

Notes on Absorption and Impedance Measurements

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Applicable Standards. There are two standards^{1,2} for the measurement of acoustical properties of materials: ASTM E1050 and ISO 10534-2. These two standards parallel one another; the first was developed in the U.S. by ASTM and the second developed by the International Standards Organization. Both describe what has come to be known as the “two-microphone” or “transfer-function” method of measuring absorption and impedance of acoustical materials.^{3,4} These standards establish acceptable conditions under which reliable data may be obtained; however, good practice suggests that equipment and test conditions exceed the minimal requirements of the standards.

The Two-Microphone Method. The two-microphone method is shown schematically in Figure 1 below. A sample of the material to be tested is placed in a sample holder and mounted to one end of a straight tube. A rigid plunger with an adjustable depth is placed behind the sample to provide a reflecting surface. A sound source, typically a high-output acoustic driver, is connected at the opposite end of the tube. A pair of microphones is mounted flush with the inner wall of the tube near the sample end of the tube.

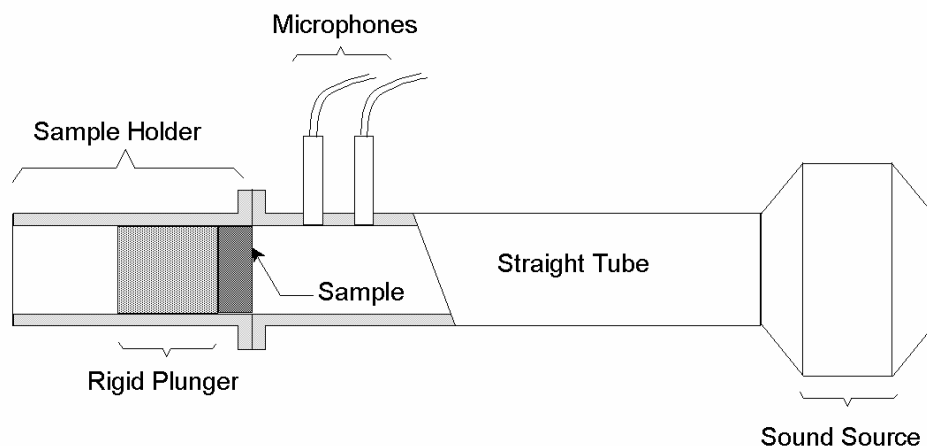


Figure 1 The Two-Microphone Method

A multi-channel spectrum analyzer is used to obtain the transfer function (frequency-response function) between the microphones. In this measurement, the microphone closer to the source is the reference channel. From the transfer function H_{12} , the pressure reflection coefficient R of the material is determined from the following equation:

$$R = \frac{H_{12} - e^{-jks}}{e^{jks} - H_{12}} e^{j2k(L+s)}$$

where L is the distance from the sample face to the first microphone and s is the distance between the microphones, $k = 2\pi f/c$, f is the frequency, and c is the speed of sound. From the reflection coefficient, the absorption coefficient α and normalized impedance $Z/\rho_0 c$ of the sample may be determined from the following equations:

$$\alpha = 1 - |R|^2 \qquad Z / \rho_0 c = \frac{1 + R}{1 - R}$$

Performance of the Two-Microphone Method. The accuracy and repeatability of the two-microphone method has been evaluated in a round-robin test⁵ administered by ASTM. In this test, samples of nominally identical material were prepared and tested by over a dozen independent laboratories, including the University of Kentucky. These results were compared to one another and to similar results obtained using the well-established but antiquated “standing wave” method.⁶ Overall, excellent agreement was obtained between the two methods.

The User’s Performance Test. Despite the good agreement reported in the round-robin test and the guidance of the standard for calibrating the microphones and conducting the measurement, the standard offers no “performance test” with which the user can evaluate the hardware, software, and the measurement process itself in the user’s laboratory. This is because there is no “standard” acoustical material whose acoustical properties are known absolutely. Instead, the standard¹ recommends that each laboratory maintain a “reference specimen” to be tested periodically for quality assurance. To be effective, the properties of the reference specimen should remain stable for many years.

However, there is an absolute test that the user can perform easily and quickly to check the measurement system and the measurement process. This test consists of measuring the imaginary part of the impedance of a closed tube of length L_0 as shown in Figure 2 below. To conduct the test, the sample is removed from the sample holder, and the plunger of the sample holder is set to a specified depth (for example, $L_0 = 0.1$ m). The depth is not important, but its value must be known accurately.

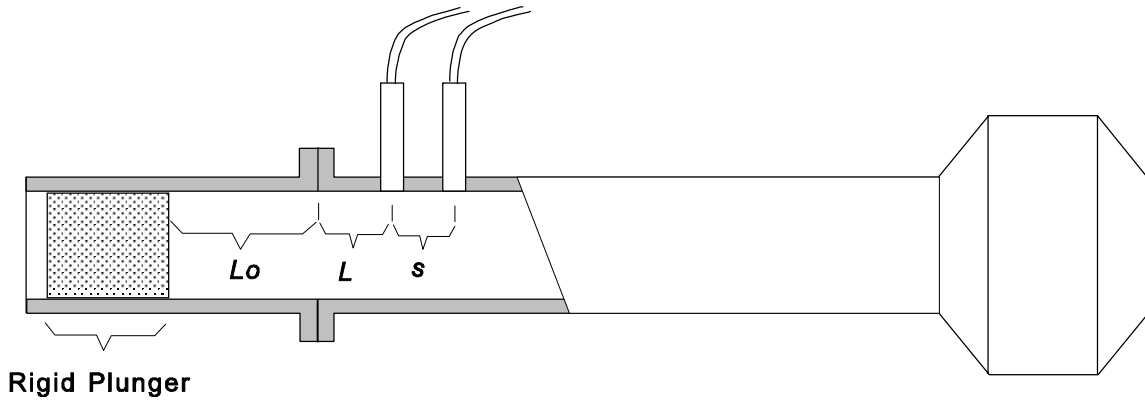


Figure 2 Measuring the impedance of a closed tube.

The theoretical normalized impedance $Z/\rho_0 c$ of a closed tube of length L_0 is given by:

$$\text{Im}(Z / \rho_0 c) = -1 / \tan kL_0$$

where $k = 2\pi f/c$. Figure 3 shows an example of the above measurement using the ACUPRO system.

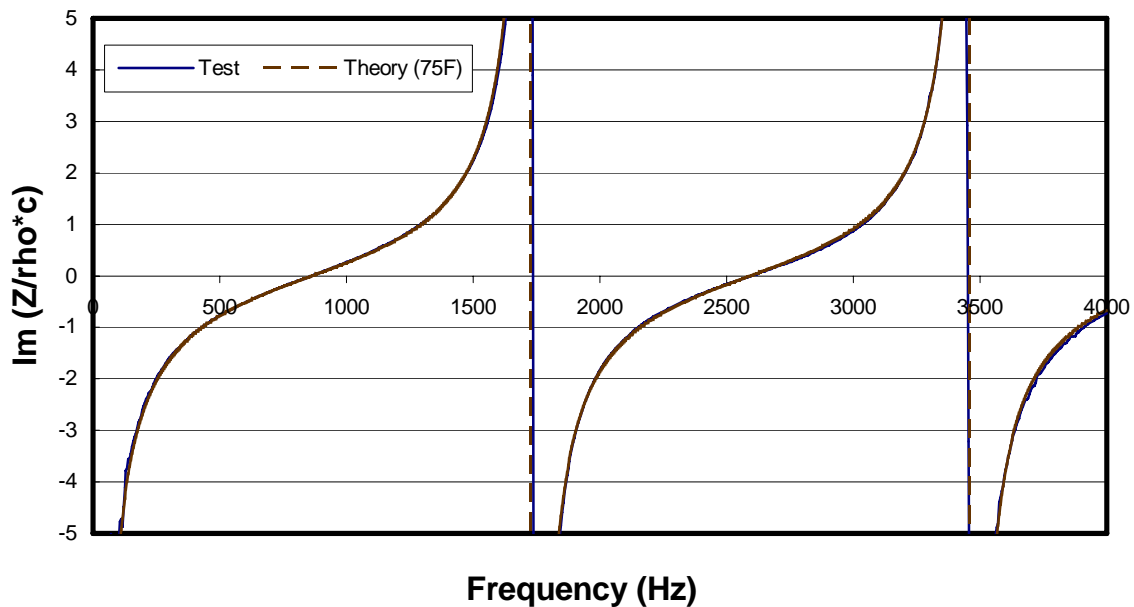


Figure 3 Comparison between the measured and theoretical impedance of a closed tube of length 0.1 m.

Signal-to-Noise Ratio. Accurate measurements of material absorption require that the sound field be substantially larger than the background noise inside the tube. The minimum signal-to-noise ratio will occur at the minima of the standing waves; these minima can be as much as 25 dB below the maximum levels in the tube. In addition, it is often necessary to measure material absorption at relatively low levels to match field conditions (e.g., approximately 65 dB for materials used in offices or vehicles). The standards¹ recommend that the level of sound in the tube be at least 10 dB greater than the background noise level, but 20 – 30 dB is preferred. Taken together, these conditions require a background noise level in the tube in the 10 - 20 dB range. To achieve this low background level, the tube must be constructed of heavy materials and must be sealed properly at all openings (microphone ports, sample holder, sound source, etc.) so that the transmission loss of the tube is at least 45 dB.

Construction of the Tube. The tube should be massive and sufficiently rigid to avoid (1) transmission of noise into the tube from outside and (2) vibration excitation by the sound source or from background sources (e.g., doors closing). The standards² recommend the wall thickness be 5 percent of the tube diameter, but 10 percent is preferred. The standards do not specify the tube material, but a material such as brass is preferred because its damping is several times that of lightly damped materials such as aluminum. Brass is also three times as dense as aluminum.

The tube must be sufficiently long to present a stable plane-wave sound field to the sample under test. All sound sources produce spherical waves that decay into plane waves over distance inside a tube. However, this distance can be quite long for large-diameter tubes. The standards recommend a tube length of at least three diameters, but this is marginal; a length of at least 10 - 15 diameters is preferred.

Sample Holder. Like the tube, the sample holder should be massive and rigid. In addition, it should have a smooth, machined surface for mating with the tube. This is necessary to insure that no sound leaks into or out of the tube where the sample holder and the tube meet. The sample holder should also have a massive back plate of at least 20 mm in length^{1,2} behind the sample. The back plate or plunger should be adjustable to permit different thickness materials to be tested and to allow for an air space behind the sample, if necessary.

Microphones and Mounting. The microphones must be mounted flush with the inside wall of the tube and isolated from the tube (to minimize sensitivity to vibration). Microphones isolated within a specially designed microphone holder that is also isolated from the tube (double isolation) provide the best results. The particular microphones used are not important as long as they are laboratory grade and are the same type and size; typically either ½ or ¼ inch microphones are used. It is not necessary to use so-called “matched” or other special microphones because a microphone calibration is conducted prior to a measurement anyway. Figure 4 shows a comparison between the absorption coefficient of a sample of 1” foam measured using pairs of ¼ and ½ inch microphones. There is no appreciable difference in these results.

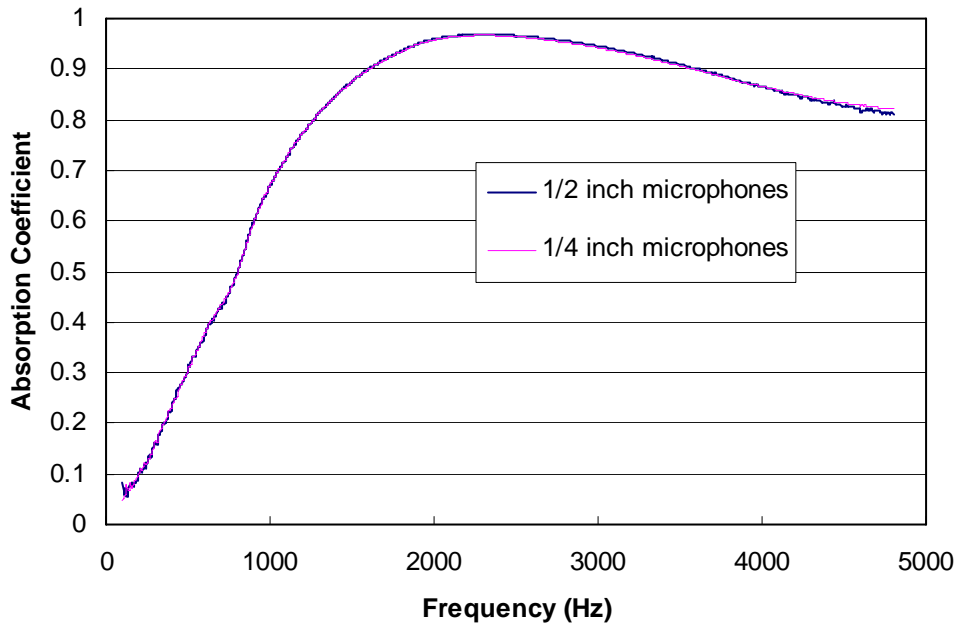


Figure 4 Absorption coefficient of 1" foam using both 1/4 and 1/2 inch microphone pairs.

Sound Source. The sound source should provide sound energy over a frequency and intensity range sufficient for testing. The frequency response of the source need not be flat (± 10 dB is sufficient¹). It is usually important for the sound source to have a high-power rating (e.g., 50 to 100 watts) so that high intensity sound may be generated inside the tube for certain types of testing. For example, the absorption of many materials is dependent on the intensity of sound; it is therefore helpful to test such materials at several levels above and below field conditions.

Mounting the Sample. Probably the closest thing to art in the two-microphone method is the mounting of the sample. According to the standards¹ the sample "...must fit snugly into the specimen holder, not so tightly that it bulges in the center, nor so loosely that there is space between its edge and the holder." Pliable materials such as foams and glass fiber are easy to cut and fit into a holder. Materials that are rigid or have stiff layers should be cut slightly undersize and sealed around the edges using Vaseline or wrapped with a couple of layers of tape to eliminate the air gap between the sample and the tube. The goal is to achieve a very slight interference fit between the sample and the holder.

The sample must also be in contact with the rigid plunger (see Figure 1). An air gap will affect the results. In field situations where the material is used with an air gap, the

same air gap should exist between the sample and the plunger so that the test duplicates field conditions.

Temperature Correction. The standards^{1,2} recommend that the temperature be held constant during the test to within 1° C. The software must have provisions for correcting the speed of sound and density of air for temperature.

References:

1. ASTM E1050, *Standard test method for impedance and absorption of acoustical materials using a tube, two microphones, and a digital frequency analysis system.*
2. ISO 10534-2, *Acoustics – Determination of sound absorption coefficient and impedance in impedance tubes – Part 2: Transfer-function method.*
3. Seybert, A. F., and Ross, D. F., *Experimental Determination of Acoustic Properties Using a Two-Microphone Random-Excitation Technique*, J. Acoust. Soc. Am., Vol. 61, No. 5, pp. 1362-1370, 1977.
4. Chung, J. Y., and Blaser, D. A., *Transfer Function Method of Measuring In-Duct Acoustic Properties I. Theory and II. Experiment*, J. Acoust. Soc. Am., Vol. 68, No. 3, pp. 907-921, 1980.
5. Haines, James, *Standing wave and two-microphone impedance tube round-robin test program*, ASTM Research Report No. RR:E33-1006, 1989.
6. ASTM C384, *Test method for impedance and absorption of acoustical materials by the impedance tube method.*