Paper No.336/2021

ON THE USAGE OF POROUS MATERIALS IN SOUND DAMPING. COMPACT SOUND DAMPERS AND EVALUATION OF THEIR EFFECTIVENESS

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***Abstract**: The results of the calculation of sound-damping elements of various configurations are presented. It is shown that the proposed solutions are quite effective within the frequency range from 100 up to 400 Hz. The scope of application of the research results is the improvement of methods of experimental and model studies of the properties of porous materials, as well as the manufacture of sound-damping structures for direct use in the layout of residential premises.*

***Keywords:** Delany-Bazley-Mikki model, sound-damping materials, solid transformers Delany-Bazley*

***DOI:** 10.36336/akustika20213990*

1. INTRODUCTION

One of the important tasks of the interior layout of a residential building is to reduce noise [1]. Any room, in fact, is an acoustic resonator, and if you do not take measures to reduce the noise of re-reflection (reverberation), this will create conditions for amplifying individual components of noise and, accordingly, uncomfortable living.

An effective way to solve this problem is to use sound-absorbing materials; however, their use in residential areas is associated with significant costs. Therefore, it is more appropriate to use the so-called compact porous dampers placed around the perimeter of the ceiling or in the tops of the room. Fig. 1 shows some examples of such sound-damping devices.

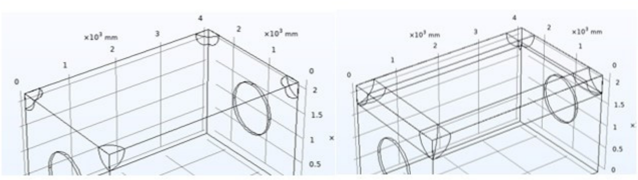

Fig. 1: Ceiling sound dampers

In our study, we used the finite element method to evaluate the damping capacity of porous materials in residential environments. We did not set the goal to calculate the propagation of sound in a room with furniture; the main task was to evaluate the damping capacity of specially made porous dampers.

The dependence of the damping factor (attenuation) on the following factors is investigated: the configuration of dampers (solid, spherical, cylindrical) with the same thicknesses, the thickness of the damper (for spheres and cylinders), and its hydrodynamic resistance (Delany-Bazley-Mikki model is used).

Solid wall sealing and its absence are two extreme cases, relative to which the absorption capacity of compact ceiling dampers was evaluated.

The conclusions of the study can be useful for designers of residential premises, developers of passive noise reduction devices.

2. GENERAL POINTS

2.1. Hubs-transformers and dampers

As an example, a system that absorbs acoustic waves we can consider a horn sound concentrator (amplitude transformer) with a sound-damping material located in the focus (or in the most „narrow place"). The absorption of acoustic energy in such a system occurs in 2 stages: first, the acoustic energy scattered in space is concentrated/localized in a small volume of space, and then it is converted into thermal energy due to the properties of the sound-absorbing material.

A similar situation, but for higher frequencies (ultrasound), is observed for dampers used in nondestructive testing to absorb the „reverse wave" emitted (reflected) by the back side of the piezo plate in relation to the controlled object. The main phenomena underlying damping (nondestructive testing, sound proofing) are the concentration and absorption of sound waves.

There are known sound-absorbing coatings using conical, parabolic and other concentrators [2], the role of which is to localize acoustic energy in a small volume of space for its further absorption (irreversible transformation into thermal energy). As an example, we can mention porous materials based on fiberglass or mineral wool can be used. In the dampers that are part of piezoelectric transducers, materials with large absorption/attenuation coefficients are used, and the damper can be a combination of a wave transformer and an absorber.

In the dampers that are parts of piezoelectric transducers, materials with large absorption/attenuation coefficients are used, and the damper can also be a combination of a transformer and an absorber [3].

Thus, horn transformers can be very effective sound absorbers (dampers) in the presence of sound-absorbing materials, the role of which can be assigned to porous materials. At the same time, the sound-absorbing elements themselves are quite compact, since the energy of the incident sound wave is localized in a small volume of space.

If we consider a living room from this point of view, then a system of three mutually orthogonal planes can be considered as a concentrator (transformer) of acoustic waves. This statement can be true even for two mutually perpendicular planes, that is, sound-absorbing materials can be located both at the vertices of the room (a rectangular parallelepiped) and along its edges (near the ceiling).

Within the framework of this approach, the task was set to conduct a comparative analysis of the sound attenuation coefficient in the room when using various options of sound-absorbing elements: from spherical absorbers to a continuous coating of walls with porous materials.

2.2. Porous materials. Basic models

The main model used for the calculation of porous materials in acoustics is the Biot-Allard model [4]. Its undoubted advantages include high accuracy of calculations and a wide range of parameters of porous materials involved in the calculations (for example, it is possible to study the dependence of the attenuation coefficient on the tortuosity of the pores). The parameters that must be set when using the Biot-Allard model are determined experimentally. The following parameters are set for the solid-state matrix: elastic properties, mechanical damping, porosity, hydraulic resistance, tortuosity of pore channels, the scale of thermal and viscous effects, permeability, and the Biot-Willis coefficient. The fluid has its own set of parameters: density and viscosity, compressibility, adiabatic index, heat capacity and thermal conductivity. This model is implemented within the Poroelastic Waves interface. However, with all the advantages, the Biot-Allard model has the disadvantage that its full calculation requires a significant amount of computing resources, so, within the Poroacoustics domain node, various simplified models are available in the Pressure Acoustics interface, which greatly facilitate the calculation. Among them: the Delany-Bazley-Mikki model, the Wilson model, the Johnson-Champeaux-Allard model, etc.

The structure of the material, however, does not play a significant role in our study. The main task is to compare different geometric configurations of sound absorbers, all other things being equal. That is why we used the Delany-Bazley-Mikki model for the initial evaluation of the piezomaterial efficiency.

3. MODELING OF A ROOM WITH DIFFERENT ARRANGEMENT OF SOUND-ABSORBING POROUS ELEMENTS

3.1. Room geometry

The geometry of the room under study is a rectangular parallelepiped, on two opposite walls of which the source and the receiver of acoustic vibrations are located. The dimensions of the room: 4000×2500×2200 mm. The sound source and the receiver are flat round pistons of large diameter, i.e., in fact, the sound radiation is simulated by the wall of the room. This situation often takes place when there is a source of very loud noise in the next room (Fig. 2).

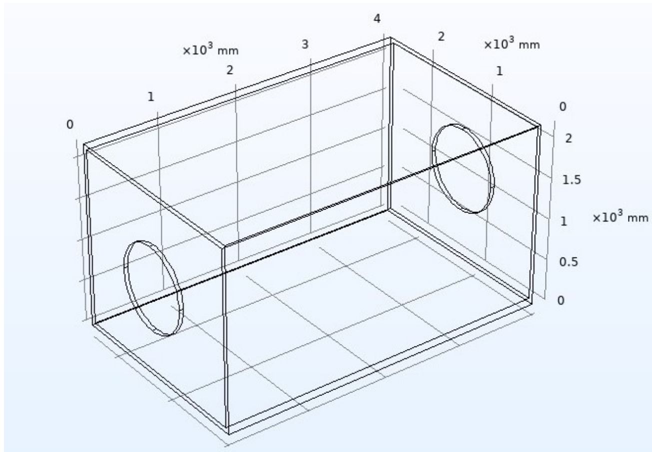

Fig. 2: Room geometry

In our case, Fig. 2 shows a room whose walls are covered with entire porous material. As sound-absorbing elements, cylindrical absorbers in the form of a sector (1/4 cylinder), placed under the ceiling like skirting boards), spherical absorbers in the form of a sector (1/8 sphere), placed at the vertices of a rectangular parallelepiped are also used (Fig. 1).

This model allows for arbitrary changes in the geometric parameters of the absorbers and the room itself (these attributes are set in the Global Definitions section, Parameters subsection), which allows you to quickly conduct a comparative analysis for a variety of different configurations of sound-absorbing elements. It is allowed to change the thickness (radius) of the absorber, the geometric parameters of the room, the hydrodynamic resistance of the material, the type of sound-absorbing elements. The calculation is based on the Delany-Bazley-Mikky model [5] using the Poroacoustics module, which is part of the Pressure Acoustic interface. The so-called Ports are used for the radiation and reception of the acoustic wave.

3.2. Dependence of the attenuation coefficient on the configuration of the sound-absorbing material

The attenuation coefficient in all cases is calculated as the ratio of the power of the acoustic signal at the input to the power of the signal on the opposite wall of the room. The following calculation parameters are selected: frequency range within 20 up to 3250 Hz (step 10 Hz), radii of cylindrical and spherical absorbers - 300-400 mm. The thickness of the entire sound-absorbing layer is 50 mm. The frequency dependence of the attenuation coefficient is shown in Fig. 3.

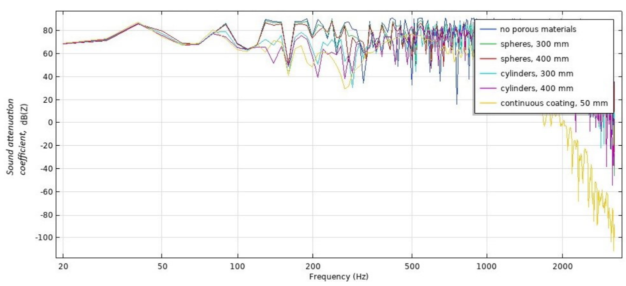

Fig. 3: Frequency dependence of the sound attenuation coefficient

As one can see from the figure, cylindrical absorbers exhibit significant efficiency, which increases with increasing volume. Within the frequency range 100 up to 400 Hz, it is almost close to the efficiency of the entire sound-absorbing coating. Thus, even in the presence of a thin sound-absorbing wall covering, the installation of additional sound-absorbing elements located in the corners between the walls and the ceiling can significantly reduce the noise level in the room.

3.3. Dependence of the attenuation coefficient on the value of the hydrodynamic resistance

It was studied for the most, in our opinion, rational case, when the absorbers are located along the perimeter of the ceiling in the form of skirting boards. The radius of the absorbers is 300 mm. Three values of hydrodynamic resistance were used in the calculations: 625, 1250, 2500 (Pa*s)/l. The corresponding graphs are given in Fig. 4.

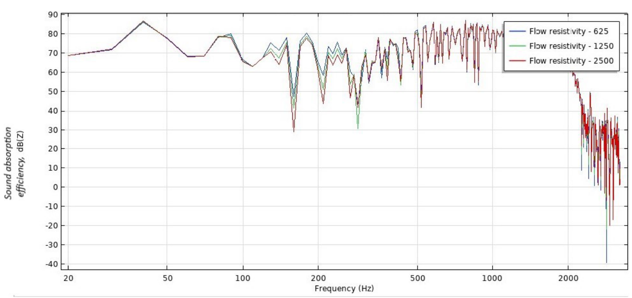

Fig. 4: Frequency dependence of the sound absorption efficiency for different values of the hydrodynamic resistance

The graphs show that the hydrodynamic resistance of the material does not play a special role in most part within the studied frequency range. An insignificant effect (a decrease in the ratio between the input and output signal) is achieved only within the frequency range from 100 up to 400 Hz. At the same time, the material with a high hydrodynamic resistance has the best sound-absorbing properties.

4. FUTURE PROSPECTS

4.1. The use of a rigorous theory of Biot-Allard

The key feature of this theory is the ability to accurately describe the structure of the material, which means that the model built on its basis can be used to predict the properties of artificially obtained porous materials. It is possible to modify the porosity, tortuosity of the pore channels, i.e. the structure of the material, which is of great importance for the creation of high-performance sound-absorbing materials and products including these materials. An example of such a study is given in [6].

4.2. Experimental determination of the properties of porous materials

It should be noted that, despite the wide possibilities of software products for modeling porous materials, only a direct experiment can give the real characteristics of these materials, as well as the parameters that characterize the effectiveness of sound-absorbing structures. The most important direction in this area is the comparative analysis of the results of the experiment and modeling, which allows us to determine the limits of applicability of computer-generated models, as well as to improve their accuracy [7].

5. CONCLUSIONS

In the course of modeling the passage of sound through a room with different configurations of sound absorbers made of porous materials, a significant efficiency of absorbers in the shape of a 1/4 cylinder located in the corners between the ceiling and walls was revealed (at the level of the calculated model).

This configuration of sound absorbers involves the absorption of acoustic energy previously concentrated in a small volume of space. The mutually intersecting walls of the room act as a hub. According to our research, this allows to significantly reduce the noise level in the room within the frequency range from 100 up to 400 Hz, which corresponds to the speech range and is especially relevant in the conditions of apartment buildings.

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