	0.1	0.12	0.013
Panels SLSP-3, 15 *mm*	0.91	0.19	0.43	0.50	0.62	0.44	0.484

5. CONCLUSION

The analysis of the obtained results shows sufficient convergence of the theoretical values of sound insulation and experimental data. SLSP-3 has increased sound absorption in octave bands of medium and high frequencies. Taking into account the coefficient of sound absorption efficiency, it can be seen, that the sound-proof panel SLSP-3 is better than the soundproof materials with a rigid structure, used in construction industry. The panel SLSP-3 has structural rigidity, so it can be used independently as the sound-proof coating, and as the filler for frame panels in various casings, acoustic screens, partitions of building structures.

CONFLICT OF INTEREST

The authors confirm that the presented data do not contain the conflict of interest.

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