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Acoustic metamaterial panel composed of funnel-shaped cell unit having multi-band negative material properties

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ABSTRACT

This paper presents two dimensional sound-proof acoustic metamaterials having tunable multi-band negative effective mass density. The acoustic metamaterial panel was composed of many periodic funnel-shaped cell units into square lattice. Each unit cell operates as multi-band resonators. By tuning unit cell the local reflected acoustic wave was almost out of phase with the incident wave. It leads to the negative effective density and created band gap for absorbing incident sound energy without transmission. Measurement of the transmission loss and negative effective mass density was performed using four microphone methods for characterization of barrier performance.

Keywords: Acoustic metamaterial, Negative effective density, Tunable multi-band resonator
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1. INTRODUCTION

Metamaterials are artificial (man-made) periodic structure having negative effective material properties. Due to the unique shape of metamaterial structure, the acoustic and vibration energy of the specific frequency can be dissipated or stopped. For this reason, the various metamaterials have been introduced for vibration and noise control.[1]-[5]

Zhang [6] had proposed a method to extract the effective properties from reflection and transmission coefficients. Zhao [7] designed an acoustic metamaterial having multi-band negative properties composed of several split hollow spheres (SHSs). Baz [8] suggested the active metamaterials to overcome the limited frequency bandwidth characteristics for a passive system. The active system composed of piezoelectric active ingredients in a fluid-solid composite structures forming the basic building block of a larger metamaterial periodic arrangements and exhibited generation of specific dispersion characteristics. Bloemer [9] designed the metamaterial composed of a hard metal with subwavelength apertures. He predicted and experimentally demonstrated that an effective angle of intromission. Most acoustic metamaterials usually were composed of acoustic resonators in the unit cell but has limited performance on generating multi band negative effective mass density through wider band gaps. As one unit cell has usually one resonator acoustic characteristics, it was difficult to induce multi band negative effective density. In this study, two dimensional sound-proof acoustic metamaterial composed of many periodic funnel-shaped cell unit under square lattice and exhibiting tunable multi-band negative effective mass density was presented. Measurement of transmission loss and negative effective mass density of unit cell of acoustic metamaterial was performed using an impedance tube.

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2. EFFECTIVE PROPERTIES OF UNIT CELL

2.1 Sample Manufacture

The Acoustic metamaterial was constructed by periodically arrary of the funnel-shaped cell units in two dimensional panel with lattice constant of separation distance of *a* = 48 mm and thickness d = 46 mm. Each unit cell had the acoustic characteristics of multi-band resonators. Due to this configuration of the funnel-shape unit cell, it operated as two resonators, with the first resonance from the body and the second resonance from the tube of the unit cell.

Fig. 1 demonstrates the schematic diagram of the funnel-shaped unit cell. The design parameters, L, V_H, and S_H are the length of neck, cavity volume, and cross-sectional area of neck of Helmholtz resonator, respectively and the L, and S_T are the length and cross-sectional area of the tube resonator. The design parameter, L, is the length for both Helmholtz resonator and tube resonator, and has an influence on both two resonators resonance. The effective neck length of Helmholtz resonator is $L+1.4a_H$ and the effective length of tube is $(L_T+L)+0.6a_T$. In this study, the tunned frequencies were selected by 3500 Hz and 4000 Hz, respectively. The other geometric parameters, L, V_H, S_H L_T, S_T were selected as $0.1mm$, $11515mm^3$, $483mm^2$, $39mm$, $95mm^2$, respectively. The fluid inside the unit cell was air and the cell was made of arylonitrile butadiene styrene (ABS) and polycarbonate (PC). The mass density of ABS and PC are 1040 kg/m^3 and 1220 kg/m^3, respectively. The Young's modulus are $1.9\times10^9\ Pa$ and $2.4\times10^9\ Pa$, respectively. The acoustic impedances of ABS and PC weres larger than the air in the cavity of unit cell. The shell of unit cell was considered as a rigid medium.

2.2 Two-load and four microphone impedance tube method

Measurement of the transmission loss and effective properties of unit cell were conducted using an impedance tube. [10] Fig. 2 shows the schematic diagram for the unit cell of the acoustic metamaterial. The frequency range of noise control depended on the tube diameter and the spacing between the microphone positions. As the internal diameter of the tube was 30mm and the spacing of microphone was 50mm, the lower and upper working frequency ranges were 500 and 6400Hz. A loud speaker at one end of the tube was used to generate the random signal over the frequency range from 0 to 6400 Hz. A removable cap was placed at the tube end to apply the two termination conditions.

3. RESULTS AND DISCUSSION

In this study, the characteristics of the funnel-shaped cell unit were analyzed. To analyze of transmission loss and effective mass density of unit cell, theoretical, experimental, and simulation methods were performed and compared each other. Fig. 3 shows the negative effective mass densities at the local at resonance frequencies of 3400Hz and 4000Hz. The former frequency, 3400Hz, was due to body configuration, and the latter frequency, 4000Hz, was due to pipe configuration of the funnel-shaped cell unit. When each part of the unit cell operates at tuned frequencies the local reflected acoustic wave is almost out of phase with the incident wave. It leads to the negative effective mass density and created band gap for absorbing incident sound energy without transmission. The development of acoustic metamaterial has led to negative acoustic properties, which helped to broaden the range of the noise control. These negative effective properties are dispersive in nature. Negative mass density implies that the particle acceleration is out of phase with the dynamic pressure gradient. These negative effective mass densities manifest when the appropriate resonances are strong enough so that the scattered field superior over the background incident field.

4. CONCLUSION

This paper presents two dimensional sound-proof acoustic metamaterial exhibiting tunable multi-band negative effective density. The acoustic metamaterial were composed of many periodic funnel-shaped cell unit with square lattice. Each unit cell operates such as multi-band resonators. Measurement of transmission loss and negative effective mass density of unit cell of acoustic metamaterial was performed using four microphone methods. The results show that the high magnitude of the attenuation was shown at tuned resonance frequencies of 3400Hz and 4000Hz, and negative effective mass densities were shown at these frequency.

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5. FIGURE

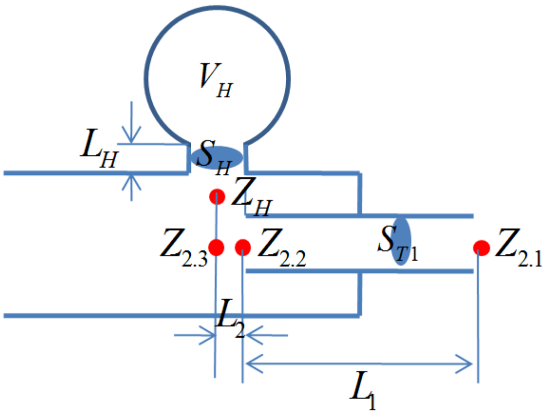

FIG. 1. Schematic representation of funnel-shaped unit cell. $Z_{2.1}$, $Z_{2.2}$ Z_H, $Z_{2.3}$ are the radiation impedance of pipe end, the input impedance of pipe, the impedance of Helmholtz resonator and total impedance of unit cell, respectively

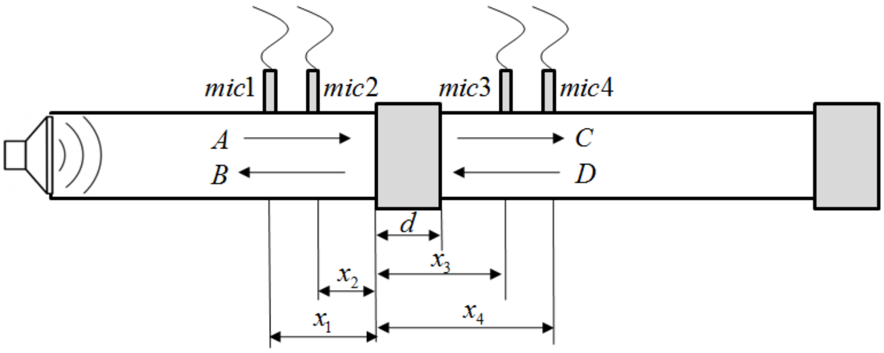

FIG. 2. Two-load and four-microphone impedance tube method and wave propagation in tube

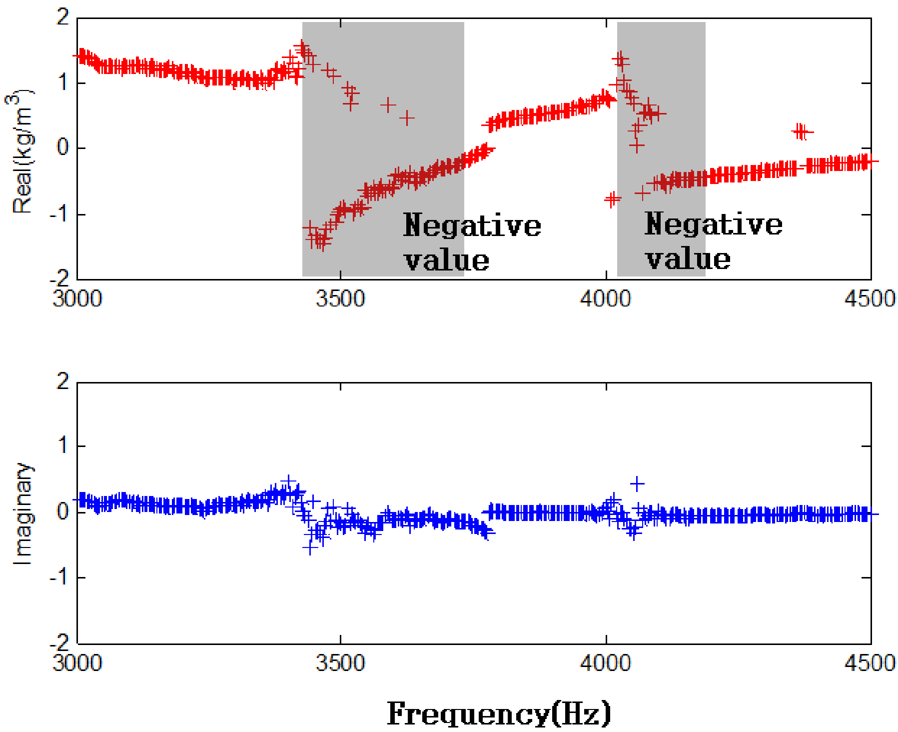

FIG. 3 Measured effective mass density of the unit cell of acoustic metamaterial