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A method for measuring diffuse-field sound absorption coefficients of materials using parametric loudspeaker

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1. Introduction

In general, there are two methods to measure the absorption coefficients of materials normally by using the impedance tubes and the reverberation rooms, respectively.[1, 2] The method with an impedance tube can only measure the absorption coefficients in the case of normal incident. However, the measurement results have significant difference from the practical condition. The reverberation room method can measure the diffuse-field sound absorption coefficient of materials, but it requires large size of samples and special instruments. Moreover, it is costly to build a large reverberation room for creating ideal diffuse-fields.

Recently, an array of ultrasonic transducers has been exploited for the directional audible sound reproduction in air by using the nonlinear interaction of sound beams.[3-5] It is known as a parametric loudspeaker regarding the application of the parametric array theory. This paper investigates the possibility of using a parametric loudspeaker to obtain the diffuse-field absorption coefficients of materials without a reverberation room. Based on the measurement of a group of different incident angles absorption coefficients, the diffuse-field sound absorption coefficients are derived and compared to those obtained by a reverberation room method. It shows that the proposed method is able to obtain the diffuse-field absorption coefficients accurately.

2. Transfer function method

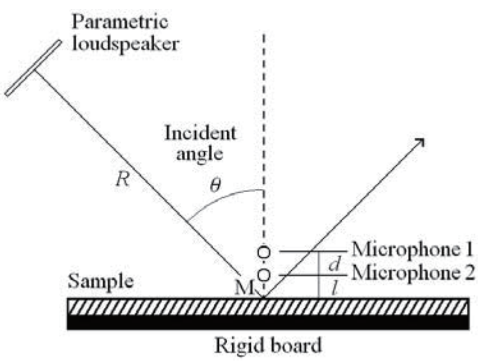

Fig. 1 Schematic diagram of the experimental setup.

Figure 1 shows a schematic diagram of the experimental setup. Two microphones are located above the sample with distance l and (d+l), respectively. The parametric loudspeaker is rotated around origin point M with a distance of R.

Suppose the incident wave P_{in} and the reflected wave P_{re} are plane waves, and the resulting sound signals are measured using microphones near the reflecting surface. The transfer function between the two microphones can be derived and then used to calculate the absorption coefficient.[6, 7]

P_1 and P_2 represent the sound pressures measured at the two microphones, repectively.

$$p_1 = P_{in}e^{jk(d+l)\cos\theta} + P_{re}e^{-jk(d+l)\cos\theta} \quad (1)$$

$$p_2 = P_{in}e^{jkl\cos\theta} + P_{re}e^{-jkl\cos\theta} \quad (2)$$

The transfer function from microphone 1 to microphone 2 is defined as

$$H_{12} = \frac{p_2}{p_1} = \frac{e^{jkl\cos\theta} + re^{-jkl\cos\theta}}{e^{jk(d+l)\cos\theta} + re^{-jk(d+l)\cos\theta}} \quad (3)$$

The reflection coefficient is given by

$$r = \frac{H_{12} - e^{-jkd\cos\theta}}{e^{jkd\cos\theta} - H_{12}} e^{2jk(d+l)\cos\theta} \quad (4)$$

The absorption coefficient can be calculated from eq. (5)

$$\alpha = 1 - |r|^2 \quad (5)$$

The restricted condition of this method is $0.2 < 2d/\lambda < 0.8$, where the wave length $\lambda = 2\pi f/c$. In this test, the distance between the two microphones, d, is 0.05 m. Correspondingly, the limitation on the frequency is deduced as: $680 < f < 2720$ Hz. In this paper, the testing frequency range is chosen to be between 1000 Hz to 2500 Hz.

3. Experimental Results and Discussion

3.1 The influence of the incident angle on measuring absorption coefficients

A parametric loudspeaker with ultrasonic carrier at 40 kHz is adopted as the sound source, two G.R.A.S 46BE microphones and a B&K

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PULSE system are used to measure the sound pressure. The sample is a 45 *mm* thick polyurethane foam sponge. The size of the testing piece of material is $1.2 \times 1.2\, m^2$. The parametric loudspeaker is located 1.9 *m* away from the point M. A sweep signal is used as the excitation sound source.

In this experiment, all the measurements are carried out in an anechoic chamber. The incident angle θ is varied from 0° to 85° with a step of 5°. The typical measurement results of absorption coefficients for 4 different incident angles are shown in **Fig. 2**. It can be seen that there is no significant difference among the measurement values of absorption coefficients below 1500 Hz for the angle of incidence at 0°, 30°, 60° and 80°, repectively. However, for the testing frequncy above 1500 Hz, the meaured values of absorption coefficients decreased with the increase of the incident angle.

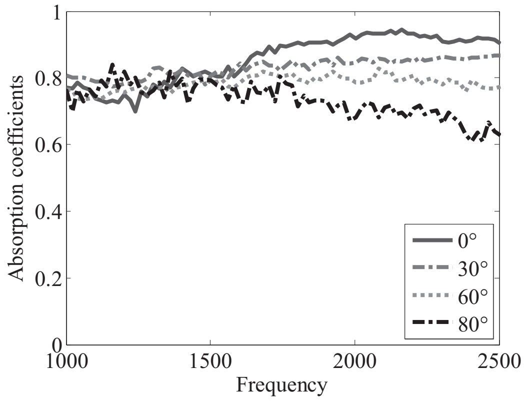

Fig. 2 Comparison of the absorption characteristics for different incident angles.

3.2 The comparison of the new method to the reverberation room results

In the diffuse-field, the phases and directions of the waves that incident on the sample are randomly distributed, we can neglect all phase relation and the interference effects. Assume the intensity distribution of the incident sound is consistently over all directions, the relationship between the diffuse-field sound absorption coefficients and the oblique incident sound absorption coefficients can be expressed by[8)]

$$\alpha_i = 2\int_0^{\pi/2} \alpha_\theta \cos\theta \sin\theta \cdot d\theta \qquad (6)$$

where α_i is the diffuse-field sound absorption coefficient, α_θ is the oblique incident sound absorption coefficient at the incident angle of θ. Here, 18 groups of different incident angles θ_j are considered in the experiment conduceted in an anechoic chamber. Thus, a discrete approximation of Eq. (6) can be calculated by

$$\alpha_i = \frac{\sum_{j=1}^{18} \alpha_{\theta_j} \cos\theta_j \sin\theta_j}{\sum_{j=1}^{18} \cos\theta_j \sin\theta_j} \qquad (7)$$

Figure 3 compares the result of α_i got from Eq. (7) and the reference results (REF) which are measured in a reverberation room.

The difference between the results with these two methods testing conditions is relatively small. The errors are less than 3% for most frequencies within the testing frequency range. Although there is 6.5% error observed in the measured results at the frequency of 1250 Hz, the most results agree well with the reference values. This leads to the conclusion that the method is able to simulate a diffuse-field in the reverberant room.

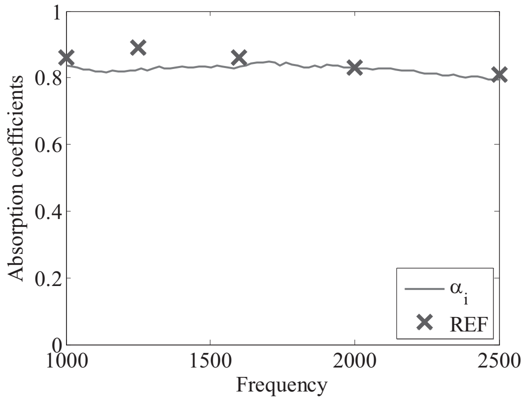

Fig. 3 Comparison between the results obtained by the new method and the reverberation room.

4. Conclusion

It is shown in this paper that we can evaluate the diffuse-field sound absorption coefficients in free field by using the parametric loudspeaker and two microphones. The present method is based upon the directional property of the parametric loudspeaker and the transfer function method. The experimental results show good agreements with the reference results measured in a reverberation room. The difference between the results under two testing conditions is less than 3% for most frequency ranges. It is promising to use the proposed method for practical applications.

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