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ON THE USE OF STRUCTURED POROELASTIC MATERIALS FOR NOISE CONTROL AT LOW FREQUENCY

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ABSTRACT

Porous materials are widely used for noise control due to their light weight and excellent sound absorption, except in the low frequency range. This paper presents two configurations where a poroelastic material is structured to address this limitation by taking advantage of a skeleton resonance at low frequency. The design allows easy adjustment of the targeted frequency without increasing the mass density or sacrificing space. First, the acoustic propagation in a duct is considered. It is controlled by an array of poroelastic lamellae, which provides an increased sound attenuation around the first bending resonance of the lamellae. Secondly, the weaknesses of sound transmission through a single or double panel partition are addressed. They are mitigated by a network of poroelastic clamped beams, the first bending resonance of which is adjusted to the first mode of the finite size plate or to the mass-spring-mass resonance of the double panel. For both configurations, experimental proofs of the concept are shown. Finally, a numerical model, which can take into account the periodicity of the structure, makes it possible to analyze the dissipation mechanisms and the effect of the governing parameters, such as the mass ratio, the Young's modulus and the airflow resistivity.

Keywords: *in duct sound attenuation, poroelastic metamaterial, sound insulation, double wall partition*

1. INTRODUCTION

Low-frequency noise control is a challenge for many industries, such as automobiles, aircraft and buildings. The attenuation of these noise disturbances can make use of passive treatments involving porous materials, the effectiveness of which is limited by their thickness relative to the wavelength. To overcome this limitation, metamaterial and metasurfaces have been designed with subwavelength resonators often arranged in periodic structures to control wave propagation and stop bands [1–4].

The aim of this paper is to show how one can take advantage of the skeleton resonances of a poroelastic material [5,6] to create a "poroelastic metamaterial" and obtain a better noise control. The design allows easy adjustment of the targeted frequency without increasing the mass density or space. Two configurations are addressed (Fig. 1): first, we consider the acoustic attenuation in a duct with a structured liner [6], and secondly, the sound insulation weaknesses of a single or double wall partition [7].

2. SOUND ATTENUATION IN WAVEGUIDES BY POROELASTIC LAMELLAE

The poroelastic metamaterial consists of a network of parallel lamellae of height l = 25 mm, width w = 15 mm and length L = 200 mm, made of melamine foam. The mode

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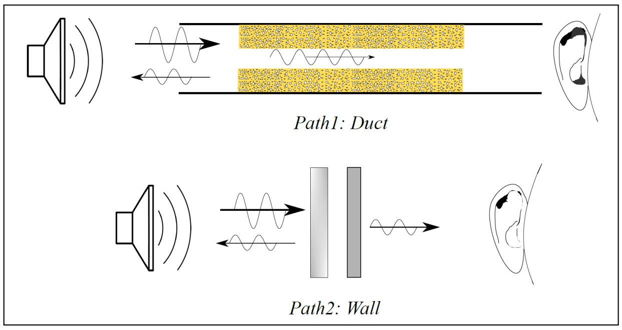

Figure 1. The two addressed noise control configurations.

of the first bending frequency f_b can be estimated by

$$f_b \approx 0.56 \frac{w}{\ell^2} \sqrt{\frac{E}{12\,\rho}} \tag{1}$$

where E is the Young's modulus and ρ is the mass density of the foam. The network of 20 lamellae is inserted on two sides of the duct as depicted in Fig. 2. The length of the lamellae are perpendicular to the wave propagation direction in the duct. In that way, the acoustic wave excites the first bending mode of each lamella producing a local increase of the sound transmission loss around 500 Hz as shown in Fig. 3. This frequency is well approximated by Eq. ()1) giving 543 Hz. Results obtained in our experimental test bench [8] are close to simulations obtained by finite element model (see [6] for more details). The model allows to analyze the dissipation mechanisms and optimize the poroelastic metamaterial according to its properties such as airgap, airflow resistivity, Young's modulus and loss factor.

3. SOUND INSULATION OF SINGLE OR DOUBLE WALL PARTITION WITH POROELASTIC RESONATORS

Single and double wall partitions are known for their sound transmission loss weaknesses close to the first mode of the finite size wall and to the mass-spring-mass resonance of the double wall. We propose a metamaterial made of a network of poroelastic beams whose first bending mode is tuned at the targeted resonance [7]. The beams are fixed on several spaced supports added on the panel (see Fig. 4). The first resonance frequency can be

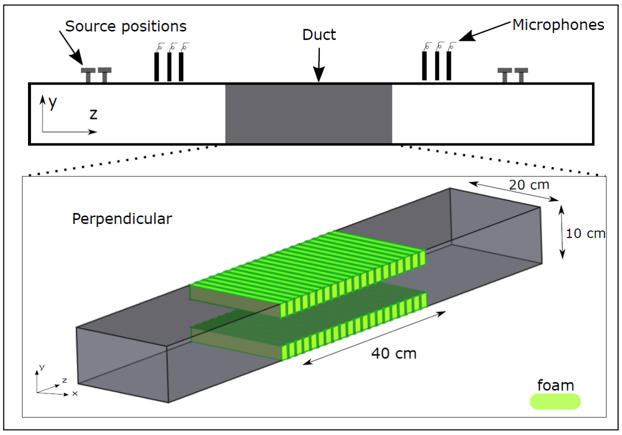

Figure 2. Test bench for transmission loss measurement and poroelastic lamellae network set perpendicular to the duct axis.

estimated considering a clamped-clamped beam by

$$f_1 \approx \frac{4.73^2}{2\pi L^2} \sqrt{\frac{EI}{\rho S}}, \tag{2}$$

where E is the Young's modulus, ρ is the mass density, $I = bH^3/12$ is the second moment of area, L is the beam length, H is the beam thickness and $S = bH$ is the cross section area.

3.1 Finite size single wall

First, the sound transmission loss of a finite size single wall is studied in a rectangular duct under normal incidence. For the experimental setup, beams are made of thermocompressed melanine with a ratio of 2.9 having the following properties [9, 10]: mass density of 24.2 kg.m^{-3} and airflow resistivity of 41 kNm^{-4}s. These properties insure a mass ratio resonators over panel of 8%. Fig. 5 compares the transmission loss of the single wall without and with resonators. It is shown that the poroelastic metamaterial increases the transmission loss up to 12 dB at the first mode of the panel.

3.2 Double wall partition

The double wall partition is investigated by simulation considering a periodic finite element model using the Floquet-Bloch theorem. Fig. 6 shows that the transmission loss in diffuse field is increased up to 12 dB at the double wall resonance thanks to the resonators. The

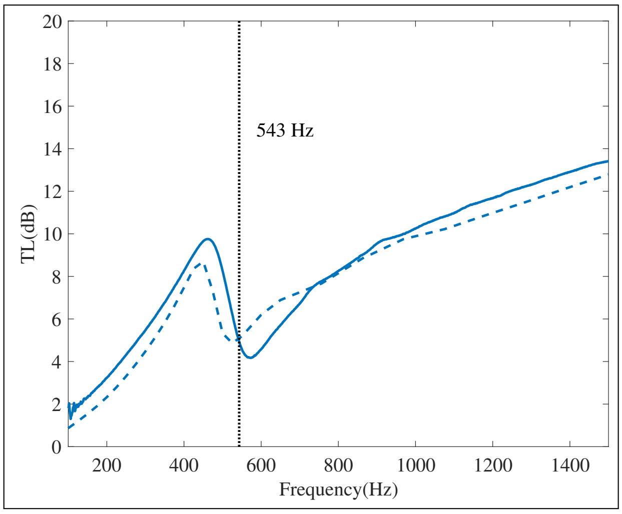

Figure 3. Sound transmission loss of the poroelastic lamellae network: measurement (continuous line) and simulation (dashed line).

model (see [7] for more details) allows to investigate the dissipation mechanisms and the impact of several parameters like airflow resistivity and filling fraction of the air gap between the two walls.

4. CONCLUSION

The three presented configurations show that the skeleton resonances of a purposely structured poroelastic materials can provide an integrated means of combining the properties of the sound absorbing material and vibration of its structure to achieve a better attenuation at a given frequency. Optimization of the poroelastic metamaterial requires a balance between dissipative and non-dissipative parameters that can be determined thanks to simulation tools.

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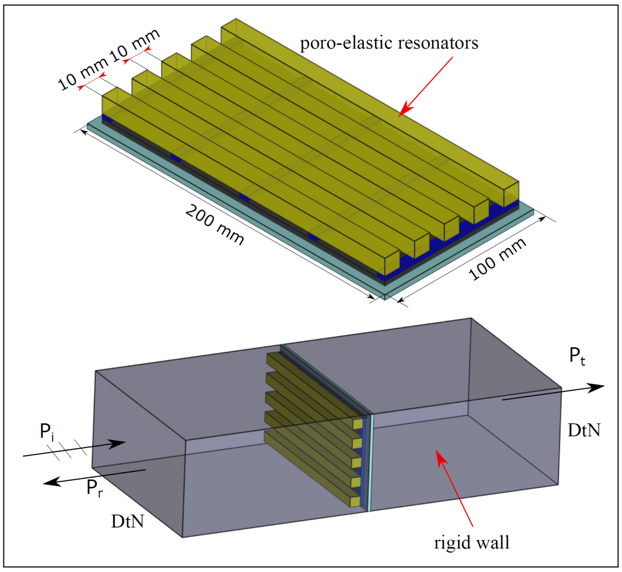

Figure 4. Poroelastic resonators on single wall.

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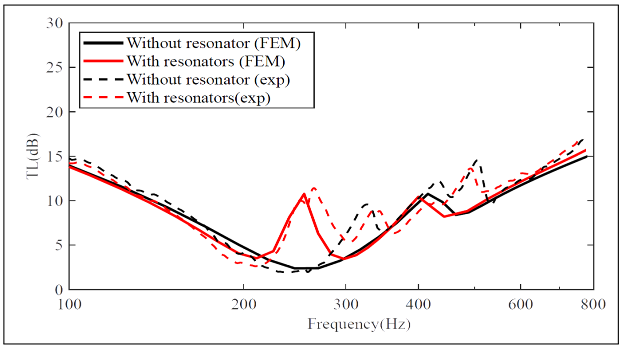

Figure 5. Simulated and measured transmission loss of the single wall without and with proroelastic resonators.

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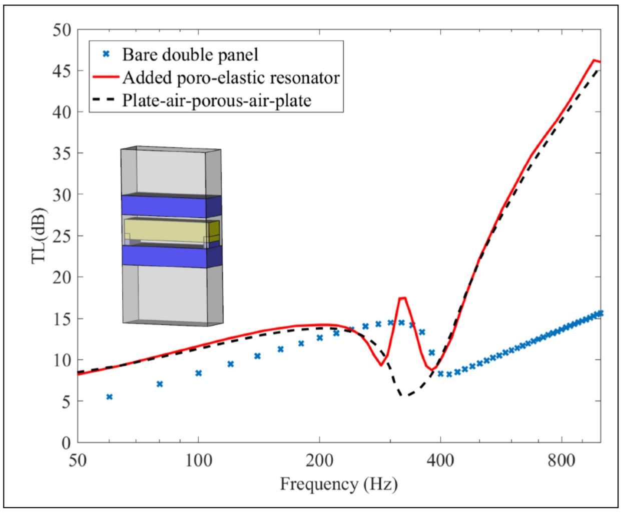

Figure 6. Simulated transmission loss of the double wall partition without and with poroelastic resonators.