The study on sound-absorbing properties of oblique micro-perforated panel

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Abstract

The oblique micro-perforated panel is distinct to ordinary micro-perforated panel in terms of structure, such as oblique appearance, and open holes are not orthogonal to the panel’s surface. According to Dr. Maa’s theory, the wide-band sound absorption characterization of micro-perforated panel absorber is determined by its high acoustic resistance and low acoustic mass reactance, he also derive its prediction formula in sound absorbing coefficient. The formula whether is applicable to oblique micro-perforated panel is the aim of this research.

The study measures the sound absorbing coefficient in reverberation room for 12 sets ordinary micro-perforated panels in 4 different back air space depths, with the purpose of exploring the effects of hole orientation, hole section slope, hole appearance-index, hole area, percentage of perforated area, hole depth, and uneven grade of surface.

Key word: micro-perforated panel, oblique micro-perforated panel, Dr. Maa’s theory, sound absorption material

1. Foreword

The sound absorption theory of micro-perforated panel had been derived by Dr. Maa at 1974 (reference 1). Based on the action of sound wave in tube, Dr. Maa derived the theory and prediction formula about acoustic impedance of micro-perforated panel. Furthermore, he derived the prediction formula of sound absorbing coefficient in perpendicular and random incidence respectively.

According to the research on sound absorption property of micro-perforated panel by Dr. Maa, the factors of sound absorption coefficient of micro-perforated panel including 1. hole diameter 2. hole depth 3. percentage of perforated area, 4. air space depth, 5. uneven grade.

The prediction formula in sound absorbing coefficient in diffuse field is showed as follow:

\[ \bar{\alpha} = \int_0^{\pi/2} \alpha_\theta \sin 2\theta d\theta \]  
(Eq.1)

where, \( \alpha_\theta \): the sound absorbing coefficient with the sound incidence angle \( \theta \).

\[ \alpha_\theta = \frac{4r \cos \theta}{(1 + r \cos \theta)^2 + [\omega m \cos \theta - \cot(\alpha D \cos \theta / c)]^2} \]  
(Eq.2)

\[ r = \frac{32 \mu}{pc} \left( \frac{t}{d^2} \left[ \sqrt{1 + \frac{x^2}{32}} + \frac{\sqrt{2} x d}{8 t} \right] \right) \]  
(Eq.3)

\[ m = \frac{t}{pc} \left[ 1 + \frac{1}{\sqrt{9 + \frac{x^2}{2}}} + 0.85 \frac{d}{t} \right] \]  
(Eq.4)

D : back air space depth
The small-hole side facing on back air space is defined as “funnel shape”, the large-hole side facing on air space is defined as “anti-funnel shape”

2.2 Back air space Depth:
4 kinds of depth: 5cm, 10cm, 20cm, 50cm.

2.3 Hole area:
As the hole is oblique, it divided into 1. small-hole side area. 2. large-hole side area.

2.4 Hole depth:
Defined as the depth of hole which is entirely-enveloped by the wall. Refer to H1and H2 in figure 3.

2.5 Percentage of perforated area:
The ratio of whole areas of small-hole side to the panel area.

2.6 Surface uneven grade:
It divided into 1. large-hole side surface uneven grade.(addressed as h1) 2. small-hole side surface uneven grade(addressed as h2). Refer to figure 3.

2.7 Hole appearance-index:
Calculated by the ratio of hole’s perimeter to perimeter of equal area circular hole. It also divided into two indexes 1. large-hole side appearance-index. 2. small-hole side appearance-index.

2.8 Inclination of $\theta$:
since the hole is not perpendicular to the surface, so we have the hole slope defined by Inclination of $\theta$.

\[ x = \frac{d}{2} \sqrt{\frac{\rho_0 \omega}{\mu}} \]  
(Eq.5)

\[ \mu \] : kinematic viscosity of air
3. The Relationship between Structure Factors of Absorbers and Sound Absorption Coefficients

3.1 The inference of hole shape:

【figure 4】show the sound absorption coefficients of one of the oblique micro-perforated panel samples on different hole shape. The difference of the average of sound absorption coefficients on “anti-funnel shape” and “funnel shape” is not distinct, and each standard deviation of the 1/3 octave band sound absorption coefficients is less than 0.04, reveal the inference of hole shape on $\alpha$ is not significant.

As the sound absorption coefficients between 160Hz–250Hz on anti-funnel shape setting is slightly higher than these on funnel shape, the study select anti-funnel shape as the other samples’ setting mode.

3.2 The inference of back air space depth:

With the adding of air space’s depth, the average of sound absorption coefficients of oblique micro-perforated panel absorbers increase, and the resonant frequency moves toward low frequency. Illustrated as 【figure 5】.

Because the dimensions of the 12 oblique micro-perforated panel’s structure factors are different from each other, the study analyzes the correlations of individual structure factor and sound absorption coefficient with statistics, and use SPSS software.
As the correlate analysis shows the significant correlations of lots of structure factors (probability value < 0.05), the study analyse the true correlations between individual structure factor and sound absorption coefficient with partial correlation coefficient.

The study using statistics software SPSS to calculate the partial correlation coefficients of the individual structure factor and 1. oblique micro-perforated panel absorber’s sound absorption coefficients obtained by testing (address as $\alpha_T$). 2. the result of $\alpha_T$ subtract the calculated sound absorption coefficients of ordinary micro-perforated panel absorber (address as $\alpha_C$ which possess the same hole area (take small-hole side area for oblique micro-perforated panel), percentage of perforated area, depth of back opening and air space as oblique micro-perforated panel absorber. The ordinary micro-perforated panel is in the assumption of having even panel surface. The correlation analyses show as follow.

3.3 The correlation of hole area and sound absorption coefficient:
The correlation between large-hole side area and $\alpha_T$, large-hole side area and $\alpha_T - \alpha_C$, small-hole side area and $\alpha_T$, are not significant (probability value > 0.05). The partial correlation coefficients of small-hole side area and $\alpha_T - \alpha_C$ at 160Hz~3150Hz between 0.41~0.76.

3.4 The correlation of hole depth and sound absorption coefficient:
The correlation between hole depth H1 and $\alpha_T$, hole depth H2 and $\alpha_T$, are not significant.

3.5 The correlation of perforated area’s percentage and sound absorption coefficient:
The partial correlation coefficients of perforated area’s percentage and $\alpha_T$ at 200Hz~3150Hz between -0.31~ -0.74. The partial correlation coefficients of perforated area’s percentage and $\alpha_T - \alpha_C$ at 315Hz~3150Hz between -0.31~ -0.51.

3.6 The correlation of uneven grade and sound absorption coefficient:
The partial correlation coefficients of large-hole side surface uneven grade and $\alpha_T$ at 250Hz, 500Hz, 1000Hz, 2000Hz between 0.36~ 0.68. The correlation between large-hole side surface uneven grade and $\alpha_T - \alpha_C$, small-hole side surface’s uneven grade and averring of 125Hz~4000Hz $\alpha_T$, small-hole side surface’s uneven grade and averring of 125Hz~4000Hz $\alpha_T - \alpha_C$, are not significant.

3.7 The correlation of hole appearance-index and sound absorption coefficient:
The partial correlation coefficients of small-hole side appearance-index and $\alpha_T$ at 250Hz~4000Hz between 0.32~ 0.63. At 125Hz~4000Hz, the partial correlation coefficients of small-hole side appearance-index and $\alpha_T - \alpha_C$ between 0.44~ 0.90. The correlation between large-hole side appearance-index and averring of 125Hz~4000Hz $\alpha_T$ is not significant.

3.8 The correlation of Inclination of $\theta$ and sound absorption coefficient:
The correlation between Inclination of $\theta$ and $\alpha_T$ is not significant. Accept 1600Hz - 2500Hz - 4000Hz, the partial correlation coefficients of Inclination of $\theta$ and $\alpha_T - \alpha_C$ between -0.31~ -0.50.

4. Conclusion

According to the analysis of partial correlations and the theory of micro-perforated panel absorber’s sound absorption property, the study reveals the following conclusions.

1. The inference of hole shape to sound absorption coefficients is not significant. Sound absorption coefficient on anti-funnel orientation setting is slightly higher at low frequencies.

2. The average of sound absorption coefficients of oblique micro-perforated panel absorbers increase with the adding of back air space’s depth. And the resonant frequency also lower with the adding of back air space’s depth.

3. The correlations between hole area of large-hole side and sound absorption coefficients are
not significant (probability value > 0.05). The correlations of $\alpha$ and appearance-index of large-hole side, $\alpha$ and surface uneven grade of small-hole side are not strong.

4. Lowing perforated area’s percentage assists the increasing of sound absorption coefficients of oblique micro-perforated panel absorbers at middle and height frequencies.

5. The viscous drag force increasing with the adding of perimeter of equal area circular hole, may enhance the correlations between appearance-index of small-hole side and sound absorption coefficients.

6. The baffle effect may decrease the correlations of surface uneven grade of large-hole side.

7. The result of sound absorption coefficients of oblique micro-perforated panel absorbers subtract sound absorption coefficients of micro-perforated panel absorbers by calculated which with the same structure factors, could stress the adverse inference of inclination $\theta$ of hole to sound absorption coefficients of oblique micro-perforated panel absorbers.

5. Reference


