

Acoustic radiation efficiency of a structure covered by a porous layer

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Introduction

Porous materials such as polymer foams are well known as sound absorbers [1]. In many applications, they are attached to a structure subjected to vibrations. Considering the structure, they act as an intermediate layer modifying the coupling conditions with the acoustic domain. If this layer increases acoustic radiation, several consequences would occur. First, absorption or isolation efficiency of the porous material would be limited, because the level emitted by the vibrating structure would be amplified. Secondly, damping of the structure by radiation could be no more negligible, as usually assumed for a structure in a light fluid [2, 3]. The aim of this study is to investigate how a porous layer bonded to a vibrating structure may affect its acoustic radiation.

Experimental investigation

Measurement of the radiation efficiency of a plate with or without covering porous layer has been performed. Radiation efficiency σ_R is defined as the ratio of the acoustic radiated power Π_A over the vibratory power Π_V [2, 4].

The experimental configuration is an aluminium clamped plate [1.2 mm \times 22 cm \times 28 cm] placed in a rigid baffle (see Fig. 1). The back face is connected to a shaker. Vibratory power of the plate is determined from the quadratic mean of normal velocities measured at several points by a laser vibrometer. The front face that can be covered by a porous layer is radiating in an anechoic chamber. Acoustic radiated power is determined using an intensity probe made of two $\frac{1}{2}$ inch microphones spaced by 12.5 mm. Measurements are valid between 300 Hz and 4 kHz. The whole surface of the plate is manually scanned. Two polymer foams are used (see table 1) : foam A is more resistive, softer and heavier.



Figure 1: Experimental set-up

	Foam A	Foam B
Thickness (mm)	20	40
Air flow resistivity (N s m^{-4})	26 600	3300
Skeleton Young's modulus (Pa)	190 000	300 000
Skeleton density (kg m^{-3})	57.2	29

Table 1: Properties of materials

Results are presented in Fig. 2. Radiation efficiency of the plate without foam is increasing with frequency because the experimental frequency band is below coincidence frequency, calculated at 10 kHz for an 1.2 mm thick aluminium plate. Beyond this frequency, radiation efficiency would reach unity. Between 1 kHz and 3 kHz, radiation efficiency is increased with both foams. This increase, more important with foam A, goes up to 100.

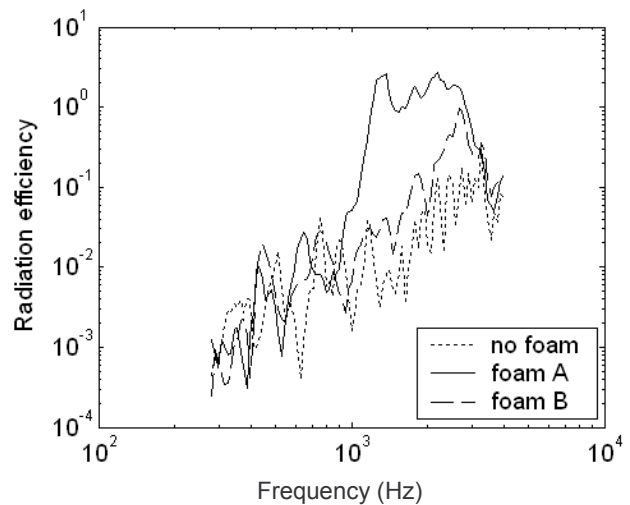


Figure 2: Measured radiation efficiency of a clamped plate with or without a covering porous layer (Foam A or B)

Model

In the literature the few papers dealing with structure radiation and porous material [5, 6] make use of the equivalent fluid model [1] to describe the porous layer. This model is not suitable for our purpose because it assumes that the skeleton is motionless whereas in our configuration the skeleton is directly in contact with the moving structure. Therefore Biot model [1] has to be used. In a first step, a 1D model has been developed to calculate the acoustic radiation efficiency of a covered piston in a semi-infinite duct (see Fig. 3). This simple model is able to account for the behaviour of the porous layer in its thickness.

The flat piston is animated by an harmonic velocity of amplitude v_0 . In the porous layer, according to Biot theory, two types of longitudinal waves can propagate forward and backward. This leads to four waves of amplitude A, B, C, D . In the fluid domain, only one wave of amplitude E propagates from the porous interface. Boundary conditions between each media are continuity of stress and displacements [7]. This system is solved numerically. Radiation efficiency is given by the ratio of the quadratic amplitude $|E|^2$ over the quadratic velocity of the piston v_0^2 , normalized by the square of the characteristic impedance of the air to get unity for a non-covered piston.

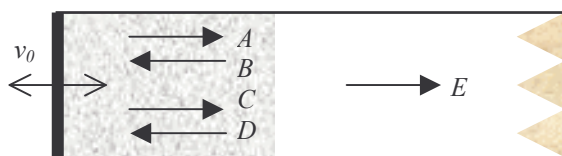


Figure 3: Modelisation of a porous layer radiating in a duct

Fluid equivalent model has also been used in order to compare both model. In that case only, one kind of wave propagates forward and backward in the porous layer.

Results are presented in Fig. 4. It is shown that the radiation efficiency is not affected by the porous layer in the low frequency range for both material and model. In a mid-frequency range, Biot model predicts an increase. It is related to skeleton resonances, since the equivalent fluid model, assuming a rigid skeleton, can not predict it. The radiation efficiency is more important with foam A. At higher frequencies, the radiation efficiency decreases. Note that the equivalent fluid model also differs from Biot model in the higher frequency range, predicting a slower decrease.

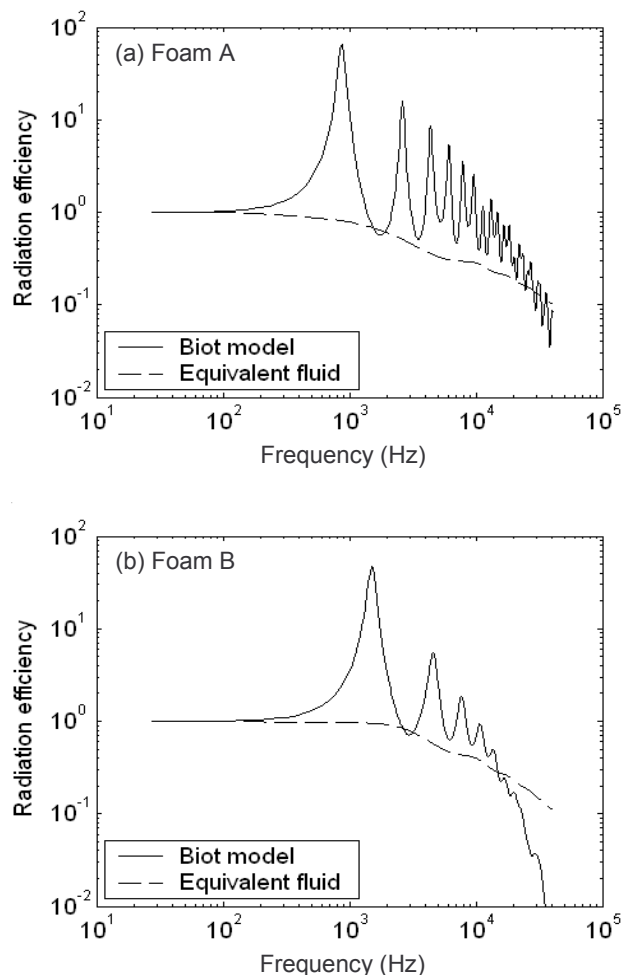


Figure 4: Simulation of the radiation efficiency of a flat piston in a duct covered by foam A (a) or foam B (b)

Conclusion

Radiation efficiency of a clamped plate covered with or without a porous layer has been measured. An increase is observed in a mid frequency range with a porous layer. This increase has been predicted by a 1-D model based on Biot theory. Comparison with equivalent fluid model confirms that it is due to skeleton resonances in the thickness of the porous layer.

Although a 1-D model can predict the influence of a porous layer on the acoustic radiation of a structure, a 2-D model accounting for the modal behaviour of the structure will be developed to confirm these tendencies. Further work is characterisation of mechanical properties of porous materials in this context.

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