Investigation of a Periodic Acoustic Metamaterial for Multi-Tonal Noise Attenuation

Zacharie Laly *3, Christopher Mechefske †1, Sebastian Ghinet ‡1, Behnam Ashrafi ♦2, and Charly T. Kone #3
[1]CRASH, Centre de Recherche Acoustique-Signal-Humain, Université de Sherbrooke, Québec, Canada.
[2]Department of Mechanical and Materials Engineering, Queen's University, Kingston, Ontario, Canada.
[3]Aerospace, National Research Council Canada, Ottawa, Ontario, Canada.
[4]Aerospace Manufacturing Technology Center, National Research Council Canada, Montreal, Canada.

1 Introduction

Acoustic metamaterials based on periodic Helmholtz resonators constitute potential solutions for low-frequency noise attenuation. Laly et al. [1,2] used the finite element method (FEM) to study the sound attenuation performance of porous material with embedded periodic Helmholtz resonators which contain damping material in the cavity and multiple transmission loss (TL) peaks were obtained. Abbad et al. [3] investigated a front membrane cavity Helmholtz resonator embedded in a porous matrix and observed that the TL was improved at the Helmholtz resonance with a degradation of the sound absorption.

In this paper, the TL of acoustic metamaterial based on periodic Helmholtz resonators containing a damping material in the cavity to which a small mass is attached is investigated using FEM. The mass that is attached to the membrane is a solid material. The TL of the proposed metamaterial presents multiple resonant peaks while only one peak is obtained using a conventional resonator. It is demonstrated that the resonant frequencies and the number of TL peaks can be controlled by the size and material properties of the added mass.

2 Finite element design and analysis of periodic acoustic metamaterial

Figure 1 shows a Helmholtz resonator with extended neck that contains a damping material in the form of a membrane in the cavity. A small solid mass with cylindrical shape is attached at the center of the membrane. The radius of the added mass is denoted by R and its thickness by H. The resonator is periodically embedded within a porous material. Figure 2 shows the cut-out view of the numerical geometry and the mesh of the periodic unit cell (PUC).

The membrane and the attached solid mass are modeled as linear isotropic materials using the solid mechanics module of COMSOL Multiphysics while the air inside the neck is modeled using the thermo-viscous acoustic module to account for the viscous and thermal dissipation effects. The porous layer with airflow resistivity of 26 kN s m^{-4}, a porosity of 99%, a tortuosity of 1.02, and respective characteristic viscous and thermal lengths of 150 µm and 300 µm is characterized using the Johnson-Champoux-Allard model [4].

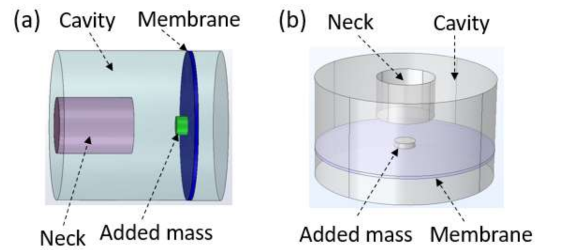

Figure 1: Helmholtz resonator with a membrane in the cavity (a) geometry (b) numerical model.

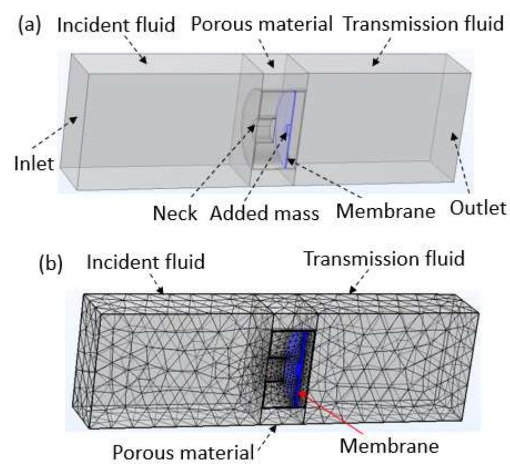

Figure 2: Cut-out view of the acoustic metamaterial (a) geometry of the PUC (b) mesh of the PUC.

The membrane material is ethylene vinyl acetate rubber with a thickness of 1 mm, Young's modulus of 5 MPa, density of 660 kg/m^3 and Poisson's ratio of 0.45. The radius of the neck is set to 15 mm and the diameter of the resonator cavity is 70 mm with a length of 40 mm, which is equal to the thickness of the porous material. Periodic boundary conditions are applied on all parallel planes.

Plane wave radiation conditions were applied on the inlet and outlet planes to minimize the reflection of acoustic waves. A normal incidence plane wave with pressure amplitude of 1 Pa was applied on the inlet and the transmission loss was calculated by the following relation:

$$\mathrm{TL} = 10\log_{10}(W_{in}/W_{out}) \quad (1)$$

where W_{in} and W_{out} are respectively the incoming power at the inlet plane and the outgoing power at the outlet plane. Figure 3 shows the TL of the metamaterial for membrane free and fixed boundary conditions without added mass. The

* zacharie.laly@usherbrooke.ca
† chris.mechefske@queensu.ca
‡ sebastian.ghinet@nrc-cnrc.gc.ca
♦ behnam.ashrafi@nrc-cnrc.gc.ca
\# tenoncharly.kone@nrc-cnrc.gc.net

length of the neck is 15 mm and the membrane is located at 10 mm from the bottom inner wall of the resonator cavity. The TL with a conventional resonator shows one resonant peak of 43 dB at 692 Hz. When a membrane is integrated into the resonator cavity without added mass, the TL shows 2 peaks of 47 dB and 42 dB at 596 Hz and 1044 Hz respectively for membrane free boundary conditions and 5 peaks are observed with membrane fixed boundary conditions.

Figure 4 shows the effect of the added mass size on the TL. The length of the neck is set to 20 mm and the membrane with a thickness of 1 mm is located at 8 mm from the bottom inner wall of the cavity. The added mass is made of steel with a thickness of 2 mm and radius R varying from 1 mm to 6 mm.

With a radius R of 1 mm, the TL resonant frequencies in Fig.4 are 510 Hz, 612 Hz, 884 Hz and 1006 Hz where the TL peaks values are 29 dB, 38 dB, 30 dB and 27 dB respectively. With a radius of 4 mm, the resonant frequencies are 510 Hz, 646 Hz, 956 Hz and 1086 Hz. Apart from the first resonant frequency, the other three resonant frequencies with R= 4 mm have increased compared to R=1 mm. With R=6 mm, 3 resonance frequencies are observed which are respectively higher than the first three resonance frequencies with R=1 mm and R=4 mm. The TL resonance frequencies increase when the radius of the added mass increases. The resonance frequencies can then be controlled by adjusting the radius of the added mass.

Figure 5 illustrates the effect of the added mass material properties on the TL. The distance between the membrane and the bottom wall of the cavity is 8 mm. The length of the neck is 20 mm while R and H are set to 3 mm. The TL in Fig. 5 presents 6 resonant frequencies when the added mass is made of steel and 5 resonant frequencies are observed when the added mass is made of aluminum.

3 Conclusion

The TL of an acoustic metamaterial based on a periodic Helmholtz resonator was investigated using FEM. A membrane was integrated within the resonator cavity to which small solid masses were attached. It was demonstrated that the multiple TL resonant frequencies and peak values generated can be controlled by adjusting the parameters (size and material properties) of the added mass.

Acknowledgments

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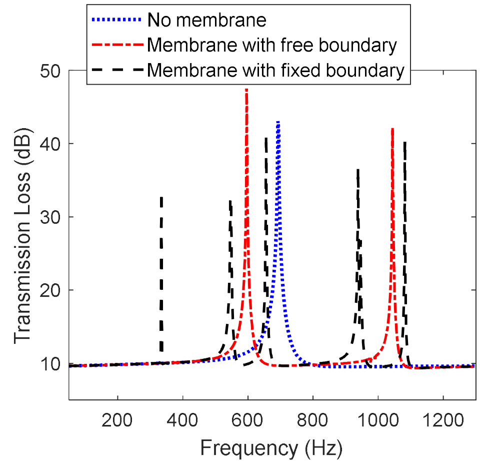

Figure 3: Comparison of the transmission loss.

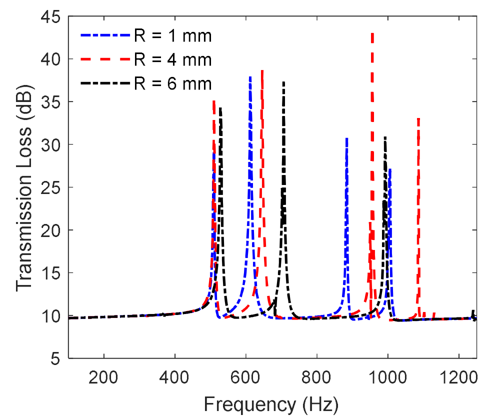

Figure 4: Effect of the added masses on the transmission loss.

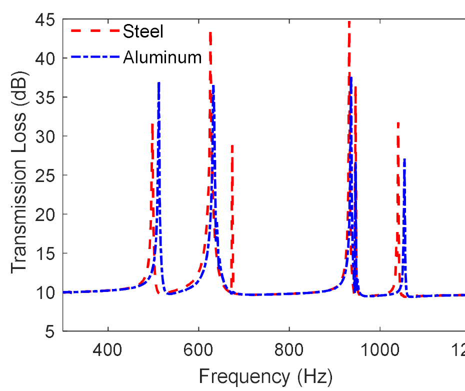

Figure 5: Effect of the added mass material properties on the TL.

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