Modeling and Sound Insulation Performance Analysis of Two Honeycomb-hole Coatings

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Abstract. During the sound transmission loss test in the standing-wave tube, the unavoidable reflected wave from the termination of downstream tube would affect the precision measurement of sound transmission loss (TL). However, it can be solved by defining the non-reflected boundary conditions when modeling based on the finite element method. Then, the model has been validated by comparing with the analytical method. Based on the present model, the sound insulation performance of two types of honeycomb-hole coatings have been analyzed and discussed. Moreover, the changes of parameters play an important role on the sound insulation performance of honeycomb-hole coating and the negative Poisson's ratio honeycomb-hole coating has better sound insulation performance at special frequencies. Finally, it is summarized that sound insulation performance is the result of various factors that include the impedance changes, the waveform transformation and so on.

1. Introduction
The acoustic coatings that are laid on the surfaces of underwater machines and have kinds of functions such as sound absorption, sound insulation, vibration suppression, shock resistance and so on. And they are the key and the only technology that can resist active and passive detections. Acoustic coatings usually are viscoelastic composite structures that have kinds of hole types, such as spherical holes and column holes as in [1]. The coatings also can be filled with locally resonance scatterers as in [2]. While sound absorption property of these structures are good, they possess other properties as well. For example, sound insulation property of a kind of cylinder hole coating under static pressure had been analysed by Panigrahi as in [3].

Honeycomb-hole coating has been applied in many fields for its high intensity and impact resistance. As for noise control, Ruzzene has analysed the vibration and sound radiation of sandwich beams with honeycomb truss core in the air by the finite element method as in [4]. And Zhao has analysed transmission coefficient and sound transmission loss of underwater honeycomb truss structures by transfer matrix method and percentage of sound energy method and got the conclusion that as for sound insulation property, this structure has better performance among circular hole rubber coating and solid rubber coating under the condition of same thickness as in [5]. As in [6], honeycomb-hole coating that is set vertically between upper and lower panels is similar to traditional cylinder hole coating in structural style, but it has bigger deformation and more influence on acoustic property under static pressure.

Changing the arrangement of the hole as the holes are set to be parallel to panel instead of the vertical arrangement has little influence on acoustic property when static pressure changes. In this paper, sound transmission property of honeycomb-hole coating that is in parallel array has been
analysed. Based on the three-microphone method, sound transmission loss computational model has been established by ANSYS software; then, the influence of structural parameters on sound insulation property has been analysed; finally, the difference of sound insulation theories at low and medium high frequencies has been analysed.

2. Finite element method model and its verification

The actual measurement of TL in standing wave tube is to use the four-microphone method for the reason that complete sound absorption is difficult to realize at the end of downstream tube and unavoidable reflected wave will influence the accuracy of the result. When the FEM is adopted, the influence of the reflected wave at the end can be eliminated by modifying the end into perfect reflecting boundary condition in FEM software. So, setting one sensor in the tube is enough to measure sound pressure of transmitted wave directly.

As shown in figure 1, a finite element model for TL calculation has been established, and standing wave tube is in the form of circular waveguide and the plane wave is incident to the sample at normal incidence in the model. The side face of sample has been set as symmetry constraint to simulate the situation that the plane wave is incident to the infinite sample at normal incidence. To eliminate reflected waves at the source surface of upstream tube and the terminal surface of downstream tube and make sure that there is once incidence, once reflection and once transmission in the standing wave tube, the nonreflecting boundary condition is applied on the two faces. It should be noted that loss factor can be defined by setting the stiffness damping coefficient $\beta$. Besides, former and latter interfaces of the coating should be set as fluid solid coupling surfaces because the difference of characteristic impedance between the water and the honeycomb structure is not much.

![Finite element model for sound transmission loss calculation](image)

**Figure 1.** Finite element model for sound transmission loss calculation

In the upstream tube, the pressure $p_1$ and $p_2$ are measured independently by two microphones meanwhile. And steady state signal transmitting in the upstream tube can be resolved into two parts: one is the incident wave $p_i$ that transmits along the positive $x$ direction and the other is the reflected wave $p_r$ that transmits along the negative $x$ direction as in [7]. The formula is as:

$$p_1 = \frac{p_2 - p_1 e^{jkd}}{e^{jkd} - e^{jkd}}$$

(1)

where $d$ is the distance between the microphone ① and ②, $p_1, p_2$ are pressures measured respectively by the microphone ① and ②, and the pressure of transmitted wave $p_t$ is measured by microphone③.

To verify the correctness of the model, the two-dimensional solution of acoustic characteristics of anechoic coating containing varying sectional cylindrical cavity as in [1] is used to compare. Figure 7 in [1] has showed sound absorption coefficient of the varying sectional cylindrical cavity under rigid backing condition, so only the upstream tube and the sample need to be established in the FEM model and the calculation of sound absorption coefficient is based on the transfer function method as in [8]. When calculating, the pressure $p_1$ and $p_2$ are measured by microphones in the tube. This kind of
comparison that sound absorption coefficients are used to compare is reasonable because calculations of sound absorption coefficient and sound transmission loss are based on the same FEM model.

Figure 2 has shown the result of comparison between the two-dimensional solution and the result of the FEM. As shown in the figure, the error between two results is relatively large at medium high frequencies because varying sectional cylindrical cavity that is the actual model had been replaced by uniform sectional cylindrical cavity that is the approximate model when analyzing based on two-dimensional model and this difference between two models made the error bigger when frequency increased. Besides, reflection coefficient of the sealing layer of cylindrical hole is 1 in two-dimensional model while the FEM model was established based on the actual shape, which would cause the error as well. Despite all this, calculation results of two methods matched well in general, which illustrates the correctness of the FEM model established in this paper.

**Figure 2.** Comparison of sound absorption coefficient of cylindrical-hole coating

3. **Analysis of sound insulation property of cylindrical-hole coating**

Figure 3 shows the schematic of honeycomb-hole coating and figure 4 shows the in-plane schematic of honeycomb-hole coating. Figure 5 shows the schematic of negative Poisson's ratio honeycomb-hole coating. Two sets of parameters mainly decide sound transmission loss property of cylindrical-hole coating. One is the structural parameter shown in figure 4 as: the distance between cores of holes $a=5\text{mm}$; the wall thickness $t=0.8\text{mm}$; and thickness of front and back panels is $h_f = h_b = 1.5\text{mm}$. The other one is material parameter as: the density is $\rho = 1200\text{kg/m}^3$; Young's modulus is $E = 100\text{MPa}$; loss factor is $\eta_E = 0.2$; and Poisson's ratio is $\nu = 0.49$.

**Figure 3.** Schematic of honeycomb-hole coating

**Figure 4.** In-plane schematic of honeycomb-hole coating
3.1. **Influence of cell angles**

Under the condition that cell thickness of honeycomb-hole coating is unchanged, the change of cell angles has influence on TL property as well. As shown in figure 4, the included angle $\alpha$ is the angle between the bevel edge of honeycomb and the horizontal line. TL of honeycomb-hole coating has shown in figure 6 with different angles. The change of angle has great influence on the cycle and figures of sound transmission loss. Viscoelastic waves will reflex at the angle and the change of the angle will change the impedance that will influence TL. So, the smaller angles are, the more sound transmission loss is. In other words, the smaller angles will cause the more reflection and loss, so, the transmitted energy is less and sound transmission loss is more.

Displacement contour of honeycomb-hole coating has showed in figure 7 when the angle is 45 degree and the plane wave is incident at normal incidence at 6.5kHz, which is corresponding to the frequency of the fourth maximum value in the TL curve. At the medium high frequencies, there is waveform transformation that means there is not only the longitudinal vibration but also the obvious transverse vibration in the coating, which is different from the situation at low frequency. Because the loss factor of transverse vibration is far greater than the loss factor of longitudinal vibration, TL at the medium high frequencies exceeds 30dB.

3.2. **Comparison with negative Poisson's ratio honeycomb-hole coating**

Sound transmission loss of negative Poisson's ratio honeycomb-hole coating has shown in figure 8 with different angles that are 60°, 70° and 80°. From the result, the change of the angle has little influence on the cycle and numerical value of sound transmission loss at the medium high frequencies. Sound transmission loss with different angles is under 20dB when the frequencies are under 5kHz, but it increases obviously when the frequencies are above 6kHz. In particular, sound transmission loss with different angles reaches the maximum value at about 7kHz, 8kHz and 9kHz respectively and the maximum values are over 70dB, which is different from the result of normal Poisson's ratio honeycomb-hole coating.

Displacement contour of negative Poisson's ratio honeycomb-hole coating when the angle is 70° has showed in figure 9 when the plane wave is incident at normal incidence at 7.5kHz. The main
displacement happens at the excitation end of the coating. Because this kind of structure of negative Poisson's ratio can block the transmission of viscoelastic waves, displacements at the middle and back parts are not very obvious and the vibration at back part is really small. So, the negative Poisson's ratio honeycomb-hole coating has a good sound insulation property.

![Figure 8. Sound transmission loss of negative Poisson's ratio honeycomb-hole coatings](image)

**Figure 8.** Sound transmission loss of negative Poisson's ratio honeycomb-hole coatings

![Figure 9. Displacement contour of negative Poisson's ratio honeycomb-hole coatings, 7.5Khz](image)

**Figure 9.** Displacement contour of negative Poisson's ratio honeycomb-hole coatings, 7.5Khz

4. Conclusion

Based on test method of sound transmission loss in standing wave tube, a FEM model of honeycomb-hole coating has been established by ANSYS software and the correctness of the model has been validated by comparing with the result of analytic method. Then, the influence of structural parameters and material properties on sound transmission loss has been analyzed as: (1) sound insulation property of honeycomb-hole coating is influenced by multiple factors that include impedance mismatch, waveform transformation, damping loss and so on; (2) the change of cell thickness and other parameters has a prominent influence on sound transmission loss of the coating.

References

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Acknowledgements

This work was supported by the Natural Science Foundation of China Grant No. 51765008, Guizhou High-level Innovative Talents Program Grant No.2016-4033, and Guizhou University Innovation and Entrepreneurship Training Program Grant No. 2014-010.