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ACOUSTIC IMPEDANCE VARIATIONS OF HELMHOLTZ RESONATORS OF TWO PLATES WITH ORIFICES INLET NECK AGAINST THE DISTANCE BETWEEN THE PLATES

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Experimental examinations of acoustic impedance of complex Helmholtz resonators of two plates with orifices inlet neck using Kundt tube procedure were performed. Few variants of model resonators were studied depending on the number of orifices (and their diameters) in the plates and against variations of the distance between the plates for a constant volume of the resonator cavity.

A regular dependence of the acoustical impedance as well as the absorption coefficient against the distance between the inlet cover plates was observed for a given configuration of the orifices. Changes of the configuration (number of orifices their size and plane distribution in both plates and the relation between the lower and the upper one design) caused evident variations in acoustical properties, however no regular dependence could be found. Some configurations are more optimal than the others.

1. Introduction

Helmholtz resonators of modified geometry of their inlet neck of adequate acoustical absorbing properties have been used as elements for constructing noise absorbing panels covering a wider effective band in low frequencies range (100–350 Hz) required for applications in plant – food processing and pharmaceutical industry and studied since few years [1–4]. Some results of measurements of absorption coefficient variations of such elements i.e. Helmholtz resonators by modification of their geometrical parameters were published in [5]. The present paper is a prolongation of experiments described in [5] and the variations of acoustic impedance caused by geometrical modification of double layer inlet cover resonators are presented.

Our studies ([5] and the present paper) have been stimulated by papers of R. T. RADENBERG [6] and H. V. FUCHS [7] who considered acoustical properties of panel double layer cover resonators with elongated lateral orifices. Radenberg has shown that the most important influence on acoustic properties of such complex resonators had the distance between the layers though also distances among orifices, their diameters and cover layer thickness varied the properties. It has been observed [5, 6] an optimal distance between the layers for obtaining maximal absorption coefficient.

In this study we have mainly concentrated ourselves in examination of few model Helmholtz resonators in few variants of configuration looking for dependence on the distance between two cover layers (plates with orifices) on the acoustic impedance of the resonator. A special way to control the very short distance between two plates and to keep their collateralism was invented by the first author of the paper. An expecting effect of such double plate construction of the resonator inlet cover is the lateral elongation of the neck by the narrow space between plates and increasing of viscous losses by the friction appearing during acoustical particles movements between the plates.

2. Measurements procedure

For determination of acoustic impedance of model resonators the standard Kundt impedance tube [8] was used. The resonator was mounted in Bruel & Kjaer standing wave apparatus [9] in such a way (Fig. 1) that the resonator cavity V has presented the ending part of the tube and two cover plates with orifices formed its inlet elongated neck. The diameter of the resonator was the diameter of the insert ending of the tube where usually material samples are situated.

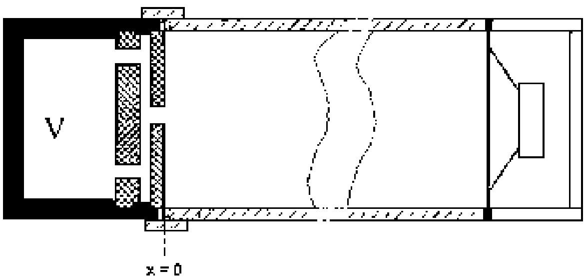

Fig. 1. A resonator of two plates neck mounted in the impedance tube.

The measured quantity was the acoustic impedance at the reference plane (Fig. 1) $x = 0$, what for standing wave condition in the tube is expressed by

$$Z = \frac{p(0)}{v(0)} = \frac{p_+ + p_-}{p_+ - p_-} Z_0 = \frac{1+r}{1-r} Z_0, \tag{1}$$

where $p(0)$ and $v(0)$ are complex values of acoustic pressure and acoustic particle velocity at the reference (inlet) plane, at $x = 0$, respectively, p_+, p_- are complex amplitudes of acoustic pressure of incident $(+)$ and reflected $(-)$ wave, respectively, Z_0 is specific acoustic impedance of the air and $Z_0 = \rho_0 c$, where ρ_0 is density and c sound velocity in air, $r = p_-/p_+$ is the reflection coefficient.

From (1) we get the normalised acoustic impedance

$$z = \frac{Z}{Z_0} = z' + j\, z'', \tag{2}$$

where z' and z'' are real and imaginary parts of z given by

$$z' = \frac{1 - r'^2 - r''^2}{(1 - r')^2 + r''^2} \qquad \text{and} \qquad z'' = \frac{2r''}{(1 - r')^2 + r''^2}\,, \tag{3}$$

where r' and r'' are the real and imaginary parts of the reflection coefficient $r = r' + j\, r''$ and $r' = |r| \cos\phi$, $r'' = |r| \sin\phi$, where ϕ is the phase shift between p_+ and p_-; $\phi = 0$ for ideal reflection.

For the Kundt impedance tube measurements procedure [8, 9] ϕ is determined by the formula

$$\phi = \pi \left\{ \frac{4x_{\min.1}}{\lambda_0} - 1 \right\}, \tag{4}$$

where $x_{\min.1}$ is the distance of the first minimum of acoustic pressure from a sample reference plane (i.e. resonator inlet plane), λ_0 – wavelength of the acoustic wave in the air.

Having $|r|$ and ϕ from an experiment one can calculate z' and z'' from (3). It is also possible to use the Smith diagram [9] for determination of the components of acoustic impedance. Simultaneously with the impedance the absorption coefficient could be determined [1] and results for that are also presented bellow in parallel with those for acoustic impedance.

3. Objects examined

The neck of the resonator was formed by two round plates of 0.1 m of diameter (equal to the cross-section of the measuring tube) with orifices of the diameter R (Fig. 2a) of a given thickness l_1 and l_2, respectively, in parallel one to the other. A special way to keep the collateralism of the plates i.e. to keep constant and to change precisely very narrow separation distance between them was elaborated (by the first author). It led in making the 0.001 m gap around the lower plate circumference in which distancing rings were situated of adequate thickness such that the resulting distance between plates was the difference between the ring thickness and the depth of the gap. In this way the solid rings could not be so thin as in the usual case when very thin foils for distancing rings were used.

Figure 2a shows an example of configuration of the double cover of the resonator. In the experiment 5 variants of similar configuration (Fig. 2b) were used with different number of orifices according to the following code: A 1-2, B 1-3, C 2-2, D 2-3, E 3-3, where the first digit represents the number of orifices in the lower plate and the second digit in the upper one, respectively. The diameter R of all orifices was the same and equal $1 \cdot 10^{-2}$ m.

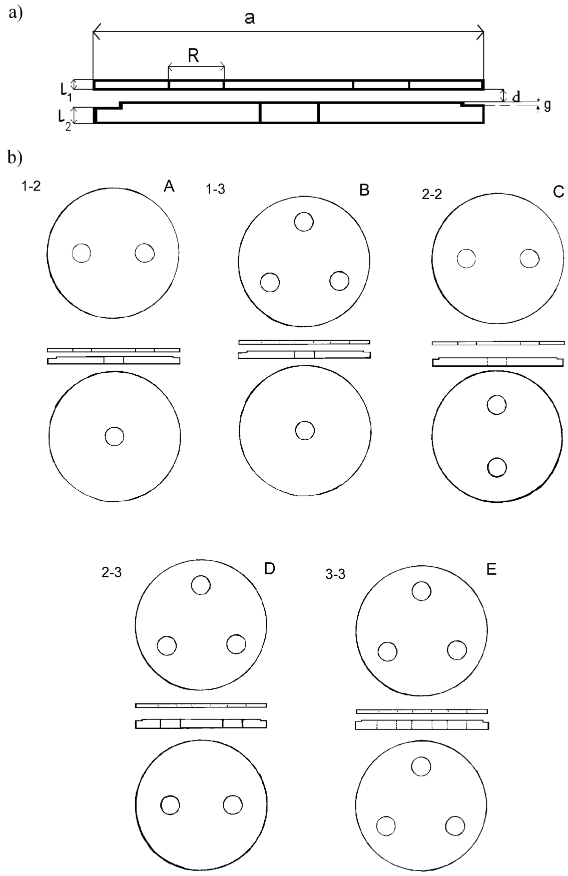

Fig. 2. A configuration of the double cover of the resonator (a) and 5 variants of configurations used in experiments (b).

4. Results

In the following Figs. 3–4 as examples the results for variants of configurations B and D are presented. In Figs. 3a, 3c and 3e, respectively, the dependencies of real $\mathrm{Re}(z)$ and imaginary $\mathrm{Im}(z)$ part and modulus $|z|$ of acoustic impedance and α (Fig. 3g) against the frequency are presented; every point is an average of 10 measurements and the standard error is marked. On the frequency axis the values correspond to the experimental ones being adjusted for given measurements in the standing wave impedance tube apparatus [9]. Six dependencies for different values of $d = 0.0001$; 0.0002; 0.0003; 0.0004; 0.0005 and 0.0006 m were obtained.

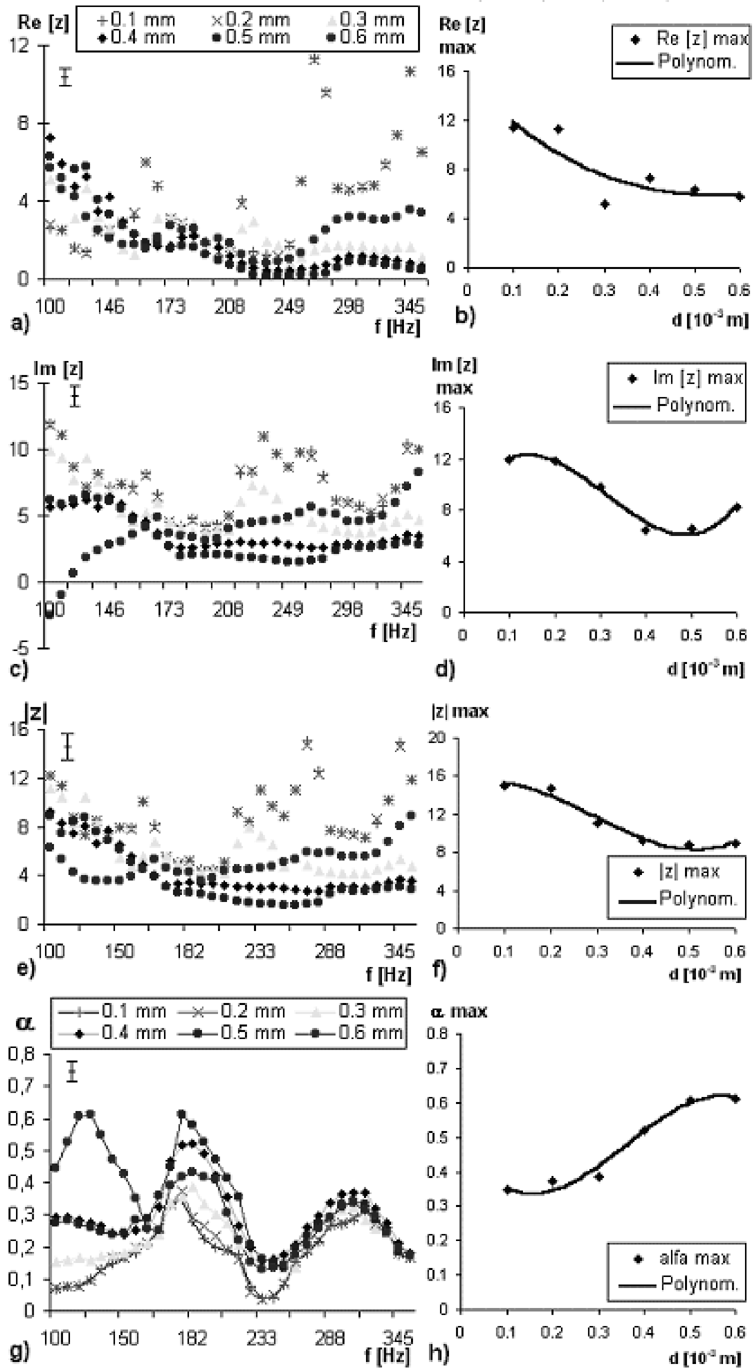

Fig. 3. Dependencies of real Re(z) (a, b) and imaginary Im(z) (c, d) parts as well as modulus $|z|$ (e, f) of acoustic impedance and α (g, h) against frequency (a, c, e, g) and of their maximum values against distance d (b, d, f, h) for configuration B 1–3.

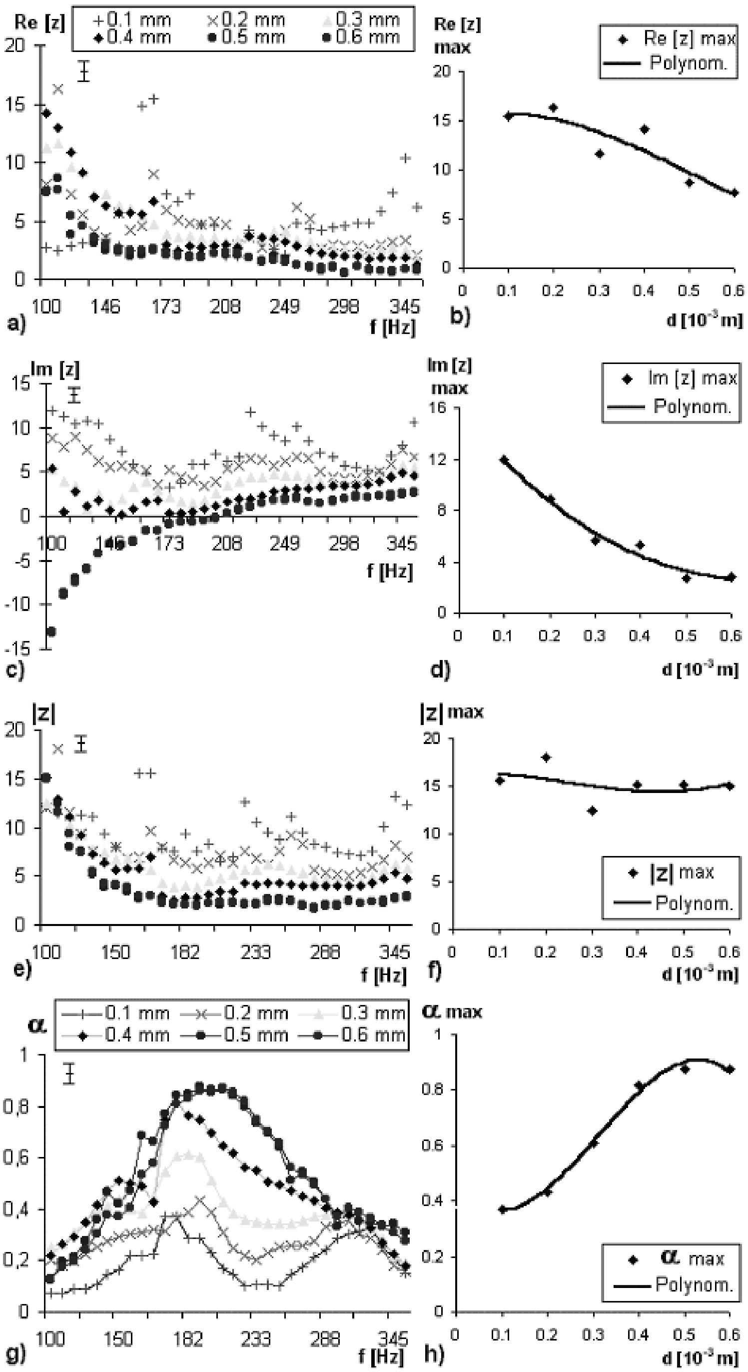

Fig. 4. Dependencies of real Re(z) (a, b) and imaginary Im(z) (c, d) parts as well as modulus $|z|$ (e, f) of acoustic impedance and α (g, h) against frequency (a, c, e, g) and of their maximum values against distance d (b, d, f, h) for configuration D 2–3.

The two maxima of impedance are observed for about 170 and 250 Hz and their values depend on the distance d. That dependence of the maximal values against the distance d is shown in Figs. 3b, 3d, 3f and 3h, respectively. One can notice a decrease of both $\mathrm{Re}(z)_{\max}$ and $\mathrm{Im}(z)_{\max}$ as well as the modulus $|z|$ values with increasing the distance d to obtain a saturation for $d = 0.0005$ m and next increasing for larger d. For a comparison the results for acoustic absorption coefficient are shown in Figs. 3g and 3h as frequency and distance d dependencies, respectively. The two maxima of absorption coefficient on frequency dependencies correspond to the maxima of the $\mathrm{Im}(z)$ and they are a bit shifted to lower frequencies with increasing the distance d.

Similar example of results for the configuration D are presented in Fig. 4. The consecutive Figs. 4a–4h correspond to analogical dependencies as in Fig. 3, only the effective length of the elongated neck of the resonator is different. This length has been changed for a given configuration. Again one can see the two maxima on the dependencies of $\mathrm{Im}(z)$ (Fig. 4c) and of α (Fig. 4g), now for frequencies about 200 Hz and 320 Hz, however only for smaller distances $d = 0.0001$; 0.0002; 0.0003 m. However for larger distances $d = 0.0004$; 0.0005; 0.0006 m only one maximum of about 200 Hz is dominated and broadened for wider frequency range from 150–300 Hz. One can also notice the saturation effect and a tendency of appearing maximum maximorum for $\alpha_{\max}$ (Fig. 4h) for larger distances $d = 0.0005$ and 0.0006 m.

5. Discussion and conclusions

Our examinations have shown that for very small distant $d = 0.0001$ m the resonators studied presented acoustical objects of high acoustic impedance and small absorption. One can say that for very small d a movement of acoustical particles in the resonator neck between plates became blocked and that caused the large impedance and small absorption of the resonators. With increasing the distance d between the inlet plates the impedance decreased and absorption increased to obtain a saturation (or maximum of absorption properties); for those conditions acoustic particles during their movements between plates met the greatest friction and in consequence the largest absorption and smallest impedance appeared. For larger distances d one observed again increase of impedance and decrease of absorption coefficient. So, evidently there exist optimal conditions for designing resonators of two plates with orifices as elongated resonator neck to obtain acoustic objects of required acoustic impedance and absorption properties. The results have confirmed our previous studies [1–5] and the results of RADENBERG [6].

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