THE DEVELOPMENT AND EXPERIMENTAL STUDY OF THE SOUND ABSORBERS MADE OF ACOUSTIC METAMATERIALS

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This paper describes the development of efficient sound absorbers based on acoustic metamaterials (AMM). The samples in the form of cellular thin-walled periodic structures are synthesized by photopolymer material using the additive technology. Optimal parameters of the synthesizing process are found to provide the required shape of the samples. The results of experimental study of sound absorption efficiency of the synthesized AMM-samples are presented that demonstrate rather high sound absorption efficiency in certain frequency range.
Keywords: sound absorption, acoustic metamaterials, 3-D printing

1. Introduction

In recent years, much attention in acoustic scientific field is paid to enhancement of the sound absorption efficiency using new materials with unique sound properties so-called acoustic metamaterials (AMM). Several new design concepts are developed (suggested) such as black holes, acoustic diodes and others. One of these concepts that the present authors use and consider it the most practically profitable, is the concept of the “the best absorber” [1,2]. By definition, the best absorber is the body that among all possible visco-elastic bodies of the same configuration absorbs maximum energy of incident fields. As follows from the theory, the best absorber should have some special physical properties that differs it from other absorber types. One of its properties – the extended reaction to the external excitation – has been experimentally studied in the paper [3], see also [4]. On the specially designed cell-structured AMM absorber it was shown that coupling between the cells can noticeably increase absorption efficiency (up to factor 2).

In the present paper, authors examine another property of the best absorber that follows from the theory, which may be even more practically important than extended reaction. This property reads that the best absorber must be of the resonant type and its input resistance (real part of impedance) must be equal to its radiation resistance at the resonance frequency. It is here examined experimentally using impedance tubes on several AMM samples made of Helmholtz resonators and of quarter wavelength resonators of labyrinthine type. Since in an impedance tube only plane wave are excited, the radiation resistance of an absorber is always equal to ρc and the goal of the experiment was to show that maximum absorption takes place at resonance frequencies only when the resistance of the absorber is equal ρc=410 Rayl. The results of the study are presented below.

2. Experiment with Helmholtz resonator type absorber

As a first step of experimental study, a very simple sample of resonant type as Helmholtz resonator was used in the form of cubic with two holes and then an AMM sample with labyrinth type internal structure was explored, which was fabricated by 3D-printing technology.

2.1 Experimental setup

This experiment has been carried out on the impedance tube shown on Fig. 1a. It is a two microphone random excitation tube of diameter 35 mm (Spectronics) with working frequency range 150-2900 Hz. By measuring random pressure signals from two microphones one can obtain, after processing, complex reflection coefficient, complex input acoustic impedance of the sample and its absorption coefficient α. Our interest was in obtaining this coefficient and the input resistance *R* (real part of the input impedance).

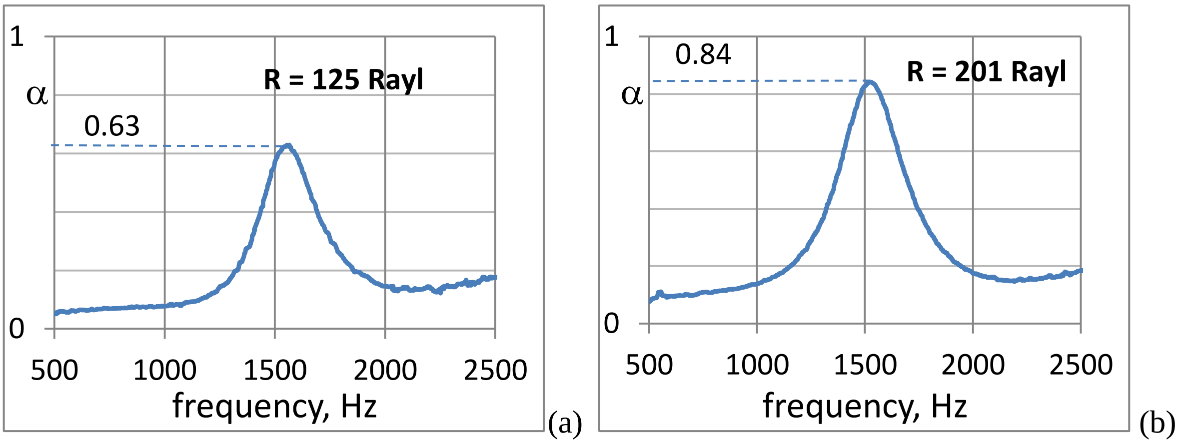
a) б)

Figure 1: The impedance tube (a) and the sample in the form of Helmholtz resonator (b).

The instrument was loaded with the sample of a hollow thin-walled cubic form with two holes (Fig. 1b); the natural frequency is about 1500 Hz. As this sample is not uniform across the tube cross-section, the instrument provided so-called effective resistance of the sample. This resistance was varied in the experiment by placing into the sample a certain amount of fine wool.

2.2 Measurement results

On Fig. 2 shown are several experimental curves of the absorption coefficient with different input resistances where Fig.2a corresponds to "empty" Helmholtz resonator without additional damping material (wool). It resistances is equal *R*=125 Rayl what is less than *ρc*=410 Rayl. Consequently, absorption coefficient is less than unity, α=0.63. Increase of the sample resistance by adding wool increases α (Fig. 2b) until it reaches the absolute maximum α=1 when *R*=408 Rayl (Fig. 2c).



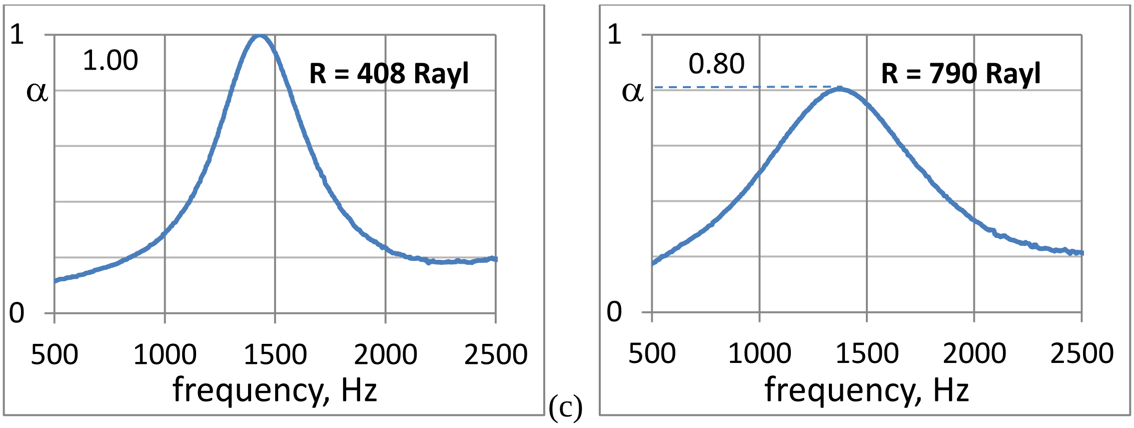


Figure 2: Frequency dependences of the sound absorption coefficient of the sample with various amount of damping.

Further increase of the resistance R decrease absorption coefficient (Fig. 2d). The measured results are summarized in Fig. 3. As can be seen, the maximum value of absorption coefficient corresponds to equality $R= \rho c$ as the theory predicted. Any deviation from that value decreases absorption efficiency.

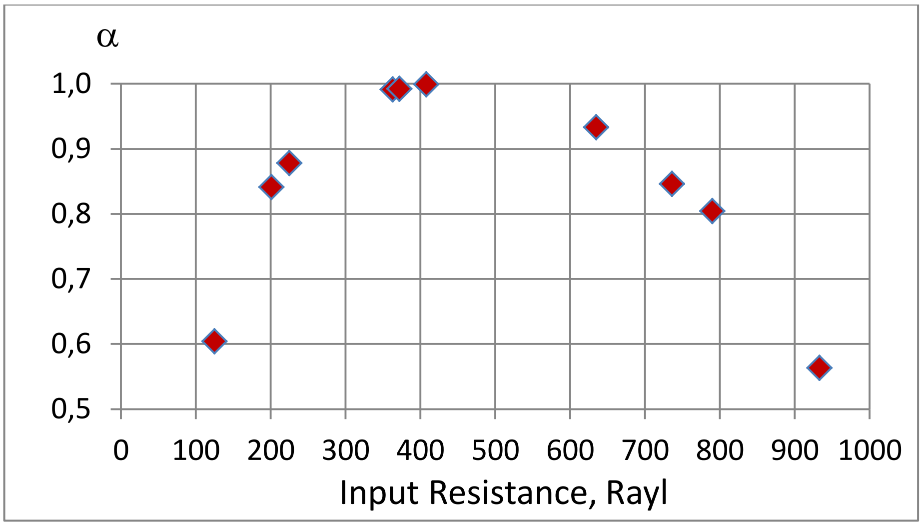
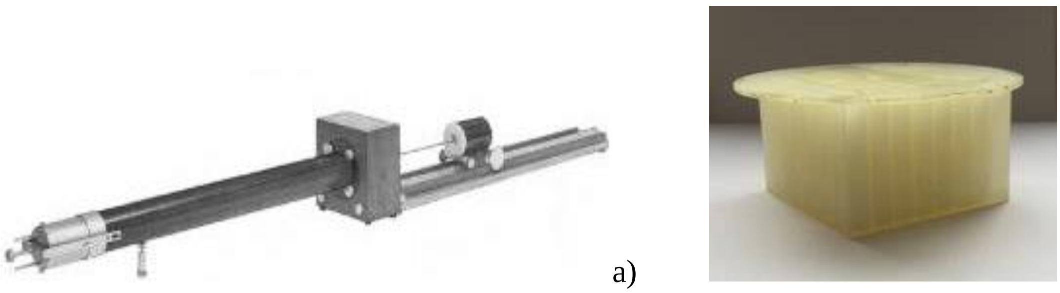


Figure 3: Dependence of the sound absorption coefficient on the sample input resistance.

3. Experiment with a labyrinthine AMM-sample

Similar experiment has been carried out with AMM type absorber sample of the resonant type, made of several quarter wavelength resonators coiled-up into rather complicated labyrinthine structure, Fig. 4b.



b)

Figure 4: Experimental setup: the instrument (a) and 3-D printed AMM sample (b).

As dimensions of the sample was several time larger than those of the first sample the measurements were conducted on another impedance tube. It is the well-known Kundt's tube, Fig. 4a, or standing wave tube of diameter 99 mm with one movable microphone (B&K 4002).

One typical result of the measurements is given in Fig. 5a, which presents the absorption coefficient as a function of frequency, while Fig. 5b shows the corresponding values of the sample input resonance. One can see that relation between these two quantities is just the same as for the first sample (Fig. 2, 3).

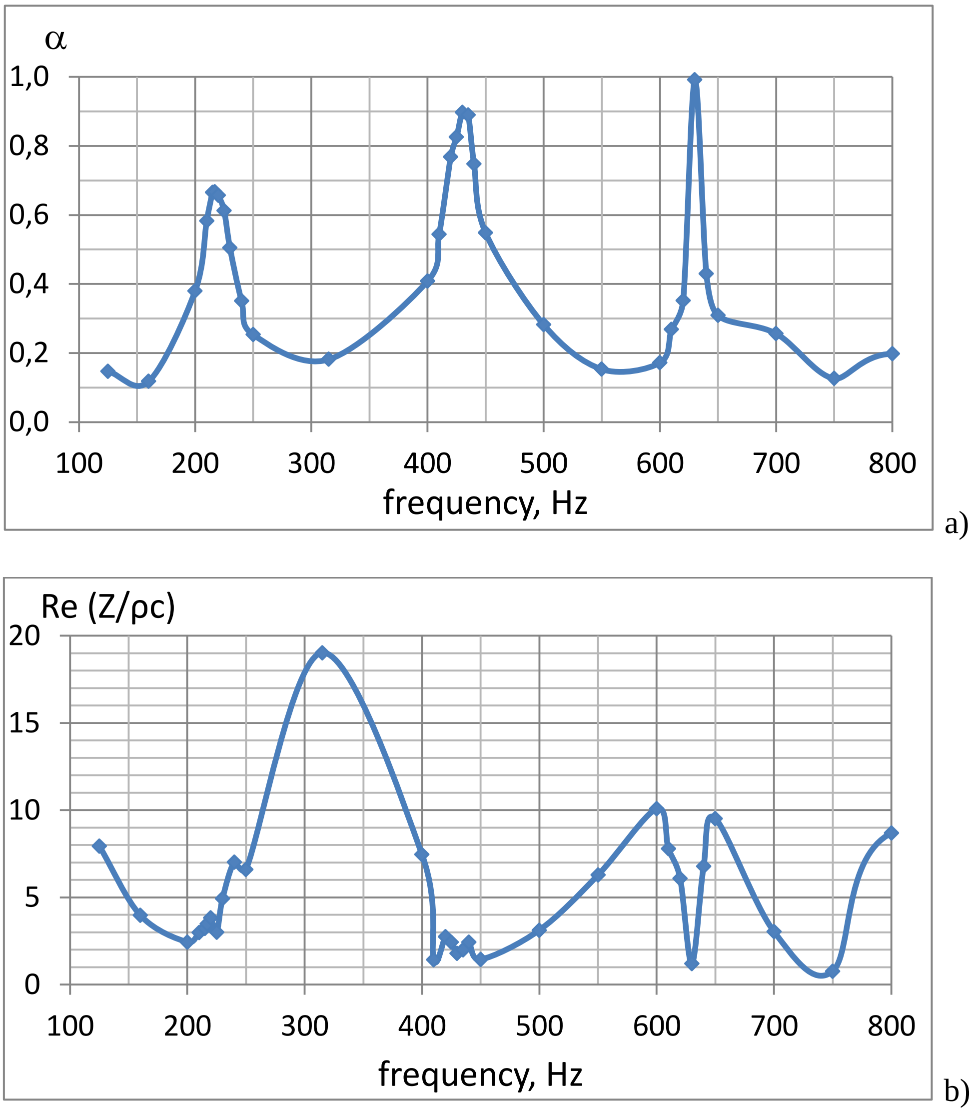


Figure 5: Frequency dependences of absorption coefficient values (a) and input resistance (b).

4. Summary

The theoretical result that the input resistance of the best sound absorber should be equal to its radiation resistance has been verified experimentally. It is shown that the efficiency of any sound absorber of the resonant type reaches its absolute maximum only when resistance equality takes place.

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