SOME NUMERIC AND EXPERIMENTAL STUDY OF MICRO-PERFORATED PANEL ACOUSTIC ABSORBERS WITH HETEROGENEOUS CAVITIES

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Abstract

The micro-perforated panel acoustic absorbers with heterogeneous cavities are widely used in acoustic engineering because of their advantage in wide frequency band. However, it is not easy to predict their acoustic impedance and absorption coefficients by theoretic or numeric method. A numeric method is suggested to predict the normal incidence acoustic absorption coefficient of the micro-perforated panel absorbers with heterogeneous cavities in this presentation. It can be considered as the combination of MAA Dah-you's theories about micro-perforated panel absorbers and the numeric simulation with finite element method. The acoustic absorption coefficients of three absorbers with triangular prism back cavities and one absorber with cone back cavity are calculated and measured in stationary wave tube to verify the numeric simulation. It can be found that the numeric predictions are in excellent agreement with the experimental results. Then, this method is used to forecast the absorption coefficient spectrum while designing a new noise barrier with a heterogeneous cavity, and the depth of back cavity and other parameters can be easily optimized. The predicted absorption coefficient spectrum of this acoustic barrier agrees well with that tested in reverberation chamber. All of these show that the presented method can be applied to predict the absorption performance of the micro-perforated panel absorbers with heterogeneous cavities instead of experiment. It will make the design of this kind of absorbers more convenient than before.

Key words: micro-perforated panel absorber, heterogeneous cavity, absorption coefficient

INTRODUCTION

Because the micro-perforated panel acoustic absorbers are able to endure high temperature, humidity, dust and prone to be cleaned, they are widely used in engineering with the requirement of high temperature, damp, fast airflow or high cleanliness in some halls such as natatorium, gymnasium, auditorium and so on. In recent years, the micro-perforated panel acoustic absorbers with heterogeneous cavities are come to be applied, because they have wider absorption frequency band than those with uniform cavities[1,2]. The acoustic absorbers composed of such kind of structure are available in some cases with limitation to the width of absorption frequency band and the thickness of acoustic absorbers, such as in the barriers along the lightweight railways, subways and highways.

However, the absorption performance of the micro-perforated panel acoustic absorbers with heterogeneous cavities can only be analyzed in experimental method, which increases the labor and cost in designing. It will be helpful for engineers to develop an effective procedures to predict the acoustic absorption spectrum of the micro-perforated panel acoustic absorbers with heterogeneous cavities. The analogy circuit of the micro-perforated panel acoustic absorber with heterogeneous cavity is suggested firstly according to the analogy principle between acoustics and electrics in this presentation. Secondly the characteristic impedance of micro-perforated panel is calculated by the theories for micro-perforated panel absorbers proposed by MAA Dah-you. Thirdly the input acoustic impedance of heterogeneous cavity is calculated by finite element method. Finally, the acoustic impedance of the whole absorber can be estimated and the spectrum of acoustic absorption coefficient can be evaluated, which can be used to predict the absorption performance of acoustic absorbers.

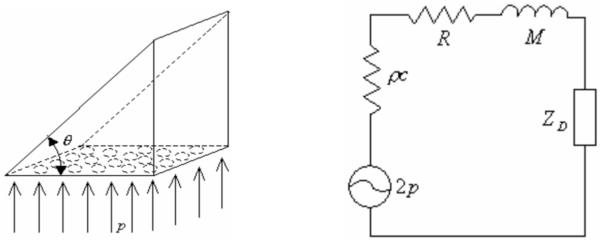

Figure 1　A general configuration of the micro-perforated panel absorber with triangular prism back cavity and its analogy circuit

THE CALCULATION METHOD FOR MICRO-PERFORATED PANEL ACOUSTIC ABSORBERS WITH HETEROGENEOUS CAVITIES

A general configuration of the micro-perforated panel absorber with triangular prism back cavity is shown in figure 1, where θ is the obliquity of cavity. According to the analogy principle between acoustics and electrics, we can get its equivalent circuit at normal incidence as shown in figure 1, where p is sound pressure of sound wave, ρ is the density of air, c is sound speed in air, R, M are respectively the acoustic resistance and acoustic mass of the micro-perforated panel. And Z_D is acoustic capacitance of back cavity.

The Acoustic Impedance Of The Micro-Perforated Panel

The acoustic impedance Z_{Spanle} of the micro-perforated panel is given as [3~5]

$$Z_{Spanel} = R + j\omega M = \rho_0 c_0 z \tag{1}$$

Where ω is the angular frequency of excitation. The relative acoustic impedance z can be written as follows:

$$z = r + j\omega m \tag{2}$$

The relative acoustic resistance and acoustic mass reactance can be derived respectively as following:

$$r = \frac{0.15tk_r}{pd^2}, \qquad \omega m = \frac{1.85\times10^{-3}\, ftk_m}{p} \tag{3}$$

k_r and k_m can be calculated by：

$$k_r = \sqrt{1+\frac{k^2}{32}} + \frac{\sqrt{2}}{8}\frac{dk}{t}, \qquad k_m = 1 + \frac{1}{\sqrt{9+\frac{k^2}{2}}} + \frac{0.85d}{t} \tag{4}$$

The constant k of the micro-perforated panel can be written as follows:

$$k \approx d\sqrt{f/10} \tag{5}$$

where t, p and d express respectively the thickness, porosity and hole radius of micro-perforated panel, and f expresses the frequency of excitation.

Calculation Of The Input Acoustic Impedance Of Back Cavity

The sound wave entering into the cavity will be reflected by complicated boundaries of back cavity, which makes distribution of sound field in the cavity become very complex. It is very difficult to obtain the solution of the distribution of sound field in the back cavity and impedance in closed form. The finite element method is suggested to model the acoustic field in the cavity as shown in figure 2. All boundaries except the micro-perforated panel could be regarded as rigid surfaces. Defining harmonic vibration velocity excitation on the surface with micro-perforated panel, the amplitude of velocity can be supposed arbitrarily such as 0.01m/s and the phase as zero. Once the sound pressure p_i and particle velocity v_i of every field point at incidence surface can be understood as shown in fig 2 and fig 3.

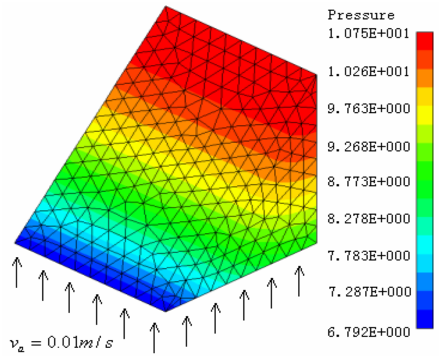

Fig.2 The sound field within the cavity

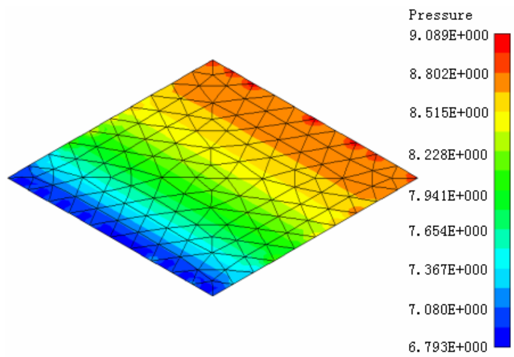

Fig.3 The sound field at incident surface

Then, characteristic impedance Z_{Si} of every field point can be calculated by

$$Z_{Si} = \frac{p_i}{v_i} \qquad i = 1,2,\cdots, \quad n \tag{6}$$

Where, n is the number of field point on the incidence surface.

The average input characteristic impedance of cavity $Z_{Scavity}$ can be calculated as follows:

$$Z_{Scavity} = \frac{Z_{S1} + Z_{S2} + Z_{S3} + \cdots + Z_{Sn}}{n} \tag{7}$$

Calculation Of Acoustic Absorption Coefficient

According to analogy circuit shown in figure 1, the normal characteristic impedance Z_{Sall} of the whole absorber shown in figure 1 can be calculated as follows

$$Z_{Sall} = R + j\omega M + Z_{Scavity} = R_{Sall} + jX_{Sall} \tag{8}$$

Where, R_{Sall} and X_{Sall} express respectively the real and imaginary parts of the normal characteristic impedance Z_{Sall}.

Then the acoustic absorption coefficient α can be calculated as follows[6,7]:

$$\alpha = \frac{4R_{Sall}\rho_0 c_0}{(R_{Sall} + \rho_0 c_0)^2 + X_{Sall}^2} \tag{9}$$

SIMULATION AND VERIFICATION

The acoustic absorption coefficients of four absorber specimens with different parameters are calculated by above method and also measured in stationary wave tube in order to validate the above method. The parameters of every absorber are as follows:

(1) The configuration of No. 1 specimen is described in figure 1. The obliquity θ is 45^{o}. The maximal depth of cavity is 120mm. The dimension, porosity, thickness and hole radius of the micro-perforated panel are 120mm×120mm, 0.8%, 1mm and 0.75mm respectively.

(2) The configuration of No. 2 specimen is described in figure 1. The obliquity θ is 60^{o}. The maximal depth of cavity is 208mm. The dimension, porosity, thickness and hole radius of the micro-perforated panel are 120mm×120mm, 0.77%, 0.8mm and 0.8mm respectively.

(3) The configuration of No .3 specimen is described in figure 1. The obliquity θ is 60^{o}. The maximal depth of cavity is 208mm. The dimension, porosity, thickness and hole radius of the micro-perforated panel are 120mm×120mm, 0.98%, 0.8mm and 0.8mm respectively.

(4) The configuration of No. 4 specimen is a taper with the height 200mm, and its micro-perforated panel is a circle. The diameter, porosity, thickness and hole radius of the micro-perforated panel are 120mm, 0.8%, 1mm and 0.75mm respectively.

Because the diameter and length of the stationary wave tube used to measure the acoustic absorption coefficients are respectively 100mm and 1000mm, the effective frequency range of it is 170~1992.4Hz. So the experimental results between 200Hz and 2000Hz are only available. The spectrum curves of calculated and measured acoustic absorption coefficients will be depicted in figures 4 ~ 7.

It can be found in figures 4~7 that the spectrum curve of calculated absorption coefficients agrees well with those of experimental results especially for their resonance frequencies. The reason why the experimental results are a little bit bigger than simulation is that the areas of the micro-perforated panel of specimens are bigger than the transverse section area of stationary wave tube. While acoustic absorber is fixed at the end of the stationary wave tube, some apertures on the micro-perforated panel are at the outside of the stationary wave tube. That lead a little part of sound wave will transmit through these apertures, especially for some lower frequencies due to better diffraction.

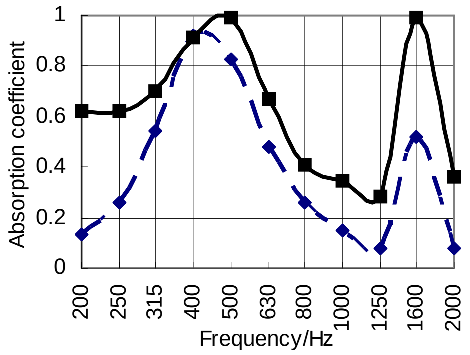

Figure4 Comparison of prediction vs. experiments (No. 1 specimen)

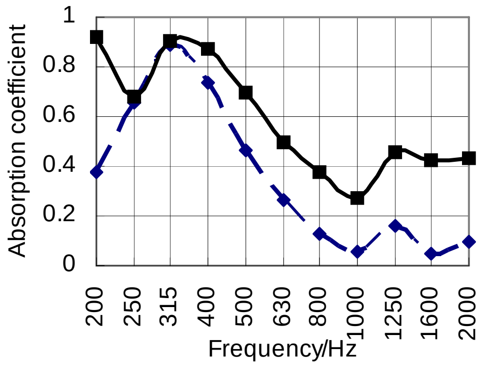

Figure .5 Comparison of prediction vs. experiments (No. 2 specimen)

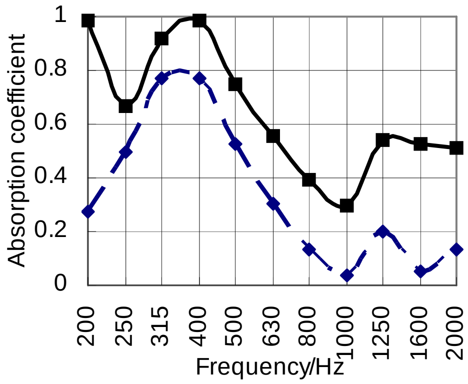

Figure6 Comparison of prediction vs. experiments (No. 3 specimen)

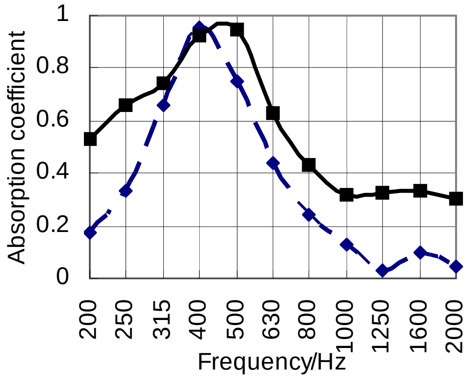

Figure 7 Comparison of prediction vs. experiments(No.4 specimen)

APPLICATION IN ENGINEERING

The aluminum fiberboard absorbs, as a kind of new acoustic absorption material, are with high acoustic absorption characteristic at high-frequency band. A novel double-surface absorption noise barrier without porous material is developed to control the noise from urban railway traffic [9]. The configuration of its transverse section is shown in figure 8.

Because of symmetrical structure shown in figure 8, an absorption element of barrier is used to analyzing acoustic absorption coefficient of the barrier. The analogy circuit for normal incidence is studied as shown in figure 8, where R_1, R_2 and M_1, M_2 express acoustic resistance and acoustic mass of the aluminum fiberboard and micro-perforated panel respectively, and Z_{D1}, Z_{D2} are respectively acoustic capacitance of cavity behind the aluminum fiberboard and micro-perforated panel.

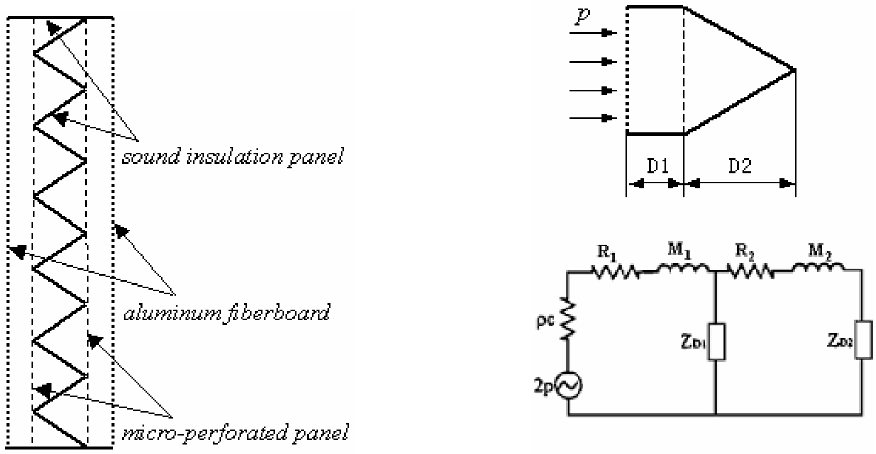

Figure.8 The section of double acoustic absorption barrier and its analogy circuit

Since the characteristic impedance of aluminum fiberboard can't be directly tested, an acoustic absorber specimen of aluminum fiberboard with a back cavity is used to measure its normal characteristic impedance rate in the stationary wave tube. The acoustic impedance of aluminum fiberboard can be obtained from subtracting the input acoustic impedance $-j\rho_0 c_0 ctg\frac{\omega D_1}{c}$ of the cavity from the measured results, and the acoustic impedance of the micro-perforated panel and triangular prism cavity could be calculated by the method mentioned above. According to analogy circuit shown in figure 8, the normal acoustic impedance of the absorber cell can be calculated as follows:

$$Z_{Sall}=R_1+j\omega M_1+\frac{(-j\rho_0 c_0\cot\frac{\omega D_1}{c})\cdot(R_2+j\omega M_2-j\rho_0 c_0\cot\frac{\omega D_2}{c})}{(R_2+j\omega M_2-j\rho_0 c_0\cot\frac{\omega D_2}{c}-j\rho_0 c_0\cot\frac{\omega D_1}{c})} \tag{10}$$

The acoustic absorption coefficient of the acoustic absorber cell shown in figure 8 can be calculated by eq. (9). The prediction of acoustic absorption coefficient spectrum is shown in figure 9, and the random incidence acoustic absorption coefficients spectrum of this barrier measured in reverberation chamber shown in figure 9 is used as a reference.

It can be found that the calculated absorption coefficient spectrum agree to that measured in reverberation room, some errors can be considered as due to the difference between the normal

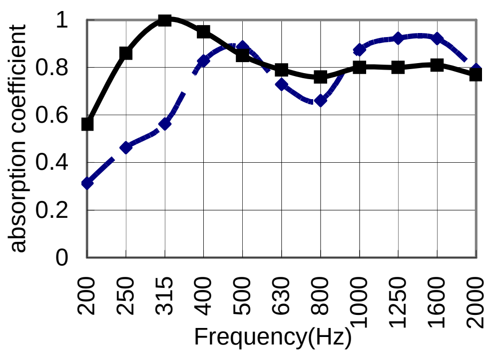

Figure.9 Absorption frequency spectrums
of simulation vs. experiment

incidence in simulation and random incidence in reverberation chamber measurement. With the help of the simulation of absorption coefficients, the dimensions of this new double-face acoustic absorption barrier can be optimized conveniently. That was applied as the double-face acoustic absorption barrier between the two traces of No. 6 urban light-weight railway traffic line in Shanghai, with the height of 1250mm.

CONCLUSIONS

Finally, some conclusions can be obtained as follows:

(1) The procedure presented is effective in predicting the normal acoustic absorption coefficient of the micro-perforated panel absorbers with heterogeneous cavities. It can be also applied to forecast the absorption performance of absorbers with other complicated cavities, which can make the design of the micro-perforated panel absorbers with heterogeneous cavities much more convenient and quicker.

(2) Although the presented prediction procedure is used for calculating normal incidence acoustic absorption coefficient, the calculated acoustic absorption coefficient spectrum, especially for their resonance frequencies, agree to measured results in reverberation room quite well. Therefore, the presented procedure can be used to forecast the absorption performance, and optimal the design parameters of this kind of absorbers for engineering.

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