The Effect of Coaxial Ring Masses with Different Contact Areas, Mass, and Distribution on Membrane-Type Acoustical Metamaterials' Transmission Loss

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The transmission loss (TL) of the membrane-type acoustical metamaterials with coaxial ring masses are investigated using the finite element method. The results show that the TL peak and resonance frequencies of the membrane-type acoustical metamaterials depends on mass, distribution of coaxial ring masses, and the contacting area of coaxial ring masses with the membrane. It is also shown that the coaxial ring masses only affect the TL at low frequencies, while the membrane is effective at all frequencies. Additionally, the double-leaf membrane-type acoustical metamaterials structure has been constructed. The roles of the membrane and ring masses of double-leaf membrane-type acoustical metamaterials structure on TL are investigated. The influence of the depth of air-cavity on the TL is then discussed.

1. INTRODUCTION

Low frequency noise has long been regarded as a pernicious form of environmental pollution because it involves blocking large-wavelength waves, which requires thick or heavy materials.[1,2] In general, it should be a low transmission loss at a low frequency with both thin and lightweight structures.[3] To overcome this difficulty, composite materials with locally resonant acoustical metamaterials were developed recently.[1,4–9] Hirsekorn proposed a heuristic model of locally resonant sonic crystals, which allowed one to predict the resonance frequencies in good agreement with the numerical simulations.[5] Li and Chan showed the existence of acoustical metamaterials, where the effective density and bulk modulus are both simultaneously negative in the true and strict sense of an effective medium.[6] A class of sonic shield materials based on the principle of locally resonant microstructures are demonstrated by Ho et al.[8] One of the main advantages of locally resonant acoustical metamaterials is the ability to prevent sound propagation at low frequencies without the addition of significant mass or modulus bulk.[10] Large-scale weighted membranes, which are traditionally used in building acoustics, have shown attenuation achieved at varying frequencies.[11,12] In addition, small-scale membrane-type acoustical metamaterials have been shown to improve sound insulation at low frequencies, surpassing the acoustic mass law by several orders of magnitude over a narrow frequency band.[1,13] Mei et al. presented a thin-film acoustical metamaterial that comprised of an elastic membrane decorated with asymmetrical rigid platelets that almost reached unity absorption at frequencies where the relevant sound wavelength in the air was three orders of magnitude larger than the membrane thickness.[14] Using the finite element analysis and experimental techniques, Christina et al. analyzed the transmission loss of membrane-type locally resonant acoustical metamaterials with the added ring masses.[10] The results showed that the addition of a ring mass to the structure either increased the bandwidth of the transmission loss peak or introduced multiple peaks. This depended on the number of rings, the distribution of mass between the center and ring masses, and the radii of the ring.[10] Meanwhile, Christina et al. fabricated the arrays of membrane-type acoustical metamaterials and found that the sound transmission at multiple frequencies could be decreased by employing nonuniform mass distribution over the cells in the array.[15] Ding et al. designed an acoustical metamaterial with multi-band of negative modulus composed of different sized split hollow spheres.[16] The results indicated that this medium could achieve a negative modulus at a frequency range from 900 to 1500 Hz.[16] Although a lot of research has been done on locally resonant acoustical metamaterials, it appears that no relevant reports have been given for acoustical metamaterial of coaxial ring masses with different cross section shapes and double-leaf membrane-type acoustical metamaterials. This paper focuses on the acoustical performance studies of membrane-type acoustical metamaterials of coaxial ring masses with different cross section shapes and double-leaf membrane-type acoustical metamaterials.

In Section 2, sample constructions will be introduced. In Section 3, the transmission loss for membrane-type acoustical metamaterials of coaxial ring masses with four kinds of different cross section shape will be studied. In Section 4, the effect of coaxial ring's mass on transmission loss of membrane-type acoustical metamaterials will be investigated. In Section 5, the effect of coaxial ring distribution on transmission loss of membrane-type acoustical metamaterials will be studied. In Section 6, the main roles of the membrane and coaxial ring s will be discussed. In Section 7, the acoustical performance of the double-leaf membrane-type acoustical metamaterials will be studied. Finally, the conclusions will be given in Section 8.