About the possibility of using acoustic screens, made on the basis of Helmholtz resonators, to reduce noise

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Abstract

The article considers the urgency of the problem of noise control in urban areas, the means of protection against noise on its propagation path from the source to the protected object, the most common of which are acoustic screens and Helmholtz resonators. The possibility of using acoustic constructions made on the basis of Helmholtz resonators is tackled upon in this paper. The results of the experimental data, both in terms of a reflected sound, and the level of absorbed sound are analyzed. During the experimental procedure resonating acoustic abilities of acoustic constructions were taken into consideration. The conclusions of the work were made.

Key words: acoustic pollution, acoustic screens, sound insulation, Helmholtz resonator.

О возможности применения акустических экранов, выполненных на основе резонаторов Гельмгольца, для снижения шума

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Аннотация

Показана актуальность проблемы борьбы с шумом на урбанизированных пространствах. Рассмотрены средства защиты от шума на пути его распространения от источника до защищаемого объекта, самыми распространенными из которых являются акустические экраны и резонаторы Гельмгольца. Рассмотрена возможность применения акустических конструкций выполненных на основе резонаторов Гельмгольца. Описана экспериментальная модель акустического экрана, а именно акустический экран, выполненный в виде резонатора с различной шириной зазора щелевых отверстий. Проанализированы результаты полученных экспериментальных данных, как по уровню отражённого звукового сигнала, так и по уровню поглощенного звукового сигнала. В ходе эксперимента учитывались резонирующие способности самих акустических конструкций. Сделаны выводы о проделанной работе.

Ключевые слова: *акустическое загрязнение, акустические экраны, шумозащита, резонатор Гельмгольца.*

Introduction

Urbanized areas (cities) account only for a few per cent of the world land area, but more than a half of the world population lives there. The expansion of urbanized space creates many environmental problems, including health decline due to the exposure to external factors.

For a long time cities were formed without any scientific planning and optimization of industrial, residential, recreational and buffer zones. This led to a merger or a mutual penetration of these areas and aggravated environmental situation of cities, especially large ones.

One of the most important factors influencing the health of the population of the city is noise. The adverse acoustic conditions can lead to cardiovascular disease and nervous system pathology in the most susceptible segments of the population. Recent research found

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out that under the influence of noise there appear changes in organs of human vision (resistance of clear vision and visual acuity reduce, sensitivity to different colors changes, etc.), take place negative changes in vestibular apparatus, the function of the gastrointestinal tract impairs, intracranial pressure increases, body metabolic processes occur, and so on.

According to the authorities in the Russian Federation more than 35 million people live in conditions of acoustic discomfort. The State report "On the Condition and Environmental Protection of the Russian Federation in 2011" shows that in the settlements through which the motorway of federal and regional significance pass, noise level exceeds the allowable value by 25 dBA even during the day [1]. These highways are mainly related to the classes of noise from I - low noise (from 55 dBA to 60 dBA) to V – very noisy (from 75 dBA to 80 dBA) [2].

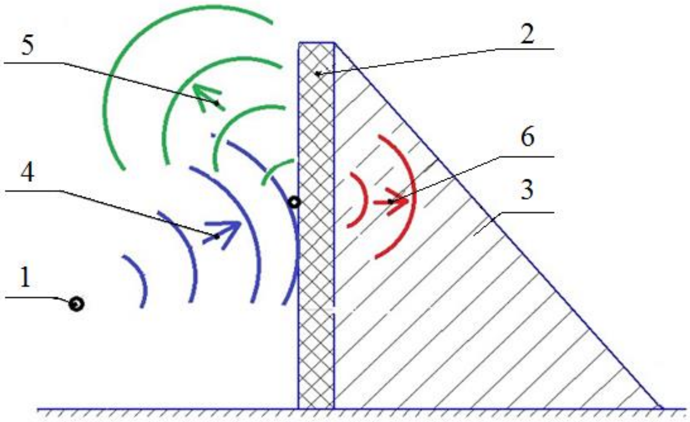
Increased noise along with air and soil pollution, are included into the "triad" of ecological environmental factors, massively influencing the morbidity of population. Therefore, the acoustic improvement of urban areas, creating the optimum acoustic environment is an important task of contemporary spatial planning.

The aim of the article is to study the possibility of increasing the effectiveness of anti-noise devices in solving the problem of acoustic noise level reduction in urban environments.

1. Means of noise protection

One of the most widespread means of the protection against noise on its propagation path from the source to the protected object is acoustic screen (AS) [3]. Acoustic screens of different designs are used both in our country and abroad. The problem of acoustic noise reduction screens is investigated in the scientific works of Russian scientists: V.A. Aistov, V.P. Gusev, B.G. Prutkov, N.I. Ivanov, G.L. Osipov, P.I. Pospelov, I.L. Shubin, N.N. Minina, N.V. Tyurin and others.

The work of the acoustic screen is based on several principles among which the reflection and absorption of an incident sound wave (fig.1) are the most important. Protection effect is achieved in the area of acoustic shadow (behind the acoustic screen) [4].



1 – a source of noise; 2 – an acoustic screen; 3 – an area of sound shadow;
4 – an incident sound wave; 5 – a reflected sound wave; 6 – a transmitted sound wave.
Fig. 1. Operating principle of an acoustic screen

The studies [4, etc.] showed that the AS has an efficiency of 3 to 22 dBA, depending on geometric parameters, the material used, location and other factors. The normative documents containing the recommendations for designing noise protection of areas adjacent to roads and railways with the help of AS were worked out [5].

The following drawbacks of an AS can be pointed out:

1) creates a sense of limited space for drivers;

2) reduces the illumination and results in a limited view, color and distortion of the image;

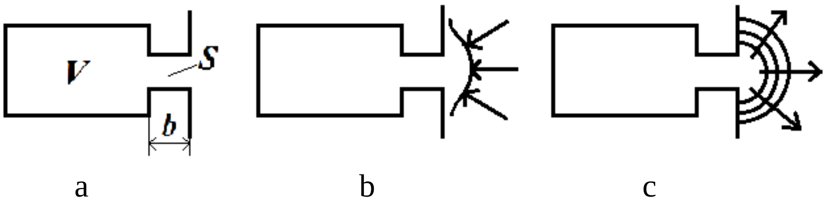
3) limits walking availability of gated section of the route (if immediate assistance is necessary, or if you need to leave the part of the route quickly);

4) high cost of materials – an average of 3 to 10 thousand rubles per square meter excluding installation operations. For the effective protection against noise the recommended height should be not less than four meters;

5)when installing the power of sound of reflecting panels practically does not reduce its strength, but only changes its direction that creates a directional flow at an angle to the vertical line, which stuns the residents of the upper floors, flying birds and results in an increased vibration of air above the road.

Another common protection remedy is the use of acoustic resonators. The use of passive resonators created on the basis of Helmholtz resonator for noise absorption and noise dissipation is described in the works of L.K. Gorohova, K.A. Velezhavina, B.M. Efimtsov, L.A. Lazarev, D.A. Elin and others.

The construction of the air resonator consists of two parts – the front and rear. In the front part there is a neck characterized by the parameters of length/ depth (*b*) and cross-sectional area (*S*). The rear part is a volume (*V*) (Fig. 2,a).



a – construction; b – deformation of the front of the incident wave; c – return of the stored energy into the surrounding space (formation of a standing wave).

Fig. 2. Principle of operation of the acoustic resonator

The principle of operation of the resonator is based on the formation of a standing acoustic wave of a different phase (Fig. 2,b and 2,c). After the contact of the front sound wave with the front of the resonator, the flow rate of the particles in the neck has the greatest velocity, and therefore, has kinetic energy. The rear part is closed and has a volume (*V*), which provides compressive accumulation of potential energy. In the resonator oscillations occur even from a relatively weak sound waves impinging on them. Resonators, depending on the phase of the standing wave forming in the construction can both amplify and attenuate a sound signal [6].

The natural frequency (Hz) of the resonator is calculated by the formula

$$f = \frac{C}{2\pi}\sqrt{\frac{S}{V \cdot l}}, \tag{1}$$

where, f – the natural frequency of the resonator, Hz;

C – the velocity of a sound in the medium, m/s;

S – the area of the mouth lip of the cavity, m^2;

V – the volume of the cavity, m^3;

l – the length of the cavity neck, m.

If the slotted openings are used instead of a series of round holes the formula (1) obtains following form:

$$f = \frac{C}{2\pi}\sqrt{\frac{b}{L\cdot h\cdot l}}, \tag{2}$$

where, l – the depth of the cavity gap, m;
b – the width of the gap, m;
L – the distance between the gaps, m;
h – the depth of the cavity, m.

The main advantage of resonators in comparison with other alternative means of passive noise control is a small size of their wave. In a free-space maximum characteristics of absorption and scattering cross sections of resonators depend on a single parameter – the length of the sound wave [7].

2. The development of experimental models of acoustic screens based on Helmholtz resonator

To evaluate the performance of AS in the studies an acoustic booth was used, which consisted of an acoustic chamber, an audio frequency generator and a sound level meter. The acoustic chamber is a rectangular construction assembled from sheets of chipboard, sheathed inside with several layers of sound-absorbing material.

In this work a construction, made in the form of an acoustic screen, combined with Helmholtz resonator [8] is proposed as a way of protection against noise. The front panel is perforated with vertical slot gaps forming the neck of the cavity. The screen can be made of different sheet materials. To maximize the effect of AS these materials must be able to maximum air damping, i.e. have the property of sound suppression [9].

The analysis of interdependencies of AS main characteristics shows, that the change of the natural frequency of the resonator at constant l and L, as it follows from (2) is substantially determined by the ratio of the clearance of the cavity b and the depth of the cavity h. Fig. 3 shows the results of simulation of frequency f on the above mentioned parameters when they are changed in the ranges of: b=0.1...1 mm, h=2...80 mm. Obviously, the change of frequency largely depends on the variations in the depth of the cavity.

When designing the test model, this indicator had a special significance. Due to the limited dimensions of the acoustic chamber maximum depth of the cavity could be no more than 100 mm. But due to the fact that this acoustic system is a system with distributed parameters, the given ratio (2) is valid only in cases when the depth of the cavity is less than a quarter of the sound wavelength, and the dimensions of the neck are less than two wavelengths [7]. On a standard frequency of 1000 Hz a quarter of the wave constitutes 75 mm. This satisfies the condition the constructed acoustic booth usage.

Proceeding from the above an experimental AS-resonator model was created (Fig. 4). The front of the resonator is made of a steel sheet in which vertical slots were made at a regular distance (L=40 mm). Functions of the neck (l=15 mm) are performed by angle-shaped profiled elements mounted in the slots with the possibility of adjustment relative to the horizontal plane of the front panel and the fixing of this position. This solution provides the possibility of adjusting the width of the slot gap (b=0...1.5 mm) without disassembling the structure of the screen.

The rear part is a rectangular sealed chamber with a depth h=75 mm. The basis of the body is made of wooden bars, the rear panel is made of a steel sheet.

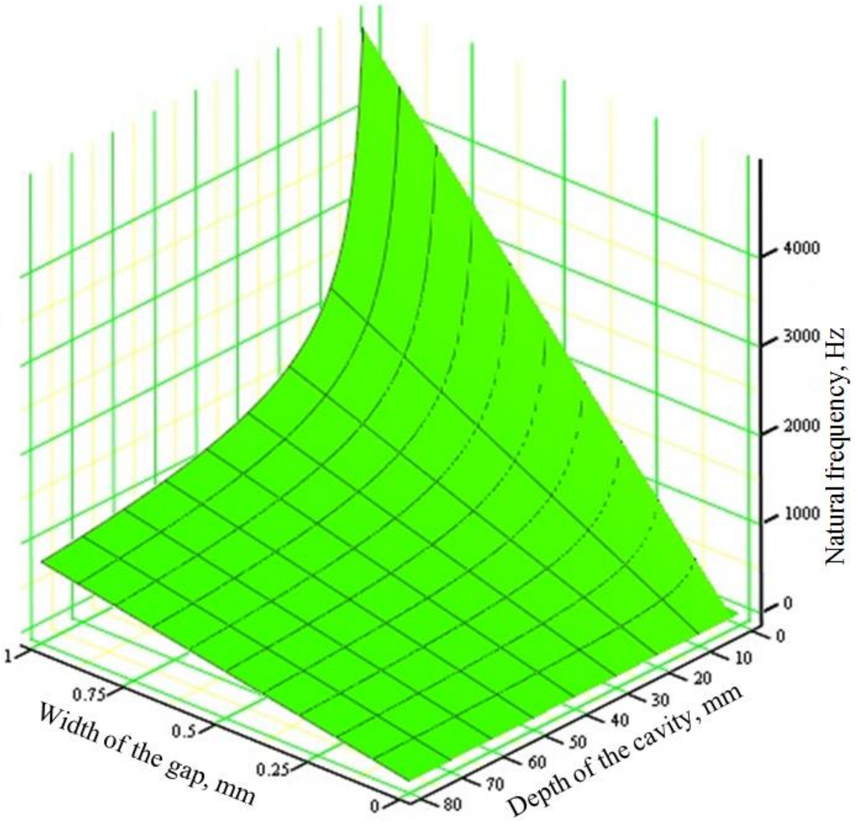


Fig. 3. The relations between the width of the gap, the depth of the cavity and the natural frequency of the resonator

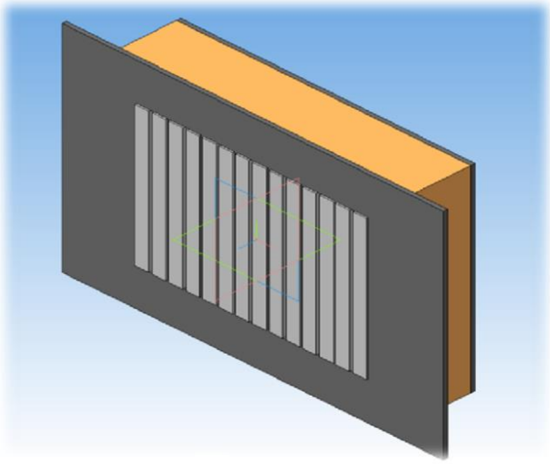
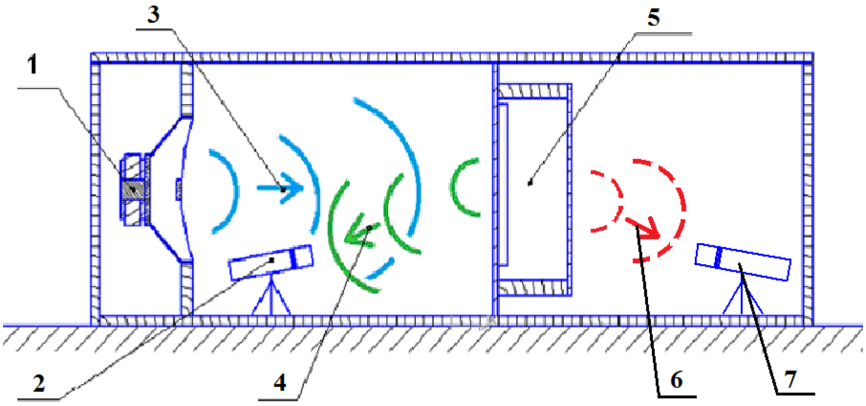


Fig. 4. Model of AS, made on the basis of Gelmgoltz resonator

3. The methodology of experimental studies

The AS-resonator was placed in the middle part of the chamber in two positions: forward, necks were towards the source of the acoustic signal, and the reverse, the rear part was towards the source (Fig.5). The measurements were performed on standard center frequencies 31.5; 63; 125; 500; 1000; 2000; 4000; 8000 Hz. Since most interest from the point of view of protecting human hearing system is the range from 1000 Hz to 4000 Hz, the measurements were carried out in steps of 100 Hz. For simplicity, the experiment studied the

AS reaction to the signal at four fixed values of the gaps – 0.25; 0.5; 0.75 and 1.0 mm. In each case, a series of measurements was carried out and the average statistical value was determined.



1 – a source of a sound signal; 2 – a sound level meter microphone in the control of the reflected wave; 3 –an incident sound signal; 4 – a reflected sound signal; 5 – an AS-resonator; 6 – a transmitted sound wave; 7 – a sound level meter microphone in the control of the transmitted sound wave

Fig. 5. The scheme of the experiment conducted

The assessment of the degree of acoustic signal attenuation is performed for the case of reflection of the incident sound wave on the front panel of the AS and for the case of sound transmission through the plane of the screen into the shadow zone. Quantitative estimations of signal attenuation in the upright AS position were obtained when comparing levels with the case of the screen in the form of a blind steel wall (the screen is installed in the reverse position). Ratings for the case of signal transmission into the shadow zone were received in the same way as a difference in level at different AS positions.

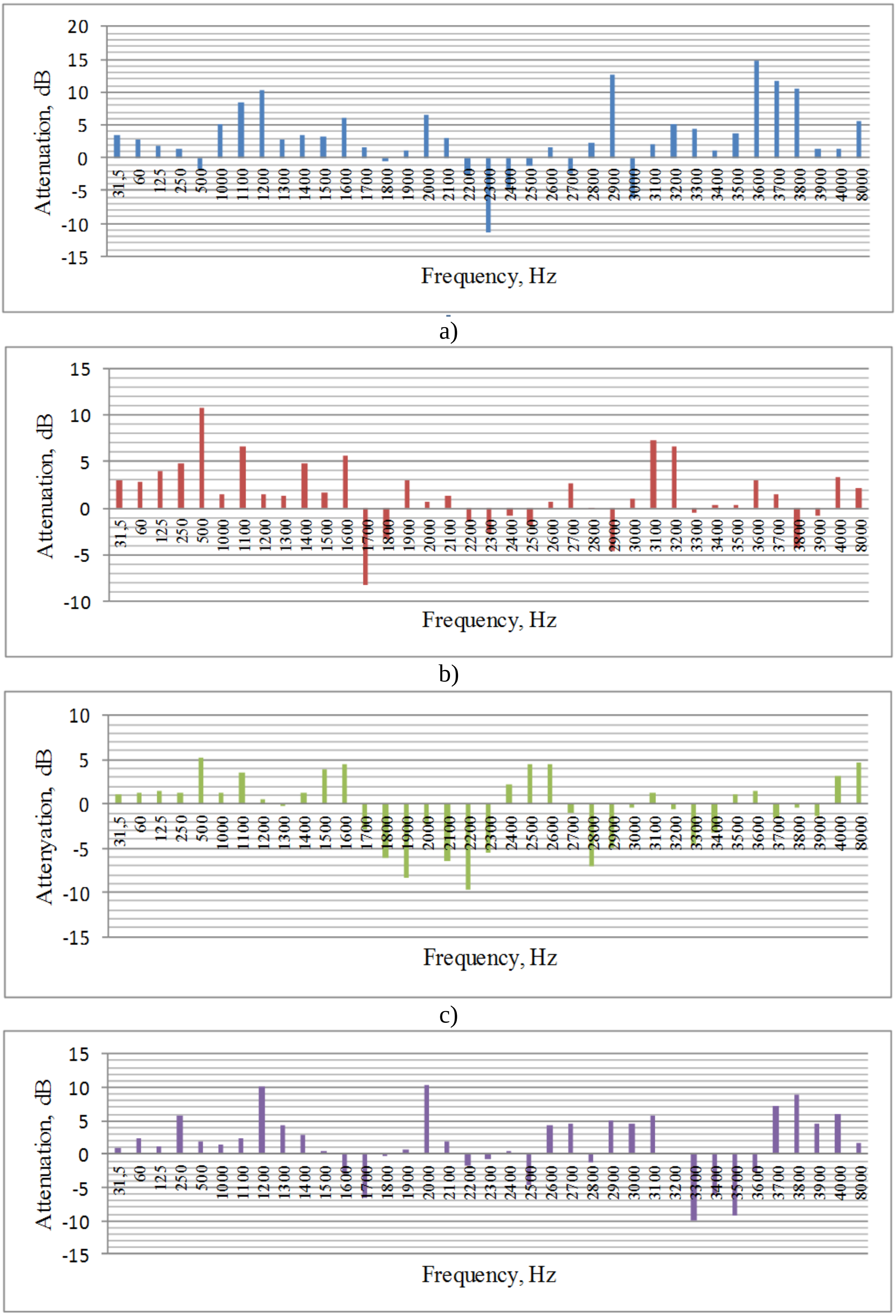
4. Practical measurements and conclusions

Estimates of changes in signal levels are shown in Fig. 6 and 7.

Fig. 7 shows the changes in the levels of the signal reflected from the AS in the case of its direct location. In fact, we are talking about the noise level attenuation in the area immediately adjacent to the screen. Estimates are given for the four values of the gaps.

A positive value on the axis of ordinates means a reduction of the audio signal when using the AS with resonators in comparison with the screen in the form of a blind wall. Accordingly, negative value indicates an increase in the level, i.e. resonance at a given frequency.

It can be seen from the histograms that in the case of existing design features of a particular model of the screen both attenuation and amplification of the reflected signal occur. Thus, when the gap size is 0.25 mm (Fig.6,a) and 0.5 mm (Fig.6,b) we can generally speak about positive effects in terms of reducing the level of acoustic signals. There are some resonance phenomena at certain frequencies, including "splashes" to the level of 5-10 dB. When the gap is 1 mm (Fig.6,d) resonance phenomena are more pronounced. And the obvious dominance of resonance phenomena occurs when the value of the gap is 0.75 mm (Fig.6,c).



a)

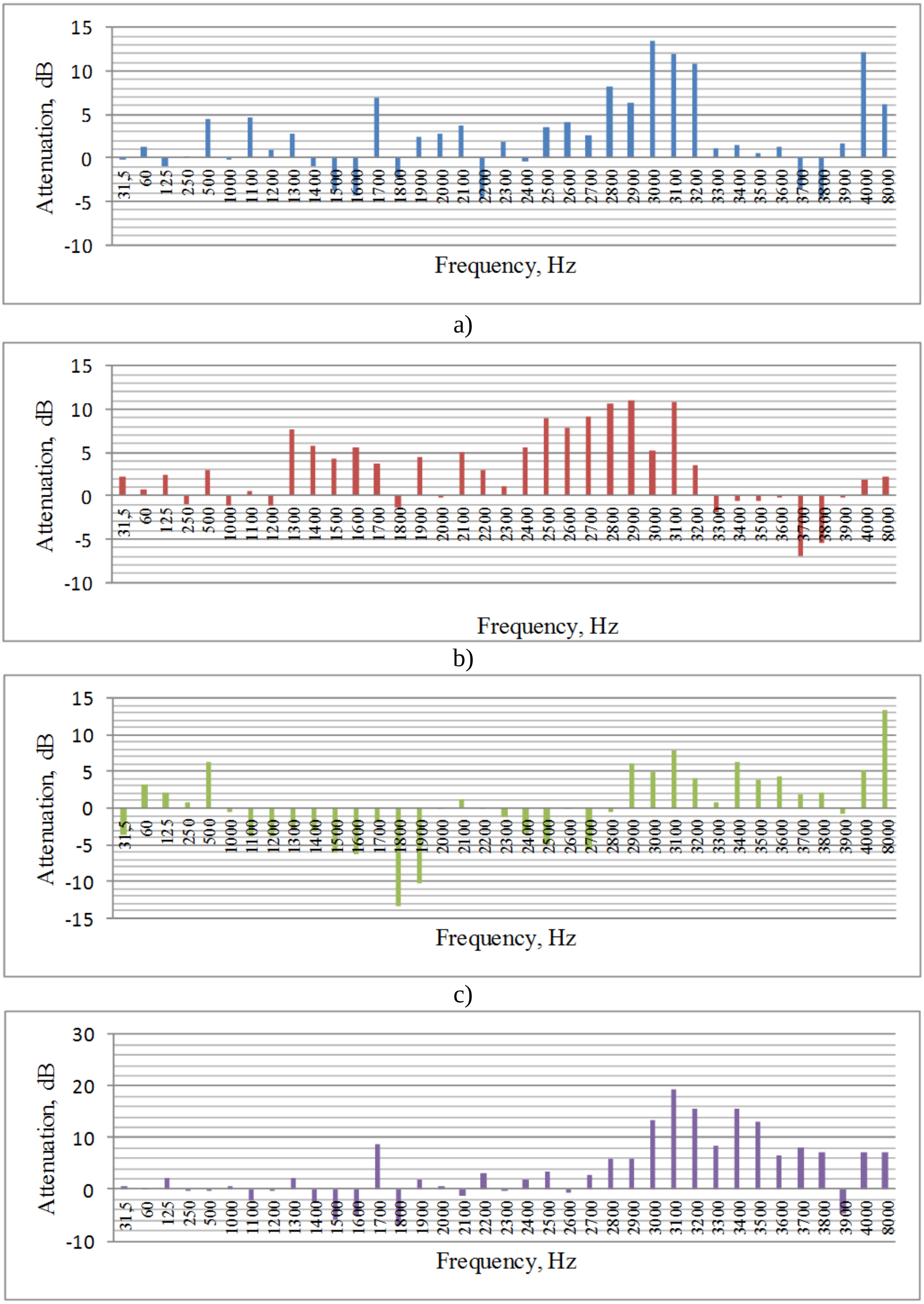
b)

c)

d)

a) *b*=0.25 mm; b) *b*=0.5 mm; c) *b*=0.75 mm; d) *b*=1.0 mm

*Fig. 6.*Histograms of the reflected signal attenuation at the given size of the gaps



a)

b)

c)

d)

a) *b*=0.25 mm; b) *b*=0.5 mm; c) *b*=0.75 mm; d) *b*=1.0 mm

Fig. 7. Histograms of transmitted sound signal attenuation at the given values of the gaps

The changes in the levels of the transmitted signal (an acoustic shadow zone) are shown in Fig.7. The presented histograms prove that, as in the first case, both attenuation and amplification of the transmitted signal take place. As a whole, we should speak about the dominance of a positive result (signal attenuation) (Fig.7,a,b,d) with individual resonance manifestations. Exception, as in the first case, is a variant with a gap of 0.75 mm (Fig.7,c), where the resonance phenomena occur half the time.

Conclusion

At this stage we can formulate the following conclusions:

1) as it is shown by the laboratory experiments, the use of acoustic screens based on Helmholtz resonators provides upon the whole a positive result – attenuation of the level of acoustic noise – and this effect is observed in the area situated both in front of the screen and behind it, in the area of acoustic shadow;

2) the presence of resonance phenomena requires a preliminary analysis of the spectral composition of the dominant acoustic noise in a particular area of the urban environment in order to "choose" the design parameters of the screen, providing at minimum the absence of the relevant resonance at significant range frequencies;

3) a further research should be directed to the combination of different gaps that can provide mutual compensation of possible resonance phenomena.

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