24th INTERNATIONAL CONGRESS ON SOUND AND VIBRATION
23–27 July 2017, London

ACOUSTIC PROPERTIES TEST OF MATERIALS BY THE DUAL-MICROPHONES BROADBAND IMPULSE METHOD

Hong Hou
Northwestern Polytechnical University, P.R.China
email: houhong@nwpu.edu.cn

Yunke Huang
Northwestern Polytechnical University, P.R.China

Jianhua Yang
Northwestern Polytechnical University, P.R.China

Paper presents the dual-microphones broadband impulse method to measure sound characteristics of acoustic materials. Based on the basic composition and process of sound pulse propagation in impedance tube, the pulse wave propagation model is respectively proposed, and sound pressure at any location of the tube can be expressed. Broadband impulse is generated in the tube and motivate the tube with a sample in the terminal. Sound pressure signals at any two location are acquired. Convert this two signals in time domain then the complex reflection coefficient and absorption coefficient in continuous band range are obtain Sound characteristics of the sponge sample and the porous glass sample have been tested by the dual-microphones broadband impulse method. Test results are coincided with which measured by impedance tube method. This method has improved the traditional impulse method without requiring impulse signal complete separation and has a value of application.

Keywords: broadband impulse method, acoustic performance, impedance tube

1. Introduction

At present, performance test of aero-acoustic material have been studied a lot, and absorption and transmission performance studies have most comprehensive application. Reverberation method is in most common use for a large sample, which utilize Sabine formula[1] to calculate absorption coefficient by measure reverberation time. The experimental repeatability of this method is undesirable due to the difference of diffusion degree in each reverberation room despite the impact of edge effect. Simultaneously, impedance tube is an essential equipment in a small sample test in which standing wave ratio method and transfer function method are considered as major broadband test methods. Sound pressure in multiple locations at impedance tube have to been measured to compute standing wave ratio and furthermore the absorption coefficient can be calculated in standing wave ratio method[2]. The method is rarely used due to the sparing of time and limitation of test frequency domain. Transfer function method[3] is an improvement on the basis of standing wave ratio method.

Broadband white Gaussian noise is used in the measurement and then normal absorption coefficient as well as impedance ratio are determined by sound pressure transfer function between two stable locations. Sound pressure phase information can be sufficiently applied to enhance work efficiency. However, this method requests to acquire sound pressure signal with two exactly matched microphones which turn to studying phase calibration of two microphones in practical application[4,5].

Recently years, pulse echo method, which is convenient for site test, is mainly used in acoustic properties tests. X.Jing[6] has generated arbitrary pulse in the space based on Vera inverse filtering; Shui Li[7] has improved the source of pulse signal by inverse filter principle; Garai and Mommertz[8] have studied site test technique with MLS signal. Liang Sun and Hong Hou[9,10] have generated good pulse waveform in sound tube and the broadband pulse absorption and transmission measurement methods are proposed.Yang Dai[11] etc. have researched for postpositional inverse filtering method, improving the broadband pulse test method.

In order to separate incident wave and reflected wave in broadband pulse test method, pulse width would be shorten with ensuring excellent waveform. This paper has researched for impedance tube pulse propagation model and obtained sound pressure signal expression at any location of the tube. Based on this model, dual-microphone broadband impulse method is proposed. Equivalent sound pressure signal related to complex reflectance and time delay can be obtained via processing sound pressure signals at two locations of the tube, and complex reflectance is measured without separation of pulse wave. Two materials are tested using this method in a large impedance tube (effective frequency200-1600Hz) and a small impedance tube (effective frequency500-6400Hz). The complex reflectance and absorption coefficient are compared with the experiment data measured in transfer function method given by B&K company test system, and the coincidence of test results illustrate the excellent precision of dual-microphone broadband impulse method.

2. Pulse propagation model in impedance tube

Pulse tube is used to measure absorption performance with a sample in the terminal. Let L be the length of the tube and $x(t)$ be the input pulse of the tube test system. Pulse transfer system contains pulse responses of the tube's terminal reflex system $h_1(t)$ (the system input is the first incident wave and the output is the first reflex wave), the tube's orifice reflex system $h_2(t)$ (the system input is the first reflex wave and the output is the second reflex wave), and the time-delay system $d(x,t)$.

According to system transfer principle, the transfer function of tube's terminal reflex system $h_1(t)$ is the complex reflectance of the material, and the transfer function of tube's orifice reflex system $h_2(t)$ is the complex reflectance of the orifice.

The first incident wave $p_i^{(1)}(x,t)$ acquired at point x from the orifice is,

$$p_i^{(1)} = x(t) * d(x,t) \tag{1}$$

where $d(x,t)$ is the time-delay system pulse response with delay of x/c seconds. Moreover, the first incident wave is right spreading.

As the result of the reflection of the first reflex wave from the terminal, the first reflex wave $p_r^{(1)}(x,t)$ at location x point is

$$p_r^{(1)}(x,t) = p_i^{(1)} * h_1(t) * d(2L-2x,t) \tag{2}$$

where $d(2L-x,t)$ is the time-delay system pulse response with the delay of $(2L-x)/c$ seconds. The first reflex wave is left spreading.

As the result of the reflection of the first reflex wave from the orifice, the second reflex wave $p_r^{(2)}(x,t)$ at location x point is

$$p_r^{(2)}(x,t) = p_i^{(1)} * h_1(t) * h_2(t) * d(2L,t) \tag{3}$$

$d(2L,t)$ is the time-delay system pulse response with the delay of $2L/c$ seconds. The second reflex wave is right spreading .

Based on the relationship above, the right spreading wave at point x after infinite inter-reflection in the tube is as

$$P_R(x,t) = p_i^{(1)} * \left(\sum_{n=0}^{\infty} (d(2L,t) * h_1(t) * h_2(t))^n \right) \tag{4}$$

Similarly, considered the transfer process of left spreading wave, treating the first reflex wave as the first incident wave of the left spreading wave, the left spreading wave at point x after infinite inter-reflection in the tube is as

$$\begin{aligned} P_L(x,t) &= p_r^{(1)} * \left(\sum_{n=0}^{\infty} (d(2L,t) * h_1(t) * h_2(t))^n \right) \\ &= p_i^{(1)} * h_1(t) * d(2L-2x,t) * \left(\sum_{n=0}^{\infty} (d(2L,t) * h_1(t) * h_2(t))^n \right) \end{aligned} \tag{5}$$

where $K^n = \underbrace{K * K * \cdots * K}_{n}$.

Thus, the total sound pressure at x can be expressed as

$$\begin{aligned} P(x,t) &= P_R(x,t) + P_L(x,\mathrm{t}) \\ &= p_i^{(1)}(x,t) * (1 + h(2L-2x,t) * h_1(t)) * H(2L,t) \end{aligned} \tag{6}$$

where $H(2L,t) = \sum_{n=0}^{\infty} (h(2L,t) * h_1(t) * h_2(t))^n$.

From equation(6), if the first incident wave $p_i^{(1)}(x,t)$, the transfer function of terminal reflex system(material complex reflection coefficient) $h_1(t)$ and the transfer function of the orifice reflex system(orifice complex reflection coefficient) $h_2(t)$ are known, the sound pressure at any location of the tube can be inferred.

3. Dual-microphone broadband impulse method

At any two points x_1 , x_2 （$x_2 > x_1$）， the first incident wave are respectively as

$$p_i^{(1)}(x_1,t) = x(t) * d(x_1,t) , \quad p_i^{(1)}(x_2,t) = x(t) * d(x_2,t) \tag{7}$$

Thus, these two incident wave follow the below given relationship,

$$p_i^{(1)}(x_2,t) = p_i^{(1)}(x_1,t) * d(x_2 - x_1,t) \tag{8}$$

From the derivation of the prior chapter, the total sound pressure at x_1 and x_2 can be expressed as

$$P(x_1,t) = p_i^{(1)}(x_1,t) * h_1(t) * (1 + d(2L-2x_1,t)) * H(2L,t) \tag{9}$$

$$P(x_2,t) = p_i^{(1)}(x_2,t) * h_1(t) * (1 + d(2L-2x_2,t)) * H(2L,t) \tag{10}$$

Convoluted sound pressures in time domain, we let $P_i = P(x_1,t) - P(x_2,t) * d(x_2 - x_1,t)$ and simplify it as

$$\begin{aligned} P_i &= P(x_1,t) - P(x_2,t) * d(x_2 - x_1,t) \\ &= p_i^{(1)}(x_1,t) * [1 - d(2x_2 - 2x_1,t)] * H(2L,t) \end{aligned} \quad (11)$$

Similarly, let $P_r = P(x_2,t) - P(x_1,t) * d(x_2 - x_1,t)$, combined with equation (7), we infer that

$$\begin{aligned} P_r &= P(x_2,t) - d(x_2 - x_1,t) * P(x_1,t) \\ &= p_i^{(1)}(x_1,t) * d(2L - x_1 - x_2,t) * [1 - d(2x_2 - 2x_1,t)] * h_1(t) * H(2L,t) \end{aligned} \quad (12)$$

According to equation (2-4) and (2-5), there is a relationship as below

$$P_r = P_i * d(2L - x_1 - x_2) * h_1(t) \quad (13)$$

P_i and P_r can be calculated via sound pressure signals acquired by microphones at points x_1 and x_2 , then $h_1(t)$ can be inferred by deconvolution based on the equation(13). Furthermore, complex reflectance characteristics $r(\omega)$ in frequency domain would be work out by FFT transformation. Absorption coefficient can be expressed as

$$\alpha(\omega) = 1 - [r(\omega)]^2 \quad (14)$$

4. Experimental test results

4.1 Test equipment

In the experiment, type SW031 acoustic tube having diameter of 29.9 mm is used to test acoustic properties of a sponge material and an anti-explosion material. Sample is put at the end of the tube with an rigid backing sticking on it. Two microphones are put into the tube wall vertically. Loundspeaker and microphones are connected with power amplifier and data acquisition instrument which are controlled by a computer.

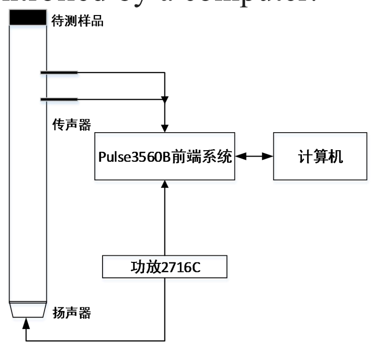
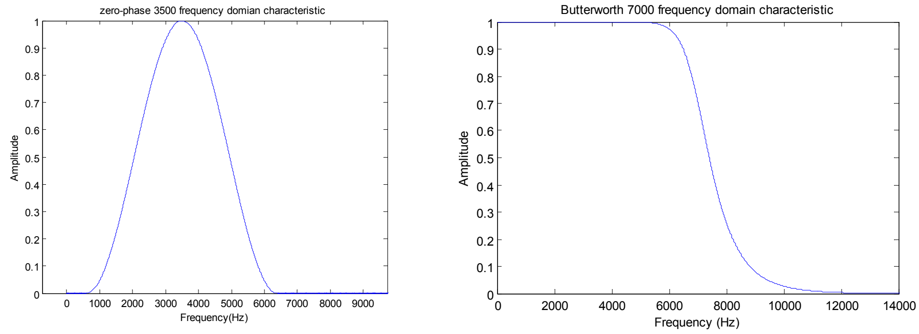


Fig.1 – Measuring Equipment sketch map

4.2 Pulse signals

The effective frequency scope is from 500Hz to 6400Hz, thus two signals as below are designed for small sample measurement: a zero-phase signal with 3500Hz center frequency, and a Butterworth signal with 7000Hz cutoff frequency. The characteristics of these two signals are as below.



(a) (b)

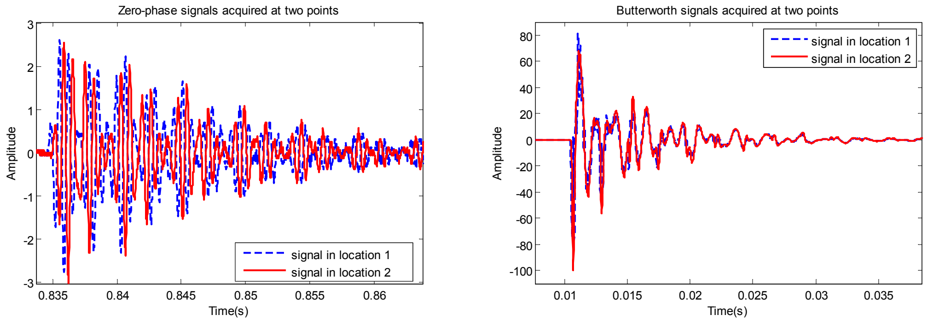
Fig.2 – (a) zero-phase signal (b)Butterworth signal

4.3 Test results

4.3.1 Sub

Sponge material

Two signals metioned above are used in measurement of sponge material. Signals acquired by microphones are as below,



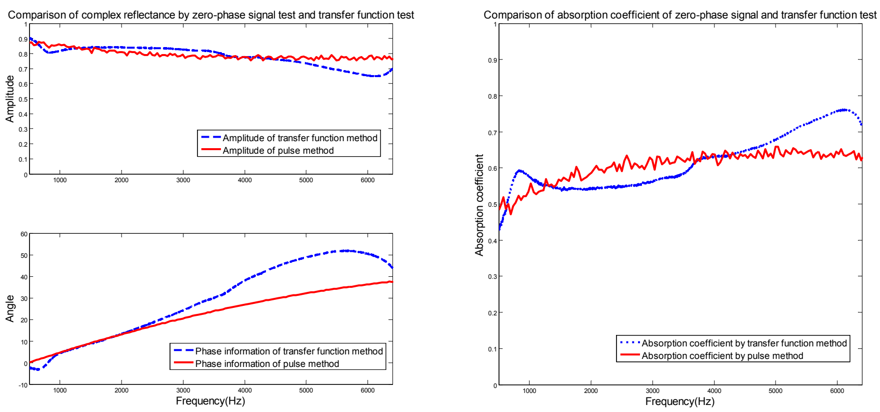
(a) (b)

Fig.3 – (a) acquisition zero-phase signal (b) acquisition Butterworth signal

As shown in Figure3, in these two locations, the zero-phase signal with 3500Hz center frequency and the Butterworth signal with 7000Hz cutoff frequency are not complete separation, meaning that incident waves and reflex waves cannot be intactly extracted.

Processing sound pressure signals with equation (11) and (12), complex reflectance and absorption coefficient will be calculated by equation (13) and (14). Then compare these consequences with transfer function method results by B&K company test system.

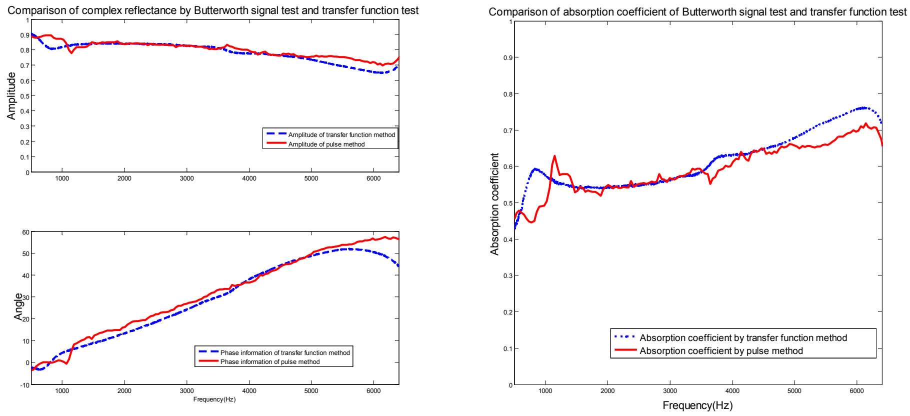
Measurement outcomes with zero-phase signal as excitation are



(a) (b)

Fig.4 – (a) complex reflectance result used zero-phase signal (b) absorption coefficient result used zero-phase signal

Measurement outcomes with Butterworth signal as excitation are as below



(a) (b)

Fig.5 – (a) complex reflectance result used Butterworth signal (b) absorption coefficient result used Butterworth signal

As shown in Figure 4 and Figure 5, the amplitude and phase of complex reflectance measured by two signals are coincident with the test result of transfer function method. Observing the curve of absorption coefficient, we can find out that the experimental error between absorption coefficients tested by Butterworth signal in this method and transfer function method are within 5%. The spectrum range of zero-phase signal is not as wide as Butterworth signal ' s, thus zero-phase signal test data in high frequency over 5000Hz has about 10% experimental error with transfer function method test data. Meanwhile, there are some fluctuations in transfer function method test process, therefore we average measured value of six times. Through comparison testing, it is obvious that material acoustic performance can be obtained accurately.

To research the repeatability of this method, we measured in each signal for six times independently, and regard the standard deviation of absorption coefficient average value as class A measurement uncertainty, namely:

$$u_{A\alpha} = \frac{1}{n}\sqrt{\sum_{n=1}^{6}(\alpha_i - \bar{\alpha})^2} \tag{15}$$

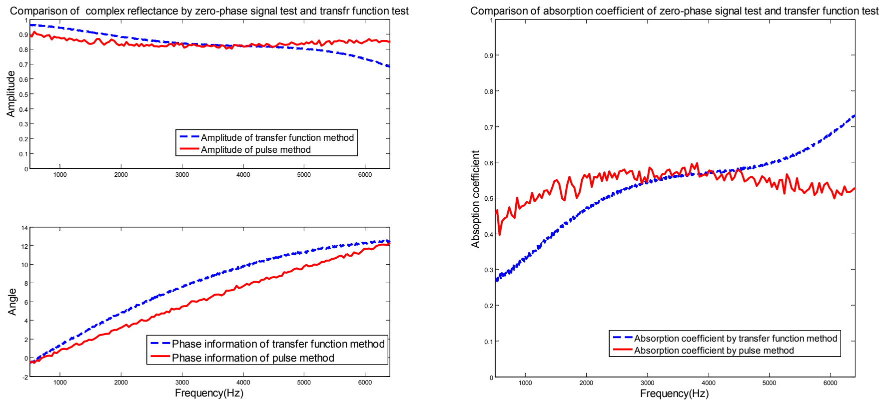
In frequency points 1024, 2048, 3072, 4096, 5120, 6144Hz, class A measurement uncertainties are as follow:

Table 1 –Measurement uncertainties of sponge material test by two signals.

Frequency	1024Hz	2048Hz	3072Hz	4096Hz	5120Hz	6144Hz
Zero-phase	0.0149	0.0128	0.0139	0.0143	0.0140	0.0134
Butterworth	0.0352	0.0303	0.0280	0.0265	0.0254	0.0246

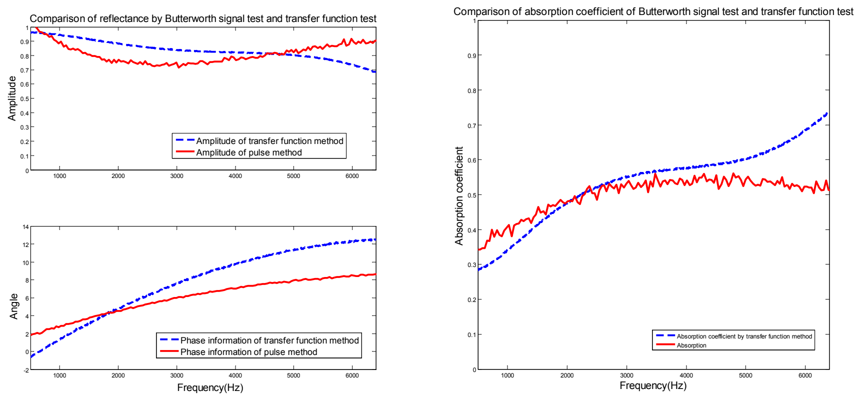
4.3.2 An anti-explosion material

To verify the method further, an anti-explosion material is tested in this paper. The same signals mentioned in previous section are used in the process. Disposed of sound pressure signals acquired by microphones in two location points, complex reflectance and absorption coefficient are worked out. The comparison of two methods are as below:



(a) (b)

Fig.6 – (a) complex reflectance result used zero-phase signal (b) absorption coefficient result used zero-phase signal



(a) (b)

Fig.7 – (a) complex reflectance result used Butterworth signal (b) absorption coefficient result used Butterworth signal

The absorption coefficients measured by two signals are coincident with the test results of transfer function method. Below 5000Hz, test result by zero-phase signal is a little greater than transfer function method result with average 0.05 difference, while outcomes of Butterworth signal measurement and transfer function method are adjacent, with 0.01 difference. Over 5000Hz, measurement results both are slightly lower than transfer function method result.

Class A measurement uncertainties calculated by six times independent measurement are as below:

Table 2 –Measurement uncertainties of this anti-explosion material test by two signals.

Frequency	1024	2048	3072	4096	5120	6144
Zero-phase	0.0208	0.0186	0.0217	0.0202	0.0196	0.0223
Butterworth	0.0132	0.0128	0.0115	0.0140	0.0158	0.0139

5. Conclusions

In this paper, we proposed a dual-microphone broadband impulse method based on impendence tube pulse propagation model to solve the problem about signal separation in impendence tube. Complex reflection coefficient can be obtained by this method through acquiring sound pressure signals at two points of the tube, without need of separation of incident wave and reflex wave in traditional test method.

Absorption coefficients of two samples are measured by dual-microphone broadband impulse method, and compared with the test result given by transfer function method. Complex reflectance and Absorption coefficient results of these two methods are mainly consistent in 1000-5000Hz. Due to the property of pulse signals and the defect of transfer function method itself, there are a little bit difference in test results in higher frequency range. Meanwhile we calculate measurement uncertainties to verify the repeatability of this method. Experiments show that dual-microphone broadband impulse method is an effective acoustic property test method.

ACKNOWLEDGEMENTS

This work was financially supported by the National Natural Science Foundation of China (Grant Nos. 11474230) and the National Key Research and Development Program of China (Grant No. 2016YFF0200900)

REFERENCES

1 ISO 354-2006.Acoustics-Measurement of sound absorption in a reverberation rooms[S].

2 ISO10534-1 Acoustics—Determination of Sound Absorption Coefficient and Impedance or Admittance—Part 1: Impedance Tube Method [S].

3 ISO10534–2 Acoustics—Determination of Sound Absorption Coefficient and Impedance in Impedance Tubes—Part2: Transfer Function Method [S].

4 H. Boden, and M. Abom. Influence of errors on the two-microphone method for measuring acoustic properties in ducts. [J]. *Journal of the Acoustical Society of America,*1986 (79): 541-549

5 B.F.G. Katz. Method to resolve microphone and sample location errors in the two-microphone and sample location errors in the two-microphone duct measurement method [J]. *Journal of the Acoustical Society of America,* 2000 (108): 2231-2237.

6 X. Jing, K.-Y. Fung, Generation of desired sound impulses, *Journal of Sound and Vibration,* 2006 (297): 616-626

7 Shui Li, Rongxing Liao. Measurements for the properties of underwater acoustic materials by broadband compressed pulse superposition method. [J]. *Acoustic Journal*, 2000,03:248-253.

8 Mommertz. E. Angle-dependent in-situ measurements of reflection coefficients using a subtraction technique. *Applied Acoustics*, 1995 (46): 251-263.

9 Liang S, Hong H. Transmission loss measurement of acoustic material using time-domain pulse-separation method (L). [J]. *Journal of the Acoustical Society of America*, 2011, 129(4):1681-1684.

10 Sun L, Hou H, Dong L Y, et al. Sound Absorption Measurement in a Circular Tube Using the Echo-Pulse Method. [J]. *Acta Acustica United with Acustica*, 2010, 96(5):973-976.

11 Yang Dai, Jianhua Yang, Hong Hou, Jianping Chen. Design and Implementation for Acoustic Pipe Test Software of Broadband Pulse Method. [J]. *Measurement and Control Technology*, 2014,12:110-113.