Sound Absorption Analysis of a Metamaterial Based on Parallel Dual Helmholtz Resonators

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1 Introduction

Conventional acoustic materials used in many engineering applications for noise reduction present limited performance at low frequency since the wavelength is large. Acoustic metamaterials represent potential solutions for low-frequency noise attenuation. Guo et al. [1] studied a structure made of multiple inhomogeneous Helmholtz resonators (HR) with extended necks for low frequency sound absorption. They performed experimental measurements on a single layer, a double and a triple layer and observed some high sound absorption peaks above the target frequency for the double and triple layer absorbers. Li et al. [2] presented a theoretical model to characterize sound absorbing materials consisting of a parallel-arranged perforated panel with extended tubes (PPET). They validated the theoretical predictions with experiments and proposed a design of four parallel-arranged PPETs with effective sound absorption from 125 Hz to 250 Hz. A honeycomb structure metamaterial made of multiple parallel hexagonal Helmholtz resonators was proposed by Laly et al. [3]. Using finite element method (FEM), they demonstrated how to design the parameters of the necks in order to create broadband sound absorption.

In this paper, a sound absorbing material made of four parallel dual Helmholtz resonators is proposed and studied numerically. The impacts of the necks' parameters of a dual Helmholtz resonator consisting of neck-cavity-neck-cavity where each neck extends into each cavity are demonstrated. It is shown that when the radius of the first or the second neck of the dual HR increases, the two resonant frequencies of the sound absorption increase while they decrease when the length of the first or the second neck increases. The proposed sound absorbing material that combines four parallel dual Helmholtz resonators shows eight sound absorption peaks and can help to reduce the noise simultaneously at eight different frequencies in several engineering applications.

2 Numerical analysis of sound absorbing material based on parallel dual Helmholtz resonators

The numerical models of the sound absorbing materials that are studied in this paper are shown in Figure 1. A dual Helmholtz resonator is illustrated in Fig. 1 (b) that consists of a neck-cavity-neck-cavity. The radii and lengths of the dual HRs' necks are denoted by R_1, H_1 and R_2, H_2 respectively. Figure 1 (a) illustrates a compact sound absorber made of four parallel dual resonators with eight sub-cavities where an extended neck illustrated in color is connected to each sub-cavity. The sound attenuation performance of the dual resonator is studied using the 2D axisymmetric model of COMSOL Multiphysics as illustrated in Fig. 1 (c) and (d). The sound absorption coefficient is obtained using the two microphones transfer function method as shown in Fig. 1(c) and (d) and Fig. 2. At the inlet, a normal incidence plane wave with pressure amplitude of 1 Pa is applied with plane wave radiation condition and the acoustic pressures at the two microphones positions M_1 and M_2 in Fig. 1 and 2 are calculated numerically.

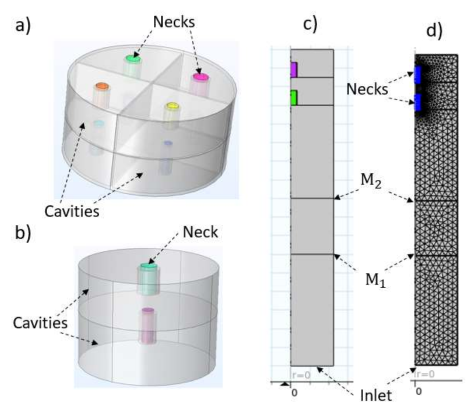

Figure 1: Finite element models (a) sound absorber made of parallel dual HR (b) dual HR (c) Axisymmetric model (d) mesh.

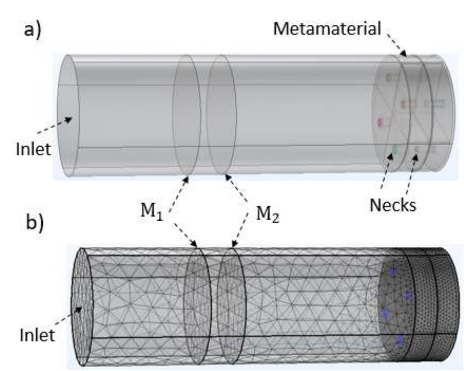

Figure 2: Numerical model using two microphones method (a) geometry (b) mesh.

In Figs. 1 and 2, the air within each neck is modeled using the thermo-viscous acoustic module to account for the viscous and thermal losses while the other domains are modeled using

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the pressure acoustics module and the walls of the resonators are considered rigid. The reflection and sound absorption coefficients are calculated using the following relations [4]

$$R = e^{2jk(L+s)} \frac{(H_{12} - e^{-jks})}{(e^{-jks} - H_{12})}, \quad \alpha = 1 - |R|^2 \qquad (1)$$

with k the wavenumber H_{12} the transfer function, s=30mm and L is the distance between M_2 and the material.

For the dual resonator in Fig. 1(b), the effect of the radius of the two necks is shown in Fig. 3. The numerical model in Fig. 1(c) and (d) is used and the depth of each cavity is set to 15 mm with a diameter of 45 mm. The length of each neck is set to 8 mm and the radii are varied from 1.5 mm to 3 mm. In Fig. 3(a), R_2=2mm and in Fig. 3(b), R_1=2 mm. The two resonance frequencies of the sound absorption in Fig. 3 increase as the radius of the first or the second neck increases.

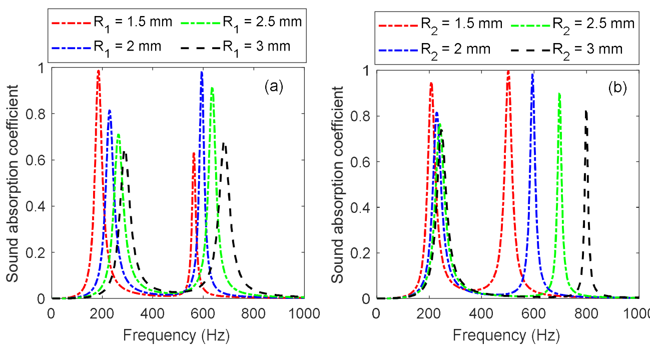

Figure 3: Effect of the radii of the necks on the sound absorption coefficient of a dual Helmholtz resonator.

The effect of the length of each neck of the dual resonator is presented in Fig. 4. The radius of each neck is set to 2 mm and in Fig. 4(a), H_1 = 8 mm while in Fig. 4(b), H_2 = 8 mm. The two resonant frequencies in Fig. 4 decrease when the length of the first or the second neck increases.

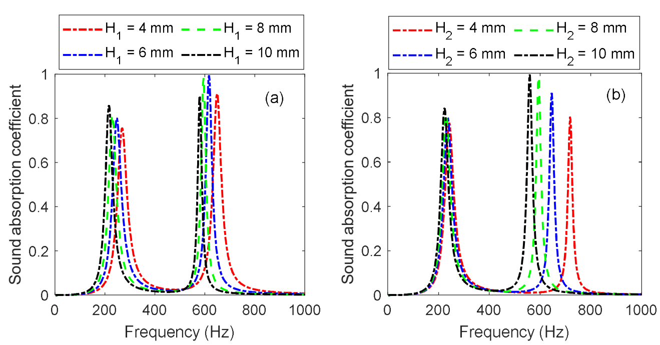

Figure 4: Effect of the length of the necks on the sound absorption coefficient of a dual Helmholtz resonator.

The sound absorption coefficient of the proposed material design (Fig. 1(a)) is shown in Fig. 5. The radii of the four necks on the top are 2.75 mm, 3 mm, 3.5 mm and 3.75 mm with the same length of 10 mm. For the internal necks, the radii are set to 2 mm, 2.5 mm, 2.75 mm and 3 mm with a length of 15 mm. The diameter of each cavity is set to 100 mm with a depth of 20 mm.

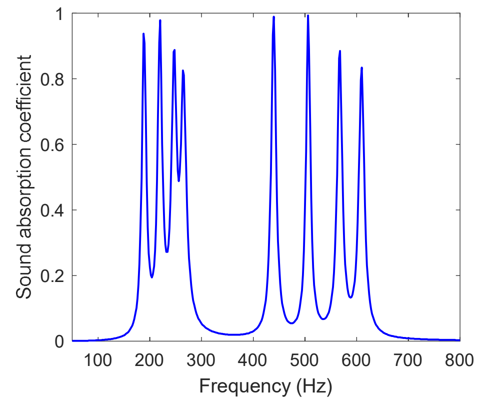

Figure 5: Sound absorption coefficient of the metamaterial.

The absorption coefficient in Fig. 5 presents eight resonant frequencies of 188 Hz, 220 Hz, 246 Hz, 264 Hz, 440 Hz, 506 Hz, 568 Hz and 610 Hz where the absorption peak values are respectively 0.94, 0.98, 0.88, 0.82, 0.98, 0.99, 0.88 and 0.83. The proposed material design in Fig. 1(a), which combines four dual Helmholtz resonators, shows eight different resonance peaks. These resonant frequencies can be tuned to specific frequencies by adjusting the parameters of the necks and the cavities volumes.

3 Conclusion

A sound absorbing material made of four parallel dual Helmholtz resonators was proposed and investigated numerically. The dual resonator presented two sound absorption resonant peaks and it was demonstrated that the two resonant frequencies increase when the radius of the first or the second neck increases while they decrease as the length of the first or the second neck increases. The material design combining four parallel dual Helmholtz resonators exhibits eight sound absorption peaks and will help to attenuate the noise at multiple frequencies.

Acknowledgments

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