A Unified Approach for the two ASTM Standards for Impedance Tube Measurements.

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1. Introduction

At present, there are two ASTM standards for impedance tube measurements, the ASTM C384 and the ASTM E1050. The former standard relies on measuring the standing-wave ratios at different discrete frequencies whereas the latter relies on measuring the broad-band transfer function at two positions with a pair of phase matched microphones. The two standards specify two different types of tubes and measurement equipment. This is not necessary. The essential requirements of the two standards can be met with a single impedance tube with a traversing probe-tube microphone. The measurements can be performed inexpensively with a PC computer and a 12 bit data acquisition board that has two A/D inputs and one D/A output.

In this report, a description of the combined setup will be presented together with results obtained by the new procedures.

2. Theoretical Background

According to the ASTM C384[1], the magnitude of the reflection coefficient R is determined by the standing -wave ratio of p_{max} and p_{min}. The phase angle, ϕ, of R is determined by the position of first minimum and the tube attenuation is accounted for by an extrapolation scheme. However, the procedure can be implemented more accurately using an exact formulation based on the plane wave analysis of the standing wave pattern in the tube. According to Ref. 2, the ratio of p_{min} and p_x at any other point can be written as,

$$\frac{|p_{\min}|^2}{|p_x|^2} = \frac{e^{2ad} + |R|^2 e^{-2ad} + 2|R|\cos(2kd - \phi)}{e^{2ax} + |R|^2 e^{-2ax} + 2|R|\cos(2kx - \phi)} \qquad (1)$$

and

$$\phi = -(2n+1)\pi + 2kd + \varepsilon \qquad (2)$$

where $\varepsilon = \sin^{-1}[(a/2k|R|)(e^{2ad} - |R|^2 e^{-2ad})]$,

a is the tube attenuation constant, k is the wavenumber and d is position of the nth pressure minimum. Assuming a is known, the reflection coefficient can be determined from Equations 1 and 2 by an iteration process based on two pressure magnitude measurements. Measurements are to be taken one frequency at a time.

For the ASTM E1050[3], two complex pressure measurements are required. The reflection coefficient is calculated according to

$$R = \left[\left(H_{12} - e^{-\gamma S}\right)\left(e^{\gamma S} - H_{12}\right)^{-1} \right] e^{2\gamma L} \qquad (3)$$

where $\gamma = ik + a$, $H_{12} = p_2 / p_1$ is the complex transfer function, S is the microphone separation, and L is the distance of the first microphone from the sample according to the convention of Ref. 3. Fixed positions for two phase matched microphones are specified in the standard. However, more accurate results can be obtained using different microphone positions for different frequencies[4]. Although broad-band measurements can be made with this procedure, more accurate results are obtained with single frequency measurements[5].

3. Proposed Test Procedures

When broad-band random noise is used in the ASTM E1050 test, p_2 and p_1 have to be measured simultaneously. But, if a deterministic type of signal is used, such as a pure tone or a maximum length sequence (m-sequence), the two pressures can be measured sequentially[6]. Recently, Chu has demonstrated that very accurate magnitude and phase measurements can be made using deterministic types of periodic signal and FFT[7]. Thus, a single set of equipment can be used to perform tests according to either one of the standards. The following schematic shows a simple setup of the equipment.

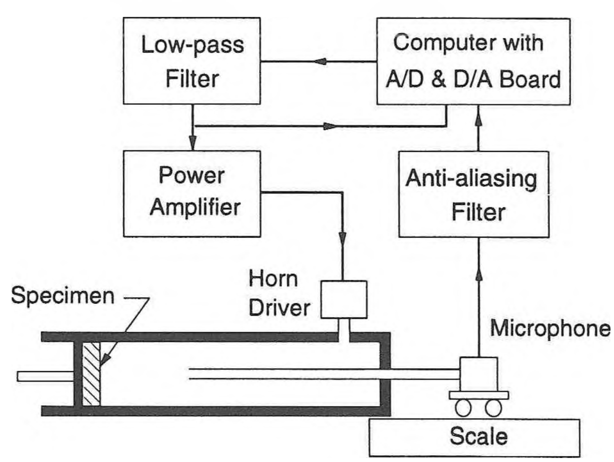

Fig. 1 Schematic drawing of experimental equipment.

Pure tone or deterministic broad-band m-sequence signals are generated mathematically by software and output through the D/A converter. A low-pass filter is used to generate a smooth analog signal before it is fed to a power amplifier which drives the horn driver. A traversing probe microphone is used to sample the acoustic pressure inside the tube at two locations. Both the driving and the microphone signals are digitized simultaneously by a two channels A/D converter. The magnitude and phase of the acoustic signal referenced to the driving signal are computed by a fast Fourier transform program (FFT). Since the signals are periodic, exact multiple periods have to be used to avoid leakage problem and special non-power of 2 FFT routine has to be used. The Glassman's general n points FFT[8] is used in this study.

A common data acquisition program can be used for both the ASTM C384 and ASTM E1050 tests. Only the sections on computing the reflection coefficient are different for the two tests.

4. Experimental Results

The procedures have been used to determine the complex reflection coefficients of a special reference sample used previously in a round robin test[9]. Pure tones at the third-octave band center frequencies from 100 to 2500 Hz were used for both the C384 and E1050 tests. The sampling frequency used was 16 kHz and the number of points used was 3200. This combination provided the exact frequency bins of the FFT for all the frequencies of interest. The results are compared with those obtained for the round robin test[9] using the two-point transfer function method. Previously, the pure tones were generated by an accurate frequency synthesizer and the magnitude and phase were determined with a lock-in amplifier. Both Figures 2 and 3 show good agreement between the two procedures and previous results.

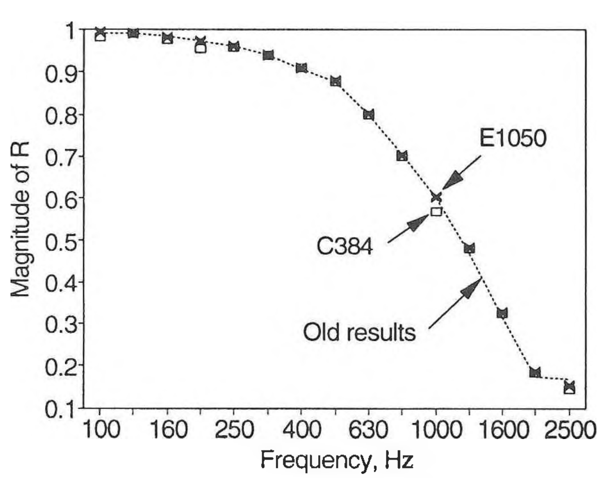

Fig. 2 Comparison of the magnitude of R obtained by the two procedures with that obtained in a round robin test.

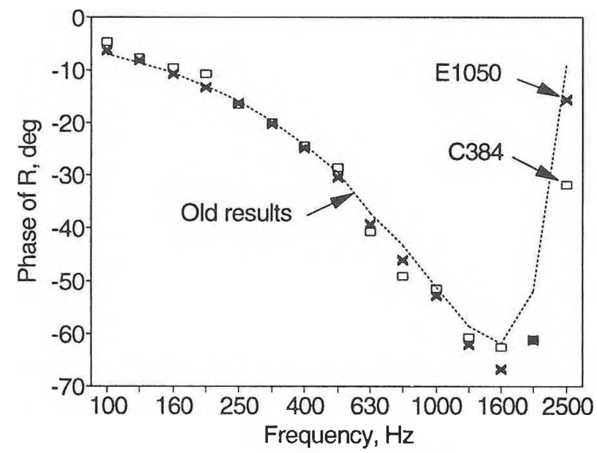

Fig. 3 Comparison of the phase of R obtained by the two procedures with that obtained in a round robin test.

5. Conclusion

It has been demonstrated that a unified approach for the two ASTM standards is possible with a single set of apparatus and equipment.

6. References

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