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Numerical and experimental study of the effect of microslits on the normal absorption of structural metamaterials

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ABSTRACT

Resonant metamaterials are emerging as novel concepts to reduce noise levels in targeted frequency zones, so-called stop bands. The metamaterial concept improves acoustic behaviour through an increase of the insertion loss. This paper concerns a first investigation on the absorption capabilities of a resonant metamaterial when thermo-viscous effects are incorporated via the addition of microslits. In a previous work, a resonant metamaterial was obtained through the inclusion of resonating structures into cavities of an open honeycomb assembly. In this study, the air gap of the honeycomb structure is reduced so as to provide viscous losses for the travelling waves. Considering that the created resonant structures with open cavities are rigid, an equivalent fluid model is used to calculate the acoustical properties of a so called microslit metamaterial. It is demonstrated that the unit cell structure can be divided into parallel elements for which the acoustic impedance can be computed via the transfer matrix approach TMM in parallel and series. Likewise, it is shown that the structural response can be predicted by FEM models allowing studying the structural effects separately from the viscous–thermal effects predicted by the equivalent fluid model. Moreover, the combined effect of both approaches is shown experimentally where it is observed that: (i) The absorption of the resonant metamaterial is increased by the addition of microslits, (ii) the modes of the test sample appear as small peaks on the absorption curve of the microslit metamaterial, (iii) the structural modes are grouped below and above the stop band and, (iv) the resonant structures do not lead to additional absorption in the stop band region. Analytical models are compared to experimental measurements to validate the models and to show the potential of this material assembly.

1. Introduction

In response to increasing customer expectations and more restrictive regulations, the acoustical behaviour of consumer goods and machinery is gaining ever more attention. Classical heavy and/or bulky solutions to improve acoustic behaviour, such as heavy layers or absorptive foams, are often undesirable given the trend towards compact and lightweight design, triggered by ecological and economic reasons. In search for novel material systems that combine lightweight characteristics with good acoustical behaviour, resonant metamaterials come to the fore, be it at least in some targeted and tuneable frequency ranges, referred to as stop bands. Resonant metamaterials with stop band behaviour are obtained through the

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inclusion of resonant cells on a scale smaller than the structural wavelengths to be influenced, opening up the path towards compact low frequency vibro-acoustic solutions [1]. Reference works such as [2,3], show that the working principles of metamaterials can be described based on the Fano-type interference between incoming waves and the waves re-radiated by the resonant cells. Their acoustic properties have been studied by Liu et al. who showed that local resonant metamaterials lead to an increased acoustic transmission loss through reflection and thus are not based on the improvement of acoustic absorption [4]. However, the possibility of acoustic absorbing metamaterials has been discussed as well by Mei et. al. who achieved absorption through large local structural deformation in the resonant cells combined with a dissipative material in the zone of deformation [5]. This was accomplished through the combination of membrane inclusions with steel inserts.

High absorption coefficients can be achieved in structures that can provide large values of acoustic resistance at the same time as low acoustic mass reactance [6]. A common solution to generate acoustic absorption is by means of poroelastic materials, like foams [7]. These are effective for airborne sound mitigation through dissipation of the acoustic waves into heat. Their working frequencies are often dependent on the thickness of the material; to be effective the thickness has to equal at least a quarter of the acoustical wavelength to be influenced, restricting their use to the mid and high frequency range. To improve the absorption performance, a mass resistance and reactance can be added to the impedance of the absorber by placing a perforated panel at the upstream side [8]. The effect is not only a shift of the frequencies of maximum absorption to a lower frequency range but an increase of the absorption peak as well. By reducing the diameter of the perforation to the sub millimetre size, the panel itself can provide energy dissipation of the sound waves into heat by viscous and thermal losses inside the perforations as a microperforated panel (MPP) [9].

In this paper a metamaterial with improved acoustic absorption behaviour is pursued. As starting point an already validated metamaterial design is used. In this design, existing air gaps are redesigned to micro slits in order to increase visco-thermal losses, similar as in slitted panels [10]. The resonant structures of the metamaterial are unchanged and apart from a possible increase in damping of the cell resonances due to the microslits, the stop band behaviour should be unchanged. In this way, a microslit metamaterial is obtained.

For the design and numerical prediction of this microslit metamaterial, different numerical techniques are applied. To assess the stop band behaviour, it is assumed that the metamaterial is periodic; however, this is not required from a physical point of view. From literature it is known that, based on an undamped Finite Element (FE) model of the unit cell of a periodic structure and the application of periodicity boundary conditions, dispersion curves for freely propagating structural waves in an infinite periodic structure can be derived [11,12]. These dispersion curves allow identification of the stop band region which corresponds to frequency zones for which no free wave propagation solutions are found.

The calculation of the acoustic absorption provided by the material is done using the Johnson–Champoux–Allard (JCA) model [13,14] which allows handling the structure–air combination in the microslit metamaterial as an equivalent fluid. The absorption peak of the microslit metamaterial is tuned by the combined effects of the diameter of the slits, the ratio of open area to total area, the thickness of the layer and a backing cavity filled with air when the metamaterial is situated in front of a rigid wall. The acoustic impedance of a resonant structure with microslits inlaid in a honeycomb structure backed by a cavity filled with air is predicted with the transfer matrix method (TMM) in series and parallel configurations [15].

The paper is outlined as follows. The design of the metamaterial is described in Section 2. Section 3 discusses the equivalent fluid modelling and the layered TMM representation. Section 4 elaborates on the results and Section 5 presents the conclusions.

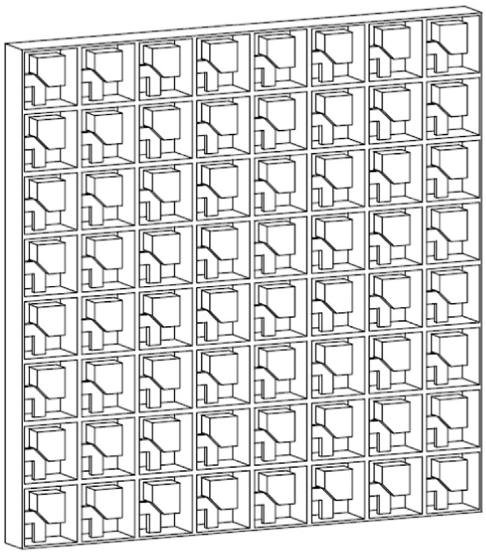

Fig. 1. Example of a metamaterial panel based on inclusion of resonant structures.