Sound Insulation Performance of Honeycomb-hole Panels

Wen-qing CHEN, Meng TAO* and Han-feng YE

School of Mechanical Engineering, Guizhou University, Guiyang, China

*Corresponding author

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Abstract. Honeycomb structure is nowadays used widely by the industrial sector. Using the three-microphone method of measuring sound transmission loss (STL) in the standing wave tube, the finite element analysis model of the honeycomb-hole panels was established to calculate STL. Sound insulation performance of honeycomb-hole panel was analyzed by using the analysis model. The effects of holes element spacing, wall thickness of holes element, panel thickness, loss factor and Young’s elastic modulus on sound insulation performance of the honeycomb-hole panel have been investigated and summarized: wall thickness of holes element, panel thickness and Young’s elastic modulus have greater effect on sound insulation performance. The result provides a reference for the engineering design and optimization of such kind of structures.

Introduction

Honeycomb structure has a good anti-vibration and sound insulation performance, and has been widely used in the space, ships, vehicles and other fields. Many scholars have studied the sound insulation performance from theory, experiment and numerical methods, and found that the use of honeycomb structure is beneficial to improve the overall sound insulation performance of light panel, especially in low frequencies[1-3]. Lu[4] gave a general model of the acoustic behavior of the foams to predict the sound absorption. Ren[5] established the vibration governing equation of the honeycomb sandwich panels to investigate the vibroacoustic performance. Wu[6] analyzed the effect of the structural parameters of honeycomb sandwich panels by theoretical model.

The honeycomb-hole panel is divided into two parts: an intermediate honeycomb holes structure which arranges with regular hexagonal holes and a sealing panel for wrapping the honeycomb structure. The main parameters of the honeycomb-hole panel include the holes element spacing \( l \), the wall thickness of holes element \( b \), the panel thickness \( h \), the panel length \( a \) and the thickness of the sealing panel \( h_0 \). The two-dimensional and three-dimensional structures of the honeycomb-hole panel are shown in Figure 1.

![Figure 1. The structure of honeycomb-hole panel.](image)

To analyze the sound insulation performance of the honeycomb-hole panel, a finite element analysis model for calculating the sound transmission loss is established by LMS Virtual. Lab. Using the finite element analysis model, the sound insulation performance of the honeycomb-hole panels with different structural and material parameters are investigated numerically, including the holes element spacing, the wall thickness of holes element, the panel thickness, the loss factor and the Young’s elastic Modulus.
Finite Element Analysis Model

The sound transmission loss of honeycomb-hole panel can be determined by using LMS Virtual. Lab software. The finite element analysis model of the infinite honeycomb-hole panel is established according to the basic principle of Figure 2. The panel sound wave is incident perpendicularly from the sound field of the incident surface, which causes the vibration of the honeycomb holes panel and fluid in the holes and the acoustic response of the acoustic field of the transmission surface. When the finite element analysis model of the honeycomb-hole panel is set up in LMS Virtual. Lab Acoustics, there are several technical details should be mentioned.

The cross section of the fluid and the sample is a square with a side length of 100 mm. The outlet of the transmission surface fluid is defined the full sound absorption boundary attribute is used to simulate the non-reflective condition, and the symmetrical boundary constraints is set at the boundary of the measured sample to simulate the infinite structure. The fluid-solid coupling between the air in the holes and the structure is weak relatively, which has little effect on the vibration and acoustic properties of the whole structure of the panel. Therefore, the finite element analysis model ignores the fluid-solid coupling between them.

\[
\begin{align*}
  t_p &= 2 \sin (kS) \frac{p_3}{p_1} e^{i \beta L_1} e^{-i \beta L_2} \\
  STL &= -20 \log |t_p|
\end{align*}
\]

where \(S\) is the distance between the field point ① and the field point ②, \(L_1\) is the distance between the field point ② and the left surface of the honeycomb-hole panel, \(L_2\) is the distance between the field point and the right surface of the honeycomb-hole panel, \(p_1, p_2, p_3\) is measured complex sound pressure of field point ①,②,③, respectively, \(k\) is the wave number, and \(j = \sqrt{-1}\).

Effect of Structural and Material Parameters on Sound Insulation Performance

In order to investigate the effect of the structural parameters of the infinite honeycomb-hole panel on its sound insulation performance, several finite element models of different structural parameters are established. Table 1 is the specific structural parameters of the different number of honeycomb-hole panels which are obtained by changing one of the structural parameters and keeping other relevant structural parameters unchanged. Besides, assuming the Young’s elastic modulus of material is 100MPa, the Poisson’s ratio is 0.39, the loss factor is 0.05, and the mass density is 1050\(\text{kg/m}^3\). In this paper, the finite element analysis model will be used to analyze the sound insulation performance of the honeycomb-hole panels in Table 1 and the effect of different structural parameters and different material parameters on its sound insulation performance.

<table>
<thead>
<tr>
<th>Panel number</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Holes element pacing</td>
<td>6.25</td>
<td>5.75</td>
<td>5.25</td>
<td>6.25</td>
<td>6.25</td>
<td>6.25</td>
<td>6.25</td>
</tr>
<tr>
<td>Wall thickness of</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.50</td>
<td>2.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Figure 2. The model of three-microphone method of STL.

As shown in Figure 2, the sound pressure transmission coefficient \(t_p\) and the sound transmission loss \(STL\) can be obtained by getting the complex pressure values of two microphones from the incident tube and one microphone from the transmission tube:

\[
\begin{align*}
  t_p &= 2 \sin (kS) \frac{p_3}{p_1} e^{i \beta L_1} e^{-i \beta L_2} \\
  STL &= -20 \log |t_p|
\end{align*}
\]

where \(S\) is the distance between the field point ① and the field point ②, \(L_1\) is the distance between the field point ② and the left surface of the honeycomb-hole panel, \(L_2\) is the distance between the field point and the right surface of the honeycomb-hole panel, \(p_1, p_2, p_3\) is measured complex sound pressure of field point ①,②,③, respectively, \(k\) is the wave number, and \(j = \sqrt{-1}\).
### Sound Insulation Performance

Figure 3 is sound transmission loss curve of the honeycomb-hole panel 1. From 100Hz to 2900Hz, the sound transmission loss of the honeycomb-hole panel increases with the increasing of frequency and reaches the maximum value (40.79dB) at 2900Hz. Then the sound transmission loss begins to decrease, and the curve appears trough (22.43dB) at about 5500Hz. The frequency happens to be the same as the natural frequency of the honeycomb-hole panel, so the honeycomb-hole panel resonates, which causes the violent vibration of the particle in the panel’s right surface. Finally, the acoustic power of the panel increases rapidly, and the sound transmission loss curve drops sharply. After leaving the resonant frequency, the sound transmission loss curve rises sharply, and a new peak (8200Hz, 44.93dB) appears. After 10 kHz, the sound transmission loss curve is not calculated, but it is not difficult to predict that the overall sound transmission loss of the honeycomb-hole panel will increase with frequency increasing and decrease at the resonant frequency.

It is worth noting that the sound transmission loss curve has a small vibration around 3400 Hz. It is the error caused by grid accuracy of the finite element method, but not the causing of the honeycomb-hole panel. It does not affect the sound insulation performance of the honeycomb-hole panel, so the similar vibration has be ignored in latter analysis.

![Figure 3. STL of infinite honeycomb-hole panel](image)

![Figure 4. STL of honeycomb-hole panels with different holes element pacing.](image)

### Different Holes Element Pacing

Figure 4 shows the sound transmission loss curves of the honeycomb-hole panel (panel 1, 2 and 3) with different holes element spacing. As seen in the figure, the spacing of the holes element has little effect on the overall sound transmission loss of honeycomb-hole panel. The smaller the spacing between the holes is, the more lateral honeycomb holes are, and the greater the attenuation of lateral vibration displacement in the direction perpendicular to the sound wave propagation is, so the sound transmission loss increase slightly. In general, since the lateral vibration displacement is weaker compared to the vertical vibration displacement, the difference in sound transmission loss of them is
not significant. In addition, the structure changes slightly, so the trough of the sound transmission loss curve corresponding to the resonant frequency is slightly different.

**Different Wall Thickness of Holes Element**

Since the sealing panel is also structurally a panel wall, the thickness of the sealing panel of the panel 1, 4 and 5 is set as the wall thickness of the corresponding holes element, respectively. As seen in the Figure 5, the wall thickness of holes element has a significant effect on the sound transmission loss of the honeycomb-hole panel. With the wall thickness of holes element increasing, the sound transmission loss increases almost at the whole analytical frequencies. The wall thickness of holes element is the main structural parameter that affects the sound transmission loss. Besides, at high frequencies (5kHz - 10kHz), with the wall thickness of holes element increasing, the frequency corresponding to the trough of sound transmission loss curve moves to higher frequencies. This is reason for that the overall structural stiffness of the honeycomb-hole panel increases. Thus, increasing the wall thickness of the holes element can improve the sound insulation performance but increase the overall mass of the panel.
Different Panel Thickness

In Table 1, the honeycomb-hole panel 1, 6 and 7 are differentiated according to the number of layers of honeycomb holes, which has 3, 1 and 5 layers of honeycomb holes, respectively. Figure 6 shows the sound transmission loss curves of the honeycomb-hole panel (panel 1, 6 and 7) with different panel thicknesses. As seen in the figure, with the panel thickness increasing, the sound transmission loss also increases at low frequencies (100Hz - 2kHz). Besides, for each additional two-layer honeycomb holes, the sound transmission loss increases about 3dB. With the panel thickness increases, the number of transmissions and reflections of the sound waves in the honeycomb structure increases. Continuous reflections and transmissions produce more propagation paths in panel so that more vibrations are attenuated and more sound waves are blocked. Moreover, the trough at high frequencies moves to lower frequencies, then the sound transmission loss rises up to about 45dB. Thus, an increase of panel thickness will reduce the natural frequency of the honeycomb-hole panel.

Different Loss Factors

Figure 7 shows the sound transmission loss curves of the honeycomb-hole panel 1 with different loss factors. As seen in the figure, the loss factor mainly affects the sound insulation performance of the trough. The bigger loss factor is, the more sound waves energy consumed at the resonant frequency, and the gentler trough of the sound transmission loss curve will be. Besides, the sound transmission loss of the non-resonant frequencies is almost unchanged, and the loss factor does not affect the overall sound insulation performance of the honeycomb-hole panel.

Different Young’s Elastic Modulus

Figure 8 shows the sound transmission loss curves for three different Young's elastic moduli of honeycomb-hole panel 1. With the Young's elastic modulus increases, the trough of sound transmission loss curve moves to higher frequencies. This is because the Young's elastic modulus represents the stiffness of the structure, and the structural stiffness affects the resonant frequency of the honeycomb structure. Since the trough moved, the frequency range of increasing sound transmission loss became wider, and the sound transmission loss before resonance became higher.

Conclusion

Based on the three-microphone measurement of sound transmission loss in standing wave tube, a finite element analysis model of honeycomb-hole panel is established. Then, the sound transmission loss curves can be obtained, which can be used to illustrate the relationship between the sound insulation performance and the structural parameters, material properties of honeycomb-hole panels:

a) The holes element spacing, which mainly affect the lateral vibration displacement which is perpendicular to the sound waves propagation direction, has little effect on the overall sound
insulation performance of the honeycomb-hole panel. The panel with smaller holes element spacing has higher sound transmission loss.

b) The wall thickness of Holes element is the main structural parameter that affects the sound insulation performance of the honeycomb-hole panel. With the wall thickness increasing, the sound transmission loss increases almost at all analytical frequencies, and the resonance frequency moves to higher frequencies.

c) The panel thickness has a great effect on the sound insulation performance of low frequencies. With the panel thickness increasing, the trough of the sound transmission loss curve moves to lower frequencies.

d) With the Young's elastic modulus increasing, the resonant frequency of the honeycomb-hole panel increases and the sound transmission loss before the resonant frequency increases, too.

e) The loss factor mainly affects the sound transmission loss at the resonant frequency. The bigger loss factor is, the less the decrease of sound transmission loss at the resonant frequency will be.

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References


