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Fabrication and evaluation of sound-absorbing meta-surface with coincidence-effect suppression

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1. Introduction

In recent years, noise problems associated with technological developments, such as transport and factories, has become an important issue. In the present study we focus in particular on the phenomenon of the coincidence effect as one of the essential keys to solving the issue. The coincidence effect[1] is an effect where the transmission of incident sound through a wall is enhanced when the wavelength of the wall deflection (lamb) wave coincides with the wavelength of the incident sound wave. In this study, we adopted designing an acoustic meta-surface[2-5] that is thinner than the wavelength of sound, but exhibits the sound insulation for wide range of frequency by suppressing the coincidence effect without additional sound absorbing materials or changing the wall thickness.

In our previous report, [6] we have designed a meta-surface structure to provide both sound insulation and sound absorption by periodically arranging holes in a plate and creating air inlets therein. The periodic structure can be regarded as a phononic crystalline structure on the plate surface. The phononic crystal[7] is an artificial material whose response properties to incident sound waves can be designed in terms of its dispersion relations (phononic band).

Simulations were carried out using a two-dimensional finite element method (FEM), after which the structures were actually fabricated and tested.

2. Acoustic Meta-Surface based on Periodic Structure

First, the sound transmission of aluminum plates with and without a periodic structure are compared by numerical simulations. In order to reduce the coincidence effect in thin plates, we have employed a grating structure by applying aluminum tapes periodically on one face of an aluminum plate. The unit cell of the proposed structure is shown in Fig. 1.

When a plane wave of 1 Pa is incident on a flat 3 mm thick aluminum plate without the periodic structure at an angle of incidence of 60°, the transmission loss drops significantly at 5310 Hz. As shown in the inset of Fig. 2, the plate is significantly displaced resonating to the incident wave, indicating that a coincidence effect occurs.

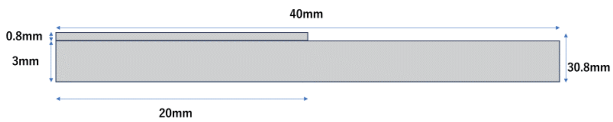

Fig. 1 Cross sectional view of unit cell in the proposed acoustic meta-surface (w/ periodic structure).

Figure 2 also shows that the transmission loss is recovered to high dB in the frequency for the plate with periodic structure. The inset of Fig. 2 depicts that the displacement in the periodic structure at the coincidence frequency is very small compared to the displacement in the plate without the structure. This implies that the existence of gap frequencies where Bragg scattering of Lamb waves takes place in the thin plate, thus blocking sound near the frequency of the coincidence effect.

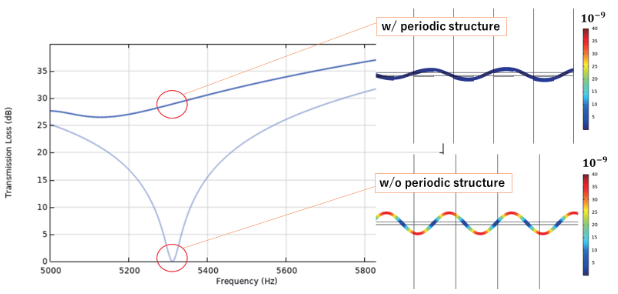

Fig. 2 Transmission loss spectra and (inset) displacement distributions in the Al plates with and without periodic structure at 5310 Hz.

3. Experimental measurement

The structure shown above was fabricated and the magnitude of the vibrations was measured using a Laser-Doppler vibrometer[8]. As the coincidence effect causes the plate to vibrate significantly when it occurs, the presence or absence of this phenomenon was confirmed by measuring the magnitude of the vibration using the vibrometer. The aluminum plate has the dimension of 200 mm high, 300 mm wide, and 3 mm thick. The periodic structure proposed in this study was fabricated by applying eight aluminum tapes of 0.1 mm thickness. Figure 3 shows the results of the vibrometer measurements. The peak around 5300 Hz of the spectrum, where the significant plate oscillations

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was observed, indicates that the coincidence effect has taken place in the plate without the periodic structure. On the other hand, the reduction of the peak is clearly observed in the plate with periodic structure, implying the coincidence effect was suppressed efficiently by the proposed structure.

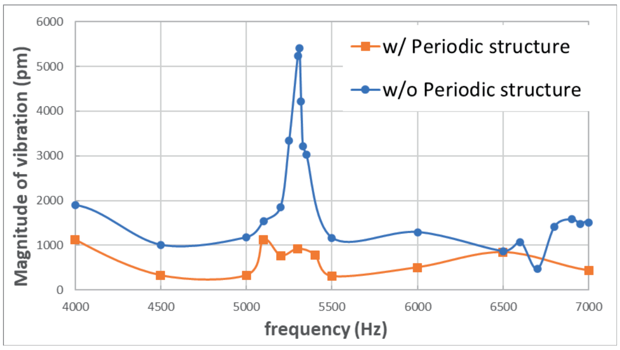

Fig. 3 Experimental results for the magnitude of vibration of normal plate and Structure 1.

4. Design of sound-absorbing meta-surface

In addition to the sound insulation, we also aimed for implementing a sound-absorbing function in the meta-surface. As shown in Fig. 4, a polypropylene membrane was applied to cover the holes between the aluminum tapes. This structure was adopted based on a sound-absorbing device called a decorated Membrane Resonator (MR)[3], where the enhanced vibration of the membrane is induced through the normal mode of the membrane and its hybrid mode with the air layer.

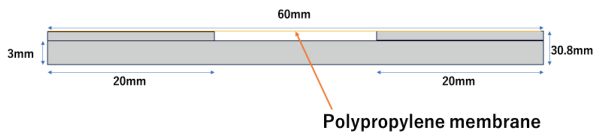

Fig. 4 Sound-absorbing structure with PP membrane (periodic MR).

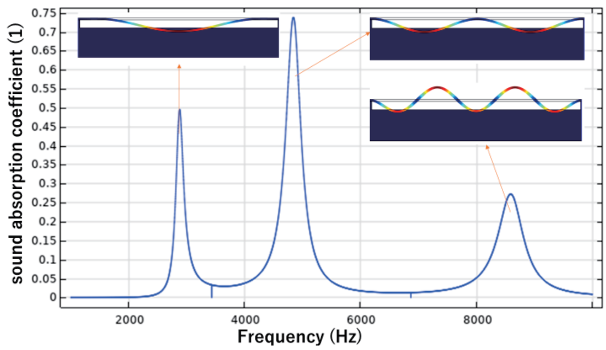

Fig. 5 Sound absorption spectrum of periodic MR and mode profiles of the membrane at the peaks indicated by the red arrows.

Figure 5 shows the simulation results of the sound absorption of the proposed meta-surface structure (referred as "periodic MR") shown in Fig. 4. The vibrational mode profile for each of the three peaks in the spectrum is also shown in the inset of the figure. These figures indicate that the energy of the incident sound wave is converted into thermal energy through the vibration of the membrane, leading to the efficient sound absorption. This can be regarded as a similar mechanism elaborated in the decorated MR. The frequency at which sound absorption occurs depends on the deformation mode of the membrane. We thus find that the addition of PP membranes to the grating structure in an aluminum plate not only provides coincidence-effect suppression, but also a sound-absorbing effect.

Conclusion

Using FEM simulations, an acoustic meta-surface structure with periodic aluminum tapes was designed to prevent the occurrence of coincidence effects. Experimental measurements for the proposed structure actually fabricated were carried out with a laser-doppler vibrometer. The results showed that the coincidence effect was effectively suppressed. This approach can be applied to various structures where high sound insulation performance is required in a limited space and weight.

It was also confirmed by FEM analysis that adding a PP film onto the periodic structure could produce a sound absorbing effect. The fabrication of the sound-absorbing structure and the experimental approach to an examination of the sound absorption effects will also be discussed in the presentation.

Acknowledgement

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