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NOISE-ABSORBING ACOUSTIC SCREEN BASED ON A HELMHOLTZ RESONATOR

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Abstract*: The paper aims at studying the noise protection potential of an acoustic screen based on a Helmholtz resonator to solve the problem of noise reduction level in the area in front of the screen. For experimental analysis, a modular acoustic screen has been made. Replaceable modules are made on the basis of a wooden frame with stiffening ribs, one side of the module is blind, another has slotted holes, which ensures the formation of noise absorbers on a Helmholtz resonator principle. Changing the position of the modules in the support racks provides the ability to change the screen reflexive surface nature. The main problem solved in this work is to experimentally determine the decrease magnitude in the sound pressure level in the area in front of the screen. The results of sound pressure level measurements at various frequencies are provided, the comparison of the reflected noise obtained values with the results obtained in the sound pressure level analysis in the case of a solid screen is given. The coincidence of the calculated values of the active sound absorption frequencies with the measured values is shown. It is concluded that there is a possibility to solve the nose reduction level problem when using such screens in areas where people can be.*

Keywords: *noise absorption, acoustic screen, Helmholtz resonator*

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1. INTRODUCTION

Acoustic noise is one of the most significant problems classified as "challenges to humanity". An inevitable consequence of technological development is an increase in noise that accompanies the operation of many technical systems and devices. As a result, the annual increase in the noise level, for example, in open spaces of cities, reaches, according to various estimates, 0.5 dB [1]. There is no doubt that in the future this process will acquire a more dynamic character due to the constant increase in the number of cars. For example, in a relatively small, according to Russian standards, the city of Murom with the population of 110,000 people according to the estimate, more than 50,000 vehicles for various purposes are registered. In recent years, the increase has averaged 1,000 units per year. Obviously, the noise load on city residents is significant and constantly increasing.

The problem of protection people from noise exposure is becoming multifaceted. Acoustic screens (ASs) are widely used among practical measures aimed at reducing noise levels. This approach is typical for decisions made in different countries [2,3,4,5,6]. Acoustic screens provide effective protection against the spread of noise deep into the residential area, but they are not without drawbacks in terms of their use in urban environments, for example, due to their overall dimensions [7].

The general principle of a noise-protective acoustic screen operation is considered in detail in a number of works, for example, in [2,7,8,9] and others.

An increase in the efficiency of noise protection screens is possible by imparting noise absorption properties to them. As a result, in addition to reducing the noise level behind the screen, in the acoustic shadow zone, we can talk about a decrease in the noise pollution level in the area in front of the screen [2,10,11], where people can be for various reasons.

The relevant literature analysis shows that the issue of noise reduction level in the area in front of the screen in relation to open urban spaces has been considered rather little [8,9]. At the same time, the use of noise-absorbing screens that absorb a sound wave energy in the area in front of it and, as a result, reduce the noise level, would reduce the acoustic load on those people may be in the area in front of the screen [9].

Screens with the property of absorbing a sound wave energy can be implemented on a Helmholtz resonator principle [12]. The possible application of such devices is described in [10]. Studies carried out in the simplest laboratory acoustic chambers have shown that such protective devices can reduce noise level by 5–6 dB. At the same time, at certain frequencies, resonance phenomena, leading to an amplification of the acoustic signal by 4–5 dB, occur [10, 11].

2. PROBLEM STATEMENT

The purpose of the article is to study the possible implementation of a noise-protective screen based on a Helmholtz resonator and to evaluate the practical possibility of using such a screen to reduce the noise level in the area in front of it. To achieve this goal, the following tasks must be solved: development and construction of screen modules using the Helmholtz resonator principle; selection of a territory (polygon) for placing a test acoustic screen; creation of a real screen layout; making necessary measurements with noise-like acoustic signals; analysis of the results obtained.

In addition, related tasks should be solved. Among them the choice of construction materials, the selection of sound-amplifying equipment and control and measuring equipment, the choice of a measurement technique, as well as a procedure for processing the results obtained should be pointed out.

To assess the noise-absorbing screen efficiency, an experimental assessment of the amplitude-frequency characteristic (AFC) of the noise signal in the near zone of the screen must be made and its comparison with the AFC of a similar screen in the absence of noise absorption pronounced properties.

This work is a continuation of the previously performed work on the analysis of the noise-absorbing capabilities of screens based on Helmholtz resonators [10, 11, 13].

3. GENERAL PROVISIONS

3.1. Acoustic screen design

To carry out studies with various AS variants, based on the well-known construction principle [2, 14], a screen layout which makes it possible to form a structure based on a combination of individual modules was created. The design is based on a combination of vertically installed bearing racks and removable modules fixed to these racks. The bearing racks are made of rolled steel with a "Tavr" profile and are reinforced in the ground. Replaceable modules have a size of 1500x1500 mm, internal depth - 40 mm. The base of the module is a wooden frame, the inner volume is filled with foam rubber, which acts as a sound-absorbing material. On one side, the blank wall is formed by a plywood sheet, on the other side, the foam rubber sheets are covered with a mesh and slats, as a result of which a slot resonance structure is formed. The slotted gap between the slats is set variable, with a change in length from 5 to 10 mm. This solution makes it possible to simulate the production of a polyharmonic resonator having a set of resonant frequencies. To ensure greater structural stability of the module, stiffening ribs are provided in its internal volume.

A computer 3D model of the replaceable module is shown in Fig. 1.

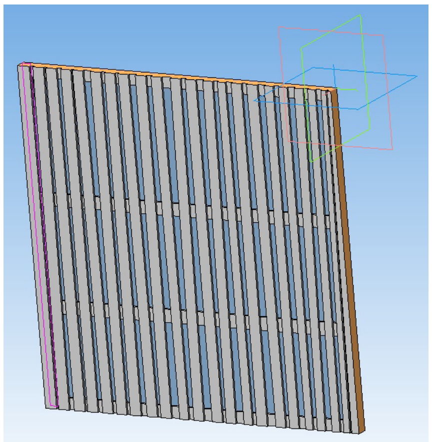

Fig.1: 3D- replaceable module model

In general, the screen structure provides for the installation of the so-called lateral displacements, the purpose of which is to prevent sound diffraction on the main screen side edges. The modules that make up the slopes are made in the form of shields of the same size, but with blank surfaces. The screen main part is 9 meters long and 3 meters high. The screen is installed in an old technical area, currently used only for the temporary placement of various construction or technological recyclable materials.

The appearance of the screen with the installed sound-amplifying equipment is shown in Fig. 2. Due to the fact that the authors of the paper were limited in the test site territory choice, the chosen place of the screen installation provided, first of all, the possibility of measurements in the screen acoustic shadow zone with a distance of several tens of meters from it. At the same time, a part of a brick structure, trees, building materials stored on the territory are visible in the photo. Obviously, all of the above can affect the nature of signal propagation along the path. In addition, a three-storey brick building is located behind the noise source at a distance of several meters.

Fig.2: Screen appearance

The box-shaped sealed along the back and side walls of the replaceable module, in combination with the slot structure formed by the rails mounted on the front side, forms a set of slotted Helmholtz resonators. Their resonant frequency [12,15] is found by the formula

$$f_r = \frac{c}{2\pi} \cdot \sqrt{\frac{b}{L \cdot H \cdot k}}, \qquad (1)$$

where
c =343 m/s speed of sound in air at an air temperature of 20 ° C;
b – slot width;
k – slot depth (resonator neck);
L – is the distance between the axes of the slots;
H – is the distance between the inner surfaces of the outer rails and the rear wall of the box.

Fig. 2 shows a variant of installing removable screen modules with the dull side to the noise source, without side bends. The variant with the installation of replaceable modules on the noise-absorbing side is shown in Fig. 3. In this version, there are also side bends and hinged anti-diffractors.

Fig.3: Screen appearance with slotted modules

3.2. Measurement technique

According to the recommendations of GOST 20444-2014 “Noise. Transport streams. Methods for determining noise characteristics”[16], the noise source was located at a distance of 7.5 m from the screen at a height of 1 m. A noise-like signal (“white noise ”) with subsequent amplification was used as the initial signal. The measuring device microphone was located at a distance of 1 m from the screen surface at a height of 1 m and was oriented toward the screen. Thus, in the opinion of the authors, an assessment of sound pressure levels (SPL) generated by the noise signal was provided in the area immediately adjacent to the working surface of the screen.

In the course of measurements, the SPL was recorded simultaneously at each of the geometric mean frequencies of the subbands. Since a noise-like signal was used, in accordance with the recommendations of GOST 23337-2014 “Noise. Methods for measuring noise in the residential area and in the premises of residential and public buildings” [16], five series of ultrasonic measurements were carried out at each of the weighted average frequencies, after which the average value for frequencies was calculated by the ratio

$$L_f = 10lg\left(\frac{1}{n}\sum_{i=1}^{n} 10^{0,1L_i}\right) \qquad (2)$$

where
L_f – is the average SPL value at frequency f;
i – is the number of measurements at a given frequency (in our case i = 1 ... 5);
L_i – is the SPL fixed value at a specific frequency in the i-th dimension.

When evaluating the screen efficiency, the principle of comparing the measurement results with the original AFC of the sound reinforcement system (noise source) was used. This approach makes it possible to mutually compensate for all "parasitic" influences, highlighting the main signal changes. At each operating frequency, the value of the SPL change ΔL_f was determined in comparison with the original signal AFC

$$\Delta L_f = L_f^{AFC} - L_f^{MP} \qquad (3)$$

where
L_f^{AFC} – SPL at frequency f at a distance of 1 m from the noise source;
L_f^{MP} – SPL at frequency f at the measurement point.

Since changing the location of the removable modules takes a lot of time, the measurements were carried out on different days, due to which because of a possible mismatch of the original signal amplitude-frequency characteristics, it is difficult to talk about the correctness of comparing the results obtained. To ensure the possibility of a reliable comparison of the results, we used the option of comparing the differences obtained by (3) in the first and second cases

$$\Delta L_{f\mathrm{p}} = \Delta L_{f1} - \Delta L_{f2} \qquad (3)$$

where
$\Delta L_{f\mathrm{p}}$ – value of SPL differential attenuation;
ΔL_{f1} and ΔL_{f2} – the SPL change magnitude in the first and second cases.

The possibility of such an approach was substantiated in [17].

3.3.Applied equipment

To generate a noise acoustic signal, an Invotone 1500 amplifier and two Delta 4215 acoustic systems (AS), providing, at a nominal audio signal power of 500 W, a maximum sound pressure level of up to 124 dB at a distance of 1 m from the acoustic systems, were used. The synthesis of "white noise" was carried out in the LabView environment using a laptop. The noise source was considered as a point source.

As a control and measuring instrument, we used a class I sound level meter ASSISTANT, which passed metrological verification at the time of measurements.

4. RESULTS OF MEASUREMENTS

The results of calculations based on the results of measurements are presented in Table. 1 and Fig. 4. Negative values characterize the amount of ultrasound attenuation in the area of a screen with an absorbing surface (with Helmholtz resonators) in comparison with a blank screen.

From the presented data it can be seen that at all weighted average frequencies of the octave ranges (except for the frequency of 500 Hz) there is a positive effect from the use of a screen with absorbing elements.

The negative effect at 500 Hz can be related to the area layout where the screen is located. Resonance phenomena may occur in the area between the screen and the building located behind the noise source. This possibility is indicated by the fact that in all cases of subsequent measurements with this screen, a comparison of both the noise reflected from the screen and the acoustic shadow transmitted into the zone with the original noise signal shows a similar "burst". In addition, the intrinsic resonant vibration frequency of the screen as a structural system also needs to be measured.

Frequency, Hz	63	125	250	500	1000	2000	4000	8000
Attenuation, dB	*-7*	*-1,2*	*-0,8*	*6,4*	*-0,6*	*-10,8*	*-4,6*	*-3,4*

Tab. 1: Attenuation of sound pressure level as measured

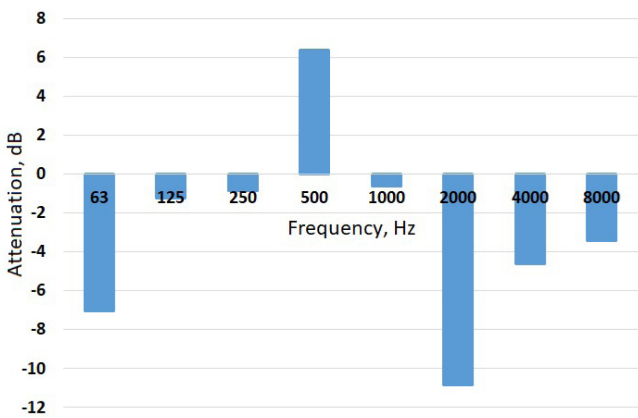

Fig.4: Noise level attenuation

Since, as noted above, the design features of the replaceable modules allow us to speak about the polyharmonic structure of the resonators, we will determine the values of the resonant frequencies by formula (1) with variations in the slot gap from 5 to 10 mm. Calculations show that with the indicated depth of the internal volume of 40 mm and the width of the slots of 50 mm, the range of a possible set of resonant frequencies is in the range from 750 to 1020 Hz. The obtained values are better compared with the results of measurements in one-third octave frequency ranges (Fig. 5). Obviously, there is some agreement between the calculated range and the practical results. If, at the same time, we take into account that under the influence of changing weather conditions, the screen wooden elements were somewhat deformed, as a result in some cases the gap increased to almost 15 mm, which gives the resonant frequency value of about 1200 Hz, then we can talk about a fundamental coincidence of the calculated and practical values.

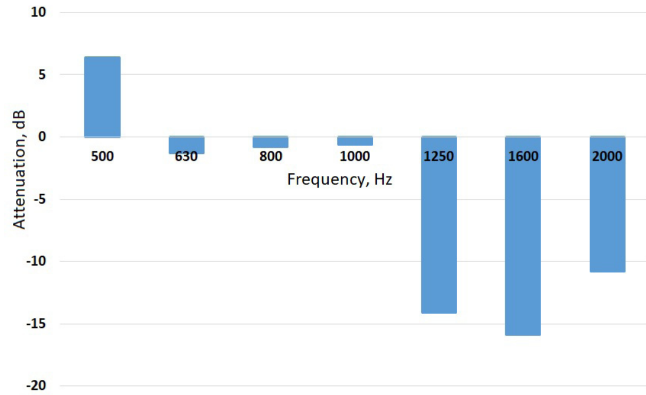

Fig.5: Noise level attenuation in one-third octave bands

5. CONCLUSION

The results obtained allow us to conclude that the use of acoustic screens based on Helmholtz resonators for solving a noise level reduction problem in the area in front of the screen is quite possible. Changing the size of the slot gaps, the distance between them, variations in the volume depth (screen thickness), in combination with the choice of various noise-absorbing material, will make it possible to find the optimal design option that will reduce the noise level in the area in front of the screen. In open urban spaces, such screens can reduce noise exposure, for example, on pedestrians when driving on narrow sidewalks, limited to busy carriageways, and, for example, a fence near an industrial enterprise or a private house. Other options for using such screens are also possible.

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