Measurement in situ of the absorption coefficient of automobile interior materials based on the pseudo-impedance tube method

Li Wei1,2; He Yansong1,2; Xu Zhongming1,2; Zhang Zhifei1,2
1. The State Key Laboratory of Mechanical Transmissions, Chongqing University, China
2. College of Automotive Engineering, Chongqing University, China

ABSTRACT
How to measure the absorption coefficient of automobile interior materials accurately in situ is a very important issue. The objective of this study was to investigate an experimental method to estimate the absorption coefficient of automobile interior materials in a free-field condition. Based on the two microphones method (TMM), pseudo-impedance tube method has been introduced to overcome the limitation of the material’s area and testing environment. In the pseudo-impedance tube method, the impedance tube is used as sound source, and the absorption coefficient is calculated by the TMM. In this paper, simulations of different sound sources directivity characteristic have been presented which demonstrates pseudo-impedance tube is more suitable than the loudspeaker. The absorption coefficients of automobile interior materials samples have been measured by the pseudo-impedance tube method. It turned out that result is in good agreement with the standard impedance tube method over 500-1000Hz. Therefore, the absorption coefficient of material can be measured with pseudo-impedance tube, this method can effectively make the distance between the signal source and automobile interior materials shorter, and it provides the possibility of measuring the absorption coefficient of automobile interior materials for a small space in situ measurement.

Keywords: pseudo-impedance tube, absorption coefficient, acoustic impedance, two microphones method

1. INTRODUCTION
Absorption material plays an important role in noise control and environment improvement. As the important parameters of sound absorption performance, the measurements of the surface impedance and sound absorption coefficient have aroused the interest of many acoustics experts and scholars. There are certainly well-established laboratory measurement methods like the impedance tube or the reverberation room measurement, but conditions in situ differ from laboratory ones by at least two factors. First the mounting conditions are usually unknown in situ and different from the ones used in laboratory. Secondly the idealized acoustic fields assumed in the mentioned standard measurement methods do not correspond at all to the fields encountered outside the laboratory. In the past forty years, they put forward various kinds of testing methods in situ, and each one had its own specific assumptions, complexity and limitations. These methods mainly include two microphones method, impulsive response method, parametric array method and pressure-particle velocity (PU) method. Two microphones method proposed by Allard and Sieben was described as measuring the sound pressure and the acoustic velocity with two microphones set very close to
the sample. The environment and the distance between the source and microphones have a great influence on the results. Impulsive response method firstly proposed by Yuzawa\textsuperscript{4} used the impulsive signal as the source arranging two microphones at the same distance to the source and different distances to the sample respectively to separate the incident wave and the reflected wave, in which finally the absorption coefficient of the sample’s surface was worked out. Davies and Mulholland\textsuperscript{5} presented another one microphone impulsive response method based on the repeated impulsive signal. Due to the difficulty of the signal repeatability, the result was less precise. Parametric array method was first used in the measurement of absorption coefficient under water by University of Southampton\textsuperscript{67} to solve the limitation of the sound source’s emitting. Institute of Acoustics of Chinese Academy of Sciences\textsuperscript{8} applied the method to the air to measure the absorption coefficient, which reduced the influence of different environments. However, the experiment results of this method proved bad agreement with the standing wave method, and the parametric array microphone was very complex and expensive. Pressure-particle velocity (PU) method\textsuperscript{9} is based on the invention of the Microflown sensor---the PU probe\textsuperscript{10}, which integrates in a single probe a miniature microphone and a particle velocity sensor. With the probe, it is possible to measure the specific impedance above the sample. There are two main factors to limit its promotion. One is that before each measurement, the PU probe must be calibrated, the other is that the general speaker was usually used as the sound source affected by the environment. From the introduction of each method above, a simple and highly directional sound source can solve the problem.

2. The two microphones method in situ

![Figure 1 The measurement principle](image)

The associated transducer setup, composed of one modified impedance tube (called pseudo-impedance tube) and two microphones is shown Figure 1. A given loudspeaker is positioned at the end of the tube, and two microphones recording the sound pressures $p_1$ and $p_2$ are located at the vicinity of the surface of the material. A stationary signal with flat spectral density is generated by the given loudspeaker within the frequency range of interest in the tube.

The two microphones method is the most famous one of the absorption coefficient measurement in situ proposed by Allard. This method mainly estimates the sound absorption coefficient by measuring the surface impedance ratio. The sound pressure in the middle of the two microphones can be approximated as

$$p = \frac{p_1 + p_2}{2}$$  \hspace{1cm} (1)

The particle velocity can be expressed as

$$v = \frac{p_2 - p_1}{\mu \omega d}$$  \hspace{1cm} (2)
The normal specific acoustic impedance at position $M$ is

$$ Z_M = \frac{p}{\nu} = -i \omega \rho d \frac{1+H_{12}}{2(1-H_{12})} \quad H_{12} = \frac{p_1}{p_2} \tag{3} $$

The surface impedance ratio of the tested specimen is

$$ Z = \left[ \frac{Z_M + i \rho c \tan \left( \frac{w_l}{c} \right)}{\rho c + i Z_M \tan \left( \frac{w_l}{c} \right)} \right] \quad h = \frac{d}{z} + l \tag{4} $$

Finally, the reflection coefficient $r$ can be expressed by

$$ r = \frac{Z-1}{Z+1} \tag{5} $$

The absorption coefficient $\alpha$ can be calculated by

$$ \alpha = 1 - |r|^2 \tag{6} $$

The principle of the two microphones method has been deduced above. Next, the directivity of the pseudo-impedance tube is analyzed.

### 3. Analysis of the pseudo-impedance tube directivity

The sound source directivity can represent the energy transfer of the sound in the process of sound wave propagation. In order to verify the feasibility of the pseudo-impedance tube measuring the absorption coefficient, the finite element method and boundary element method are used to simulate the acoustic field directivity of the pseudo-impedance tube. The finite element models of the pseudo-impedance tube and the loudspeaker are built as following figures. As the most important part, the diaphragm is built by the finite element method, while the other parts is established by the acoustical boundary element method. The boundary elements are coincident with the finite elements of the membrane structure. The diameter of loudspeaker’s diaphragm is 100mm, and the whole boundary element model size is about 270mm$\times$210mm$\times$270mm. Similarly, the pseudo-impedance tube model is built. The diameter of the tube’s diaphragm is the same as the loudspeaker. The length of the tube is 650mm. According to the distance of the measurement, the center of the directivity field is set at the center of the both diaphragms, and the radius is 1000mm. The final FEM/BEM model is built and illustrated in Figure 2.

![Figure 2 The FEM/BEM models of the loudspeaker and the pseudo-impedance tube](image)

The FEM/BEM simulations are made at the center frequencies of the 1/3-octave bands by the software LMS Virtual.Lab. Finally, the directivity of the loudspeaker and the pseudo-impedance tube is illustrated at the frequency band [250-1600 Hz] in Figure 3. As can be seen from the figures, the curves of the pseudo-impedance tube at each frequency are visibly sharper than the loudspeaker’s, which demonstrates that the pseudo-impedance tube is more suitable to be used as the sound source for the sound absorption coefficient measurement in low noise-signal ratio environment. It also guarantees that the measurement can be achieved on the small size specimen.
Figure 3 Acoustical field directivity at the center frequencies of the one-third-octave
4. Experiment

According to the proposed method above, a test system is established as Figure 4. The distance $d$ between two microphones is 50mm, the distance $l$ between microphone $M_1$ and the bottom of the tube is 65mm, and the distance $s$ between microphone $M_2$ and the surface of the tested specimen is 25mm. The tested specimen is the polyurethane material. The loudspeaker is driven with band-limited white noise so that its spectral content was mainly limited to the frequency range of 250-1600Hz due to the inner diameter of this tube is 100mm. The pseudo-impedance tube is oriented perpendicular to the tested specimen so that the normal incident absorption coefficient can be easily measured. The experimental equipment is set up as shown in Figure 4. The experiment was arranged in the late night, and the equipment was placed in an empty place. The testing environment can be regarded as a semi-free field, and the tested specimen firmly attaches to the rigid back. In the experiment, the tested specimen is the polyurethane material with the size of 700mm×700mm×70mm.

Some of the data collected in the above-mentioned procedure belonging to the proposed method is also processed in the laboratory impedance tube method (B&K Type 4206) using the standard transfer function method. The spacing between the two microphones on the tube is 50 mm, the same as the spacing in the experimental setup of the proposed methods. The measured results are used as the reference values in comparison with the results obtained with the proposed method above.
5. Results and discussion

Figure 5 Impedance ratio (real part) obtained with proposed methods and impedance tube method

Figure 6 Impedance ratio (imaginary part) obtained with proposed method and impedance tube method

Figure 7 Normal absorption coefficient obtained with proposed method and impedance tube method
In this section, the absorption coefficient and acoustic impedance ratio of the tested specimen measured with the proposed method and the impedance tube method are displayed. The standard impedance tube result is regarded as the reference value to evaluate the accuracy of the proposed methods. Figure 5 and Figure 6 show the real part and imaginary of the impedance ratio belonging to the tested specimen surface respectively, while Figure 7 shows the normal absorption coefficient of the material. Over the range of 500-1600Hz, although the impedance ratio calculated by the TMM has big differences with the reference, the absorption coefficient is very close to the reference value. Therefore, the results suggest that the proposed method is useful for the normal absorption coefficient measurement in situ. It also demonstrates that the modified impedance tube can be used as the sound source applied into the absorption coefficient measurement in situ.

6. Conclusions

In this paper, a new method based on the impedance tube is proposed for in situ measurement of the normal absorption coefficient of the acoustical material using two microphones method. The modified standard impedance tube method is applied to the field measurement. The experiment conducted on a tested specimen shows that the proposed method is close to the laboratory method—the standard impedance tube method. Experimental results also show that the pseudo-impedance tube as the sound source can offer the high directivity and decrease the influence in the absorption coefficient measurement caused by the low signal-to-noise ratio environment.

Reference