About the possibility of the use of dual–chamber acoustic screens-resonators to reduce noise

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Abstract

The paper is devoted to the actual problem – the fight against noise in urban areas. As a means of protection against noise the model of the acoustic screen-resonator is suggested. The screen-resonator consists of two chambers, one of which (the front) is a distributed Helmholtz resonator, and another (rear) forms a closed space used as a silencer. Authors consider the possibility of using such acoustic constructions to reduce noise levels in urban areas. The results of the experimental data are analyzed both in terms of a reflected sound signal, and the level of absorbed sound signal. The conclusions of the work are made.

Key words: noise pollution, dual-chamber screen- resonator, sound insulation, Helmholtz resonator, acoustic chamber.

О возможности применения двухсекционных акустических экранов-резонаторов для снижения шума

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Аннотация

Работа посвящена актуальной проблеме – борьбе с шумом на урбанизированных пространствах. В качестве средства защиты от шума рассмотрена модель акустического экрана-резонатора, состоящего из двух камер, одна из которых (передняя) представляет собой распределённый резонатор Гельмгольца, а другая (задняя) образует замкнутое пространство, которое используется как глушитель шума. Рассмотрен вопрос о возможности применения таких акустических конструкций для снижения уровней шума на урбанизированных пространствах. Проанализированы результаты полученных экспериментальных данных, как по уровню отраженного звукового сигнала, так и по уровню поглощенного звукового сигнала. Сделаны выводы о проделанной работе.

Ключевые слова: *шумовое загрязнение, двухсекционный акустический экран-резонатор, шумозащита, резонатор Гельмгольца, акустическая камера.*

Introduction

Urbanization is one of the most striking phenomena nowadays. Urbanized territories account for not more than 1% of the world land area but concentrate about 50% of the total

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world population, produce 80% of gross domestic product, but provide 80% of all emissions into the atmosphere and hydrosphere.

A by-product of any civilization is noise which is one of the most dangerous factors harmful to the environment and all living things, especially humans. In large cities, over 65% of the population complain of excessive noise. Noise and vibration significantly affect the central nervous system, noise pollution in urban areas is increasing over time.

Noise "symphony" of a city is composed of many factors: roar and rumble of railways and planes, roar of construction equipment, industrial noise and even noise of home appliances – in short, everything that surrounds a man. A special chord in this symphony is produced by the movement of vehicles, which provide up to 80% of noise. Noise level exceeds the allowable value by 25dBA even during the day time. This is especially noticeable on federal motorways passing through settlements (11,2% of the total length of federal motorways and 11,7 % of regional ones) [1,2].

Noise reduction in urban environment is a challenge with no easy solutions. It's obvious, that the first task is to reduce noise in the source (vehicles). It is generally accepted and there is relevant legislation, standards, recommendations, etc. Among the tasks of noise reduction that can be solved in a particular urban environment, are the use of so-called "low-noise" asphalt and protective constructions such as acoustic screens (AS).

The actual reduction of noise with the help of "low noise" asphalt does not provide a level higher than 3 dBA [2], which is why its usage can't change the situation radically, and the asphalt laying cost of works is rather high. The use of acoustic screens is more effective, however, it is estimated that they don't provide an effective noise reduction in the range of 3 to 15-22 dBA [2,3] either.

In addition, as it follows from [1], the proportion of noise protection screens in respect to the extent of settlements and accounts for 1,3% on federal motorways and 0,07% on regional ones, which also doesn't solve the problem in principle.

However, an AS is a promising noise protection remedy whereby, the actual task is to find methods and means to improve its effectiveness.

The aim of the article is to study the possibility of increasing the effectiveness of noise protection devices in solving the problem of acoustic noise level reduction in urban environments through the use of combined dual-chamber screens-resonators.

1. Noise protection screens based on Helmholtz resonator

The operation of an acoustic screen is based on several principles, among which the reflection and absorption of the incident sound wave are the most important. The effect of the protection is achieved in the area of a sound shadow (behind the acoustic screen) [4]. At the same time one of the major AS drawbacks is that when the reflector panels are installed, the strength of sound 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 poses an increased air vibration above a motorway. Furthermore, depending on the installation, angle noise can be reflected in the source direction, creating resonance phenomena, i.e. noise level increase in the area in front of the screen.

The reduction of this effect is provided with the help of sound-absorbing screens of different modifications. One of the possible ways of an AS design is to include Helmholtz acoustic resonators into the construction. The principle of operation of such a resonator is well described in a number of scientific works, such as [5,6], and others. Under certain design features, such a screen can provide noise level reduction in the area in front of the screen.

Estimation of the effectiveness of such an AS was given by the authors in [7,8]. The studies, conducted in the laboratory acoustic chamber, showed that a possible noise reduction before the screen in different conditions reaches 10-15 dBA. It is clear, that in a real urban environment it is difficult to ensure such noise reduction, but in the course of further work sufficient practical results can be obtained.

2. The design of an experimental dual-chamber acoustic screen-resonator

As a passive means of protection against noise a model of a dual-chamber acoustic screen made on the basis of Helmholtz resonator can be considered. The front of the acoustic screen is perforated with vertical slot gaps forming the neck cavity.

It is known, that the natural frequency (Hz) of the resonator in case of slotted gaps use is defined by the following formula [5,6]:

$$f = \frac{C}{2\pi}\sqrt{\frac{b}{L \cdot h \cdot l}}, \quad (1)$$

where f – the natural frequency of the resonator, Hz;
C – the velocity of a sound in the medium, m/s;
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 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. 1 shows the results of simulation of gap width dependence b on the frequency f and the depth h of the cavity when they are changed in the ranges: f=0.1...1000 Hz, h=1...100 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 (1) 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 [6]. On a standard frequency of 1000 Hz a quarter of the wave constitutes 75 mm. This satisfies the condition the constructed acoustic booth usage.

An experimental model of a two-chamber AS has a total size of 75 mm in depth and consists of front and rear cameras. The basis of the body is made of wooden bars, the front and rear walls as well as the internal partition are made of a steel sheet (Fig. 2).

The front chamber is a distributed Helmholtz resonator with the depth (h) of 40 mm.

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.

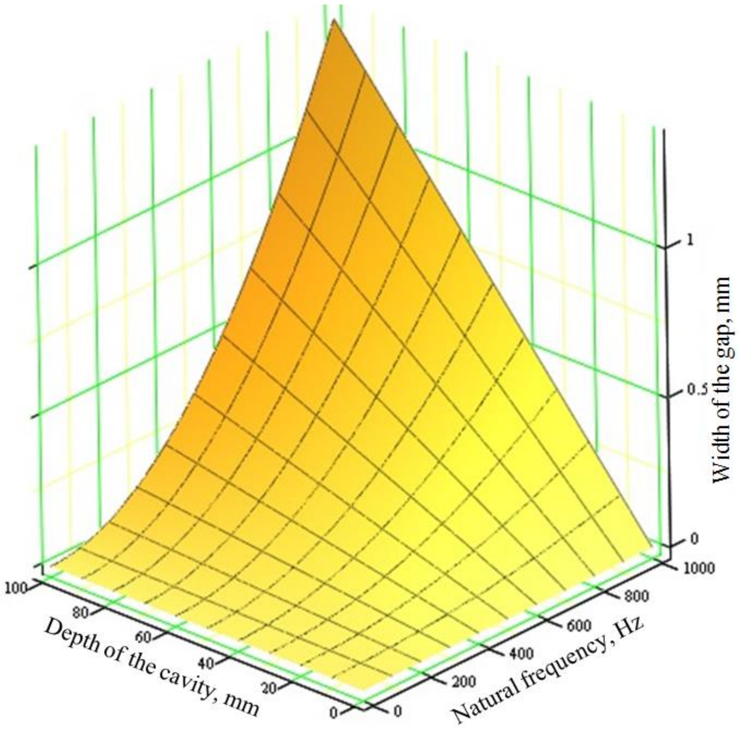


Fig.1. The relations between the width of the gap, the depth of the cavity and the natural frequency of the resonator

The rear part is a rectangular sealed chamber with a depth of 40 mm, and it can be expected to provide an additional function of a damper (silencer) for the resonant chamber.

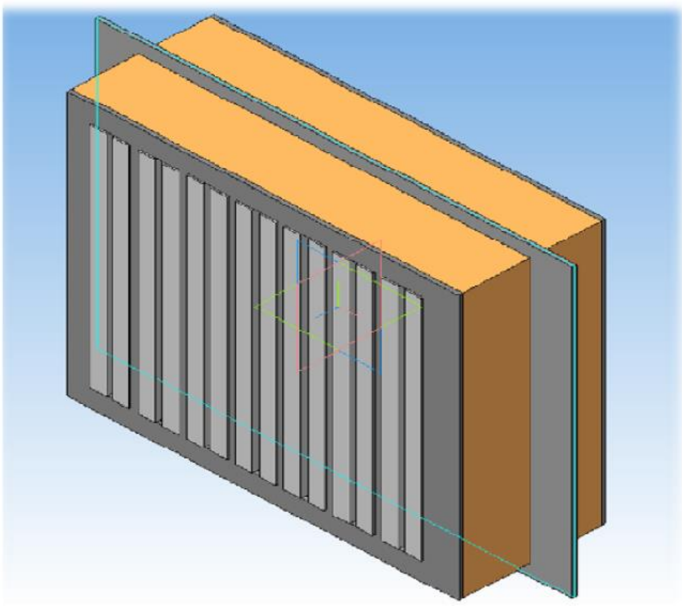


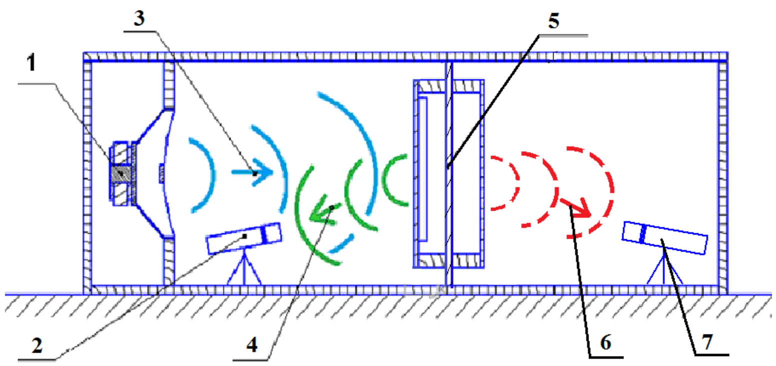
Fig.2. Dual-chamber AS model made on the basis of Helmholtz resonator

3. The methodology of experimental studies

The measurements were performed in a laboratory acoustic booth consisting of a desktop acoustic chamber, a low frequency oscillator and an ordinary sound level meter.

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.3). 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.

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. 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.



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 – dual-chamber AS-resonator; 6 – a transmitted sound wave; 7 – a sound level meter microphone in the control of the transmitted sound wave

Fig.3. The scheme of the experiment conducted

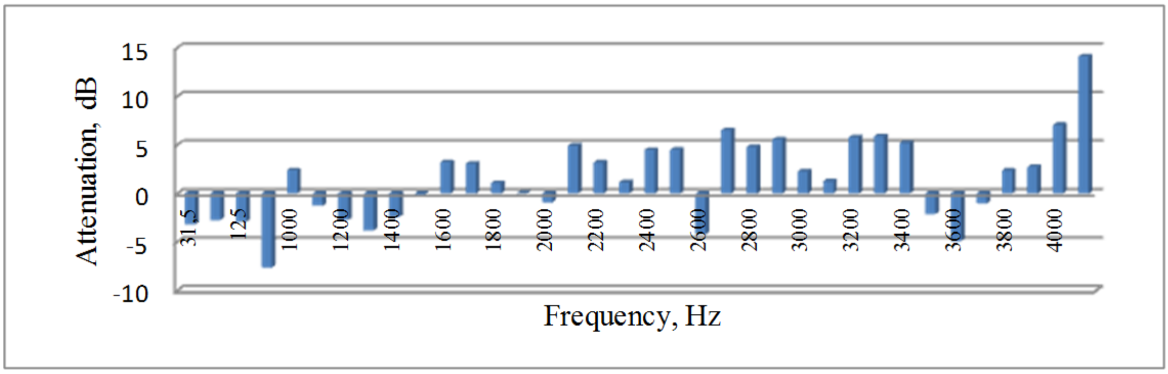
4. Practical measurements and conclusions

Estimates of changes in signal levels are shown in Fig.4 and 5.

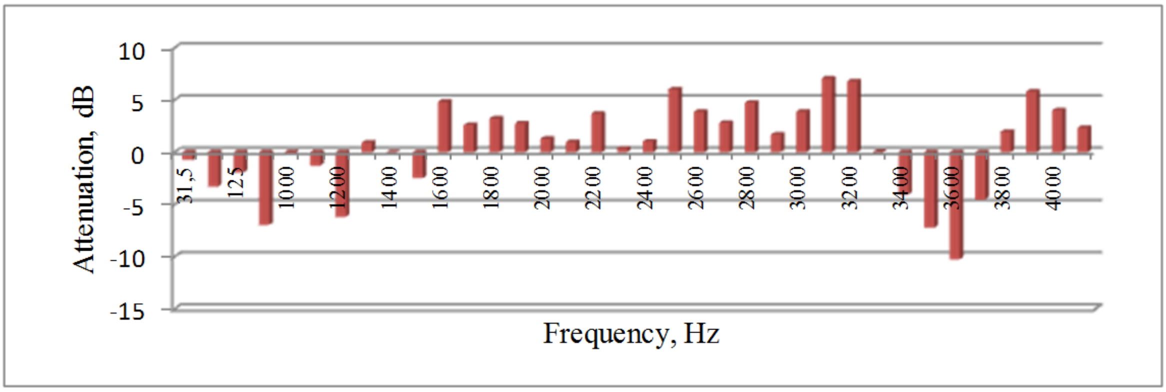
Fig.4 shows the changes in the levels of the signal reflected from the AS in the case of its direct location. In fact, we are talking about the noise level attenuation in the area immediately adjacent to the screen. Estimates are given for the four values of the gaps.

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.

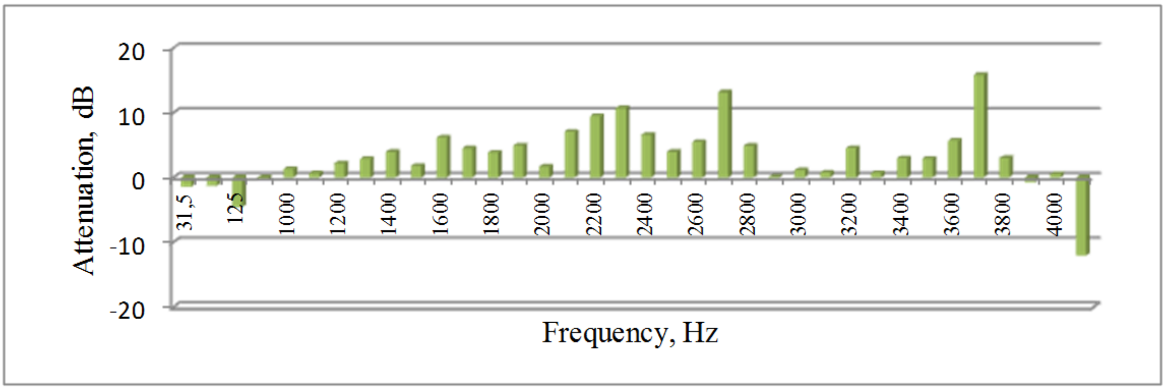
It can be seen from the histograms that in the case of existing design features of a particular model of the screen both attenuation and amplification of the reflected signal occur. Thus, when the gap size is 0.75 mm (Fig.4,c) we can generally speak about positive effects in terms of reducing the level of acoustic signals. There are some resonance phenomena at certain frequencies, including "splashes" to the level of 12 dB. When the gap size is 0.25 mm (Fig.4,a) and 1 mm (Fig.4,d) we can generally speak about positive effects in terms of reducing the level of acoustic signals. And the obvious dominance of resonance phenomena occurs when the value of the gap is 0.5 mm (Fig.4,c).



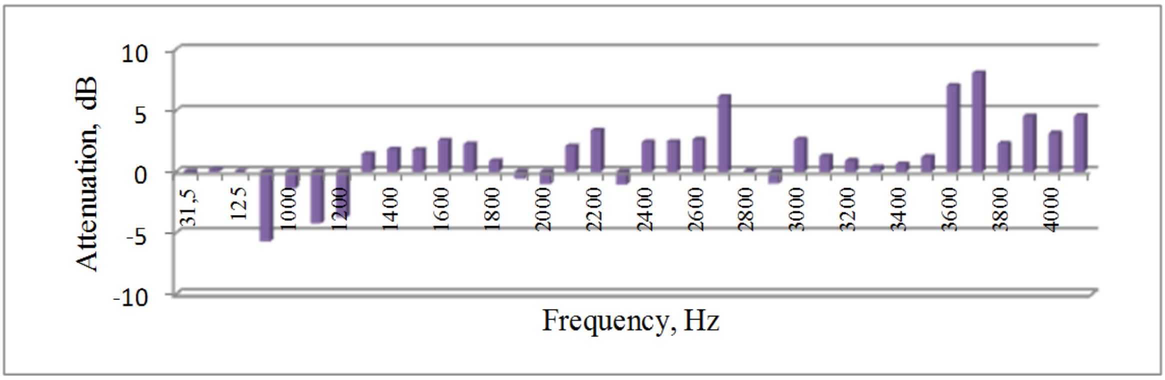
a)



b)



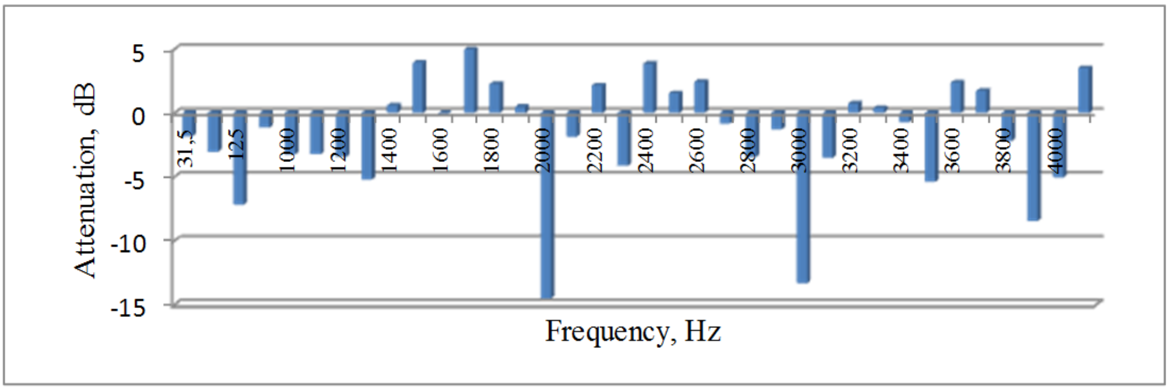
c)



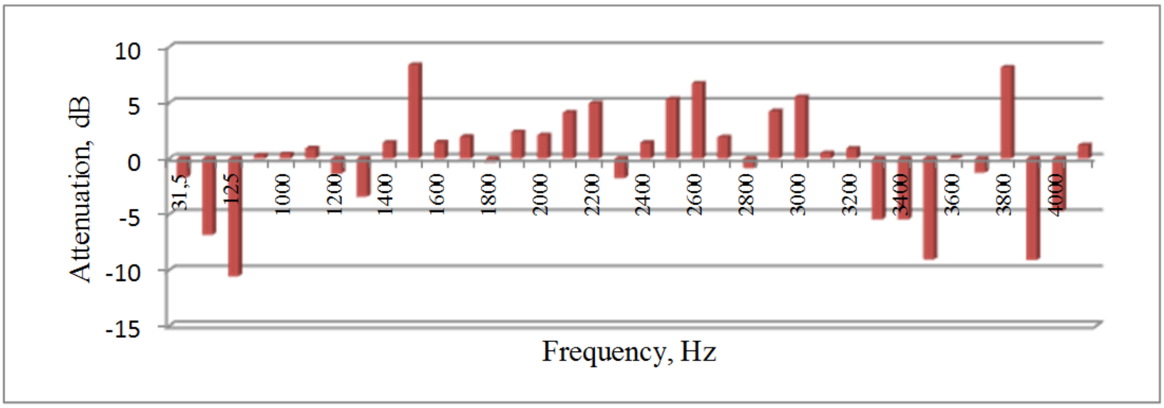
d)

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

Fig.4. Histograms of the reflected signal attenuation at the given size of the gaps



a)



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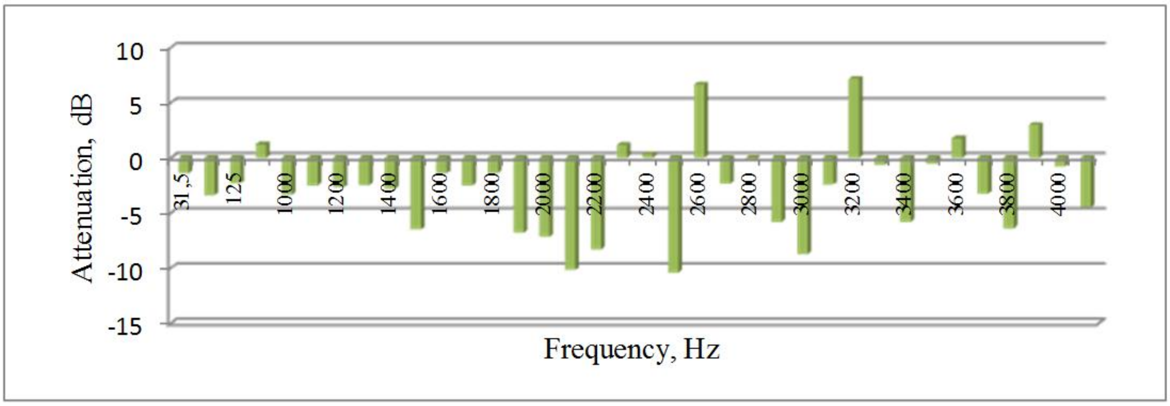
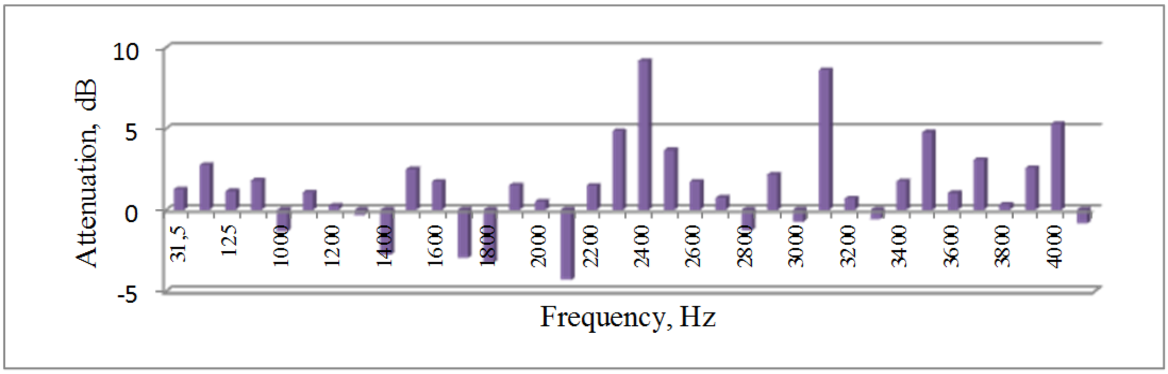


c)



d)

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

Fig.5. 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.5. The presented histograms prove that both attenuation and amplification of the transmitted signal take place.

Conclusion

At this stage we can formulate the following conclusions:

1) laboratory experiments show that the use of dual-chamber acoustic screens made on the basis of a combination of Helmholtz resonators and closed chambers, as a whole provides a positive result – the reduction of acoustic level noise, while in the area of acoustic shadow this effect is less pronounced;

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) preliminary we can talk about the positive effect provided by a dual-chamber construction in comparison with the same single-chamber in reducing noise level in the area before the screen, suggesting the effectiveness of the damping function (silencing) provided with the help of this camera;

4) in terms of assessing the impact of a closed chamber as an additional damper (silencer) to reduce the level of the signal passing through the screen in the shadow zone, there is no basis for the conclusions of the receipt of clearly positive result and, therefore, the issue requires further study;

5) further studies should be directed towards a more detailed investigation of the relationships of various combinations of values of clearances and depths of the cavity and a closed chamber in terms of finding the optimal combinations thereof, which can provide a real noise reduction in the area in front of the AS and in the acoustic shadow zone.

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References

1. Государственный доклад «О состоянии и об охране окружающей среды Российской Федерации в 2011 году» / Министерство природных ресурсов и экологии Российской Федерации. –Режим доступа: - http://www.mnr.gov.ru/regulatory/detail.php?ID=130175. [State report "On the Condition and the Environmental Protection of the Russian Federation in 2011" / The Ministry of Natural Resources and Ecology of the Russian Federation. -Access mode: - http://www.mnr.gov.ru/regulatory/detail.php?ID=130175.].

2. Иванов Н.И. Концепция снижения шума в РФ / Защита от повышенного шума и вибрации: Сборник докладов Всероссийской научно-практической конференции с международным участием, 18-20 марта 2015 г., СПб // Под ред. Н.И. Иванова. –СПб.: 2015. -С.14-26. [Ivanov N.I. The concept of reducing noise in the RF / Protection from increased noise and vibration: Proceedings of the All-Russian scientific-practical conference with international participation, 18-20 March 2015, St. Petersburg // Ed. N.I. Ivanov. SPb.: 2015. -P.14-26.].

3. Иванов Н.И. Инженерная акустика. Теория и практика борьбы с шумом: учебник /Н.И. Иванов. -3-е изд., перераб. и доп. – М.: Логос, 2015.- 432с. [Ivanov N.I. Engineering acoustics. Theory and practice of noise control: the textbook / N.I. Ivanov. -3d-ed., Rev. and add. -M.: Logos, 2015. -432 p.].

4. Шубин И.Л. Акустический расчёт и проектирование конструкций шумозащитных экранов: автореферат дис. … д-ра тех. наук. –М.: 2011. [Shubin I.L. Acoustic calculation and design of noise protection screen structures: abstract dis. ... doc. of technical sciences. -M.: 2011.].

5. Акустика: Справочник / А.П. Ефимов, А.В. Никонов, М.А. Сапожков, В.И. Шоров; Под ред. М.А. Сапожкова. — 2-е изд., перераб. и доп. — М.: Радио и связь, 1989. — 336 с. [Acoustics: Directory / A.P. Efimov, A.V. Nikonov, M.A. Sapozhkov, V.I. Shorov; Ed. M.A. Sapozhkov. - 2nd ed., Rev. and add. -M.: Radio and Communications, 1989. -336 p.].

6. Булкин В.В., Беляев В.Е., Сергеев В.Н. Конструкторские расчёты элементов РЭС в условиях механических и акустических воздействий. – Муром: Изд.-полиграфический центр МИ ВлГУ, 2004. – 131 с. [Bulkin V.V., Belyaev V.E., Sergeev V.N. Design elements calculations under mechanical and acoustic effects. -Murom: Printing center MI Vladimir State University, 2004. -131p.].

7. Калиниченко М.В., Кириллов И.Н., Булкин В.В. Анализ возможности применения звукоотражающих экранов на основе резонаторов Гельмгольца // Защита от повышенного шума и вибрации: Сборник докладов Всероссийской научно-практической конференции с международным участием, 18-20 марта 2015 г., СПб. / Под ред. Н.И. Иванова. –СПб.: 2015. -С.280-282. [Kalinichenko M.V., Kirillov I.N., Bulkin V.V. Analysis of the possibility of applying sound reflecting screens based on the basis of Helmholtz resonators // Protection from increased noise and vibration: Proceedings of the All-

Russian scientific-practical conference with international participation, 18-20 March 2015, St. Petersburg. / Ed. N.I. Ivanov. -SPb.: 2015. -P.280-282.].

8. Булкин В.В., Калиниченко М.В., Штыков Е.А., Фильков Д.Е. К вопросу об использовании шумопоглощающих средств на техногенных пространствах / Вестник Тамбовского государственного университета, т.19, вып.5, 2014. –С.1388-1392. [Bulkin V.V., Kalinichenko M.V., Shtykov E.A., Filkov D.E. To a question about the use of sound-absorbing means in technological spaces / Bulletin of Tambov State University, v.19, issue 5, 2014. -P.1388-1392.].