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Improving the noise insulation performance of vibro-acoustic metamaterial panels through multi-resonant design

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Abstract: In the search for lightweight solutions with favourable noise and vibration attenuation, locally resonant vibro-acoustic metamaterials have emerged as a promising candidate due to their stop band behaviour. When used in a sound transmission context, vibro-acoustic metamaterial panels allow to greatly improve the acoustic insulation in a targeted frequency range. However, their peak insulation is typically followed by a strong insulation dip, which hampers their broad applicability. In this work, this problem is addressed through the formerly only theoretical concept of dip reduction by optimizing a realizable metamaterial panel with multiple tuned resonators in order to reduce this insulation dip, while preserving peak performance and maintaining similar total mass. The resulting multi-resonant metamaterial design is realized and its improved acoustic insulation performance is experimentally validated.

Keywords: vibro-acoustic metamaterial, noise insulation, dip reduction, multi-resonant design

1. Introduction

Vibro-acoustic metamaterials have shown potential to create targeted frequency ranges of high vibration and noise reduction due to their stop band behaviour, which arises from adding or embedding identically tuned resonant structures on or in a flexible host structure on a sub-wavelength scale [1,2]. A high sound transmission loss (STL) peak can be achieved with vibro-acoustic metamaterial panels around their bending wave stop band frequency range, but it is typically followed by an undesirable, strong STL dip. Although damping in the resonators can improve the STL dip, it also reduces the STL peak performance [3]. A theoretical dip reduction method was recently proposed [4]: using a lumped parameter STL model of a metamaterial partition, incorporating mass-spring systems and the acoustic mass-law, the potential was shown of tuning multiple additional highly damped resonators to the STL dip frequency range in order to suppress the STL dip, while preserving the STL peak. However, only ideal mass-spring resonators were considered, the tuning was performed manually and involved impractically high damping values, and no validation on a realized metamaterial panel was performed.

2. Methodology

To bring dip reduction to reality, in this work, a lumped parameter model is first embedded in an STL optimization routine to tune multiple resonances with realizable damping values. By redistributing the main resonator mass over the additional resonators, the total added mass is maintained. The optimized resonator parameters which minimize the peak difference between STL dip and STL of the bare host panel are next translated to realizable resonators using finite element model-based design optimization [5]. The resulting design is realized and validated using acoustic insertion loss measurements [3].

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3. Results and Discussion

A conventional metamaterial is considered, composed of a 4 mm thick PMMA (Young's modulus E=4.85 GPa, density ρ=1188 kg/m^3, Poisson ratio ν=0.31, structural damping η= 0.05) host panel with resonators tuned to 600 Hz, with η=0.05 and adding 50% mass, added with 6x6 cm periodicity. A dip-reduced metamaterial is next designed, considering three additional resonators per periodic cell, with the main resonator tuned to 600 Hz and 70% of the total mass addition, and the additional resonators optimized to reduce the STL dip around 700 Hz (Fig. 1a). The optimized mass-spring resonator properties of both metamaterials are translated to realizable beam-shaped PMMA resonators [3,5], which are laser-cut and glued onto A3-sized PMMA panels (Fig. 1b). Both manufactured panels of approximately the same mass (47% added for conventional, 49% for dip-reduced) are mounted on an acoustic testing cabin to measure the insertion loss (IL) [3]. Comparing the IL difference ΔIL between the metamaterial panels and their bare host panels (Fig. 1c), it is clear that the dip-reduced metamaterial achieves a highly improved STL dip while mainly preserving the targeted STL peak around 600 Hz.

Fig. 1. (a) Predicted STL of conventional and optimized dip-reduced metamaterial panel with its parameters, (b) manufactured conventional (left) and dip-reduced (right) metamaterial panels mounted on the acoustic testing cabin and (c) comparison of the ΔIL of the conventional and dip-reduced metamaterial panel in 1/12 octave bands.

4. Concluding Remarks

In this work, a dip-reduction method for reducing the typical STL dip of metamaterial panels was introduced in an optimization routine and translated into a realizable multi-resonant, dip-reduced metamaterial panel design. Compared to a conventional metamaterial panel, the acoustic insulation of the manufactured dip-reduced metamaterial panel shows an STL dip improvement of 5 dB, while mainly preserving the peak STL performance and maintaining approximately the same total mass.

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