Experimental Study of the Cells Interaction on Linear and Nonlinear Operating Modes

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Abstract. In this article, the results of SAS samples laboratory research on an interferometer with a normal sound wave incidence at sound pressure levels of 100 and 130 dB are presented. The mutual influence of prismatic resonators was revealed, which leads to a decrease in the resonators group acoustic efficiency.

1. Introduction
At present, the ecology of air transport has become the second most urgent problem highlighted by the International Civil Aviation Organization (ICAO), giving way only to flight safety. The dominant component of the aviation harmful effects on the environment is the noise created by aircraft. The most promising way to reduce the aircraft engine noise is to use resonant sound-absorbing structures (SAS) [1]. SASs are a combination of Helmholtz cells made in the form of a polymer composite honeycomb structure.

Prediction of the Helmholtz resonators acoustic characteristics and increasing the efficiency of broadband noise reduction is the subject of research conducted by many national and foreign authors. Of particular interest are the studies of resonator groups’ interaction and their joint work. For example, in [2], the interaction of 2 or more cylindrical cells was studied. In [3], a numerical study of the closely spaced cylindrical cells interaction was carried out. The optimal distances between the cells, as well as the geometric characteristics of the neck, were identified. In studies [4, 5] A. Selamet and others found the influence of plane and non-planar wave propagation on the resonant frequency and wave attenuation in Helmholtz spherical cells while changing cell sizes. The study of the closely located resonators acoustic efficiency was the subject of research by many authors. In [2, 6], an experimental study was made of the mutual influence of closely located cells. It was revealed that when the distance between the cells necks is less than 0.25 of the wavelength, the efficiency of the pair of resonators is less than that of a single one.

At the same time, in order to choose a more effective SAS design, there is a need to study the properties of a single cell and the cells joint work, including in non-linear modes.

This paper reports on the results of laboratory research of prismatic SAS samples on an interferometer with a normal sound wave incidence at sound pressure levels of 100 and 130 dB are presented.

2. Experimental determination of SAS samples acoustic characteristics
To conduct the research, a geometric model of samples containing prismatic cells (resonators) was developed. The geometric characteristics of the cells were taken as follows: resonator height 10 mm, hexagon side length 8 mm. The diameter of the neck and the height of the resonator neck are 2 and 1
mm, respectively. In addition, a sample was developed containing a pair of resonators close to each other. Geometric models are presented in Figure 1. Based on the developed geometric models, reference samples were made using additive manufacturing technology. The manufacturing process is described in detail in [7].

![Geometric models](image)

**Figure 1.** Samples geometric models: a - A1 model, b - A2 model

Acoustic tests in an interferometer with normal incidence of sound waves are widespread due to the relative simplicity of the experiment. The experimental setup is a tube of circular cross-section, on one end of which there is a SAS sample, on the other - a speaker that irradiates the sample with acoustic waves (Figure 2). Also, microphones which record the acoustic pressure of the incident and reflected waves in time are installed at a certain distance from the SAS sample in the channel of the interferometer flush with the wall (Figure 3). After that, the obtained pressure is processed by the fast Fourier transform algorithm, as a result of which the impedance of the SAS sample is calculated.

The impedance relates pressure and normal velocity at the boundary, the acoustic properties of which it characterizes. In most works, the influence of high sound pressure levels of the incident wave is described through the velocity of particles of the medium in the hole [8-12]. Most semiempirical models are based on the works of Crandall and Melling. In the Crandall’s work [12], an expression was given for the impedance of a round hole, and in the Melling’s work [13], the effect of high sound pressure levels, which leads to the SAS nonlinear behavior, was studied.

According to the definition, the dimensionless specific acoustic impedance is expressed as the ratio

\[
Z = X + iY = \frac{p}{\rho cu_n},
\]  

where \(p\) is the acoustic pressure; \(\rho\) is the air density; \(c\) is the speed of sound in air; \(u_n\) is the acoustic velocity.

Despite the apparent simplicity of expression (1), determining the impedance of a sound-absorbing structure in practice is a difficult task. Today, preference is given to the experimental determination of the impedance of one or another SAS sample.

Two microphones are used for the measurements, since the “transfer function method” used to determine the impedance is the easiest to calculate. At the same time, this option can be implemented if there is only a piston mode in the channel, which leads to a dependence of the installation frequency range on the channel dimensions of the impedance pipe.

![Interferometer](image)

**Figure 2.** Interferometer set and ready-to-use

**Interferometer Specifications:**
- sound pressure up to 160 dB;
- frequency range 500-6400 Hz;
- size of test sample 30 mm.
1 - speaker;
2 - washer fixing the sample;
3 - SAS sample;
4 - stock;
5 - directing plug.

**Figure 3.** The interferometer internal channel

In the course of experimental studies, the dependences of the sound absorption coefficient on frequency were obtained (Figure 4, 5). Figures 6, 7 show the dependences of the complex resistance (impedance) on frequency.

**Figure 4.** Graph of sound absorption coefficient versus frequency for a single resonator

**Figure 5.** Graph of sound absorption coefficient versus frequency for a pair of resonators
Figure 6. The real (a) and imaginary (b) parts of the single resonator sample impedance.

Figure 7. The real (a) and imaginary (b) parts of the pair of resonators sample impedance.

The analysis of the obtained dependences revealed that with an increase in the sound pressure level from 100 dB to 130 dB for A1 model, the sound absorption coefficient decreases by 26.8%.

The mutual influence of the cells during their joint operation was confirmed. When the model A2 resonators work together at a sound pressure level of 100 dB, the sound absorption coefficient decreases by 11.6%. And at a sound pressure level of 130 dB there is an increase in the sound absorption coefficient by 4.4% when compared with a single resonator. This indicates a decrease in the effect of the mutual influence of the cells in non-linear operating modes.

3. Conclusion

Experimental researches of the prismatic resonators acoustic efficiency during their joint work was carried out. It should be noted that, the mutual influence of prismatic resonators was revealed, which leads to a decrease in the group acoustic efficiency. When the A2 model resonators worked together at a sound pressure level of 100 dB, the sound absorption coefficient decreased by 11.6%. And at a sound pressure level of 130 dB there was an increase in the sound absorption coefficient by 4.4% when
compared with a single resonator. The hypothesis of a decrease in the acoustic efficiency of a group of same volume prismatic cells during joint operation was confirmed.

Acknowledgments
The research was carried out at the Perm National Research Polytechnic University with the support of the Russian Science Foundation (project No. 18-79-00295).

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