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Design of Acoustic Meta-surfaces with Both Coincidence Effect Suppression and Sound Absorption Functions

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1. Introduction

The coincidence effect[1], an enhanced transmission of incident sound through the wall, occurs when the wavelength of the wall flexual (Lamb) wave and that of the incident sound wave coincide with each other. This effect has to be always considered in designing structural components of buildings, infrastructures, and automobiles.

In this study, we focused on 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. The two-dimensional finite element method (FEM) was employed to search for the optimum structure that exhibits the above characteristics in the audible frequency range (1000 Hz to 3000 Hz).

2. Acoustic Meta-Surface based on Periodic Structure

To reduce the coincidence effect in thin plate, we adopted to introduce a periodic array of hole in the plate. **Figure 1** illustrates the unit cell of the proposed structure. When a plane wave of 1 Pa is incident on a 26 mm thick aluminum wall without holes at an incident angle 30°, the transmission loss drops significantly at 1938 Hz, as designated as "Normal wall" in **Fig. 2**. As illustrated in the inset of Fig. 2, the wall is greatly displaced in response to this wave, indicating the occurrence of the coincidence effect.

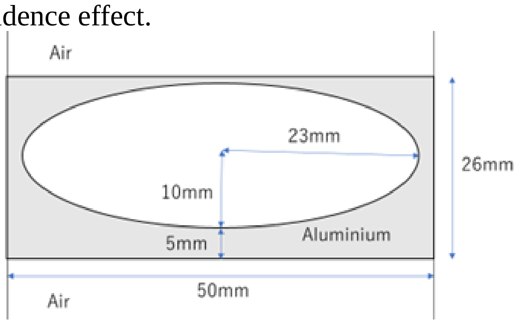

Fig.1 Cross section view of unit cell in the proposed acoustic meta-surface (Structure 1).

Figure 2 shows that in the case of the plate with periodic hole array ("Structure 1"), the transmission loss is kept at high dB in the frequency range where the coincidence effect has occurred in the "Normal wall". The inset of Fig. 2 also shows that the displacement in Structure 1 at the frequency is extremely small compared to that in the normal wall. This can be attributed to the presence of gap frequency where the Bragg scattering of the Lamb wave is undertaken in the thin plate, thereby blocking sound around the frequency at which the coincidence effect occurs.

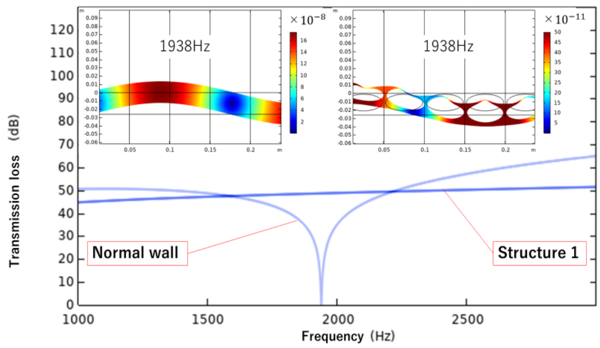

Fig. 2 Transmission loss spectra and (inset) displacement distributions in the "normal wall" and "Structure 1" at 1938 Hz.

In addition to the sound insulation by suppressing the coincidence effect, we aimed an additional function in the meta-surface by introducing a neck at the top of the hole, as depicted in **Fig. 3**. **Figure 4** shows transmission loss spectrum of the metasurface structure depicted in Fig.3 (designated as "Structure 2"). The figure indicates that Structure 2 not only prevents the coincidence effect, but also shows a peak where the transmission loss increased. Several sound-absorbing meta-surfaces have been proposed recently, *e.g.* a sound-absorbing device called Decorated Membrane Resonator (DMR)[3], which induces enhanced vibration of a membrane via its hybridized mode between membranes' normal modes and an air layer. Sound energy is converted into thermal energy through the vibration of the material, resulting in the efficient sound absorption. In the present model, the sound absorption is caused

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by the vibration of the neck section. The vibration of the wall is considerably reduced, and hence the transmission becomes low, while the reflection is also small at the frequency. This indicates highly efficient energy conversion from sound to neck vibration occurs predominantly through the mechanism described above at the frequency.

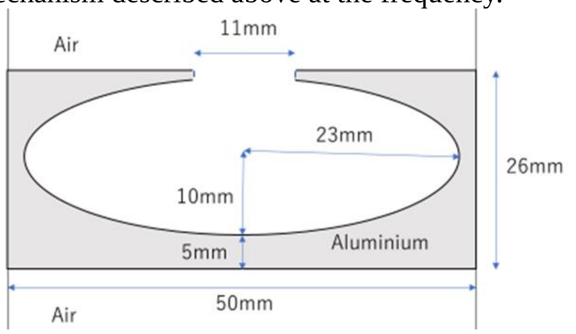

Fig. 3 Cross section view of unit cell in the proposed acoustic metasurface with sound absorption (Structure 2).

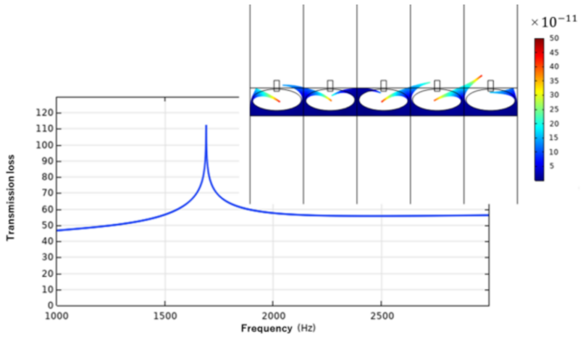

Fig. 4 Transmission loss spectrum for Structure 2 and (inset) displacement distribution at the peak frequency.

Conclusion

By using the FEM analysis, we have designed two types of acoustic meta-surface structure with periodically arranged holes that prevent the occurrence of the coincidence effect as well as the sound absorption function. As a result, the coincidence effect was efficiently suppressed and a peak with a considerably higher transmission loss was obtained due to the sound absorption effect generated by the resonant vibration of the neck in the structure. The proposed approach may be used various structures where the high insulation of sound is required within limited space and weight.

Further designing of multiple absorption peaks toward the wider band applications is being investigated. The actual fabrication and measurement of these proposed structures will be performed and reported in the presentation.

Acknowledgement

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