INTERNATIONAL

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Standard Test Method for Normal Incidence Determination of Porous Material Acoustical Properties Based on the Transfer Matrix Method[1]

This standard is issued under the fixed designation E2611; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the use of a tube, four microphones, and a digital frequency analysis system for the measurement of normal incident transmission loss and other important acoustic properties of materials by determination of the acoustic transfer matrix.

1.2 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.4 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C634 Terminology Relating to Building and Environmental Acoustics

E90 Test Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions and Elements

E1050 Test Method for Impedance and Absorption of Acoustical Materials Using a Tube, Two Microphones and a Digital Frequency Analysis System

2.2 *ISO Standards:*

ISO 140-3 Acoustics—Measurement of Sound Insulation in Buildings and of Building Elements—Part 3: Laboratory Measurement of Airborne Sound Insulation of Building Elements[3]

3. Terminology

3.1 *Definitions*—The acoustical terminology used in this test method is intended to be consistent with the definitions in Terminology C634.

3.1.1 *reference plane*—an arbitrary section, perpendicular to the longitudinal axis of the tube that is used for the origin of linear dimensions. Often it is the upstream (closest to the sound source) face of the specimen but, when specimen surfaces are irregular, it may be any convenient plane near the specimen.

3.1.2 *sound transmission coefficient, τ*—(dimensionless) of a material in a specified frequency band, the fraction of airborne sound power incident on a material that is transmitted by the material and radiated on the other side.

$$\tau = \frac{W_t}{W_i}$$

where:

W_t and W_i = the transmitted and incident sound power.

3.1.3 *normal incidence sound transmission loss, TLN*—of a material in a specified frequency band, ten times the common logarithm of the reciprocal of the normal incidence sound transmission coefficient. The quantity so obtained is expressed in decibels.

$$TLN = 10 \log_{10}\left(\frac{W_i}{W_t}\right) = 10 \log_{10}\left(\frac{1}{\tau}\right)$$

3.1.3.1 *Discussion*—In this standard the symbol *TLN* will be applied to sound which impinges at an angle normal to the test specimen, as opposed to an arbitrary or random angle of incidence.

3.2 *Symbols:*

c = speed of sound, m/s.

ρ = density of air, kg/m^3.

[1] This test method is under the jurisdiction of ASTM Committee E33 on Building and Environmental Acoustics and is the direct responsibility of Subcommittee E33.01 on Sound Absorption.

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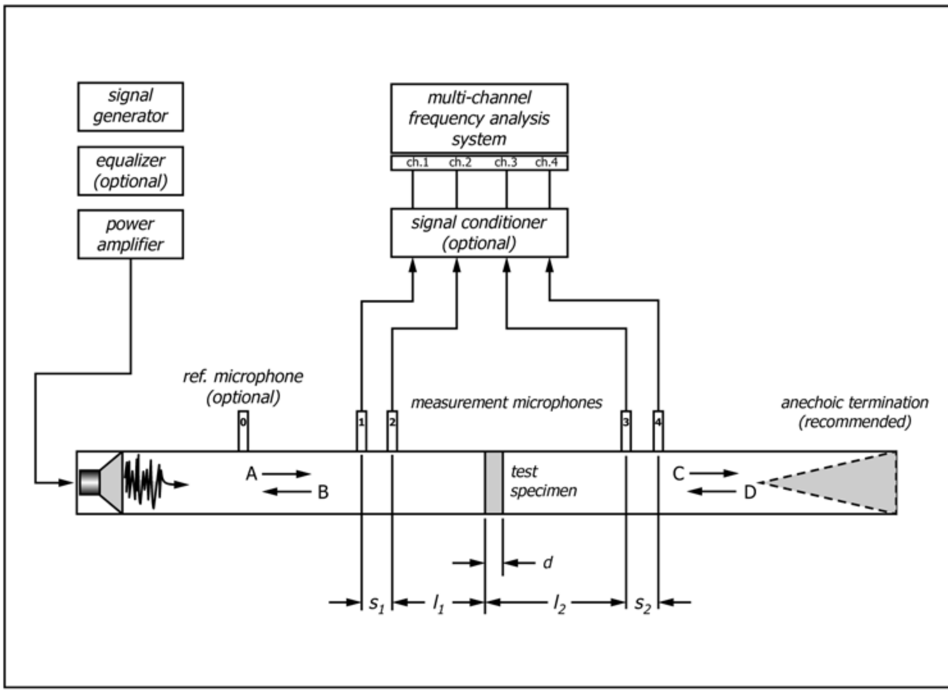
[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.



NOTE 1—A, B, C, and D are the forward and backward components of the standing wave field. 1, 2, 3, and 4 are the measurement locations; 0 is an optional reference location. Distances are measured from the specimen reference plane.

FIG. 1 Schematic Drawing of Measurement Setup

f = frequency, hertz, (Hz).

G_{11}, G_{22}, etc. = auto power spectra (autospectrum) of the acoustic pressure signal at microphone locations 1, 2, and so on.

G_{21}, G_{32}, etc. = cross power spectrum (cross spectrum) of the acoustic pressure signals at location 2 relative to location 1, 3 relative to 1, and so on. In general, a complex value.

$\bar{H}_{21}$, $\bar{H}_{31}$, etc. = measured transfer function of the acoustic pressure signals at location 2 relative to location 1, 3 relative to 1, and so on. In general, a complex value. Note that H_{11} is purely real and equal to 1.

H^I, H^{II} = calibration transfer functions for the microphones in the standard and switched configurations, respectively. See 8.4.

H^c = complex microphone calibration factor accounting for microphone response mismatch.

H_{21}, H_{31}, etc. = transfer function of two microphone signals corrected for microphone response mismatch. In general, a complex value.

NOTE 1—In this context, the term "transfer function" refers to the complex ratio of the Fourier transform of two signals. The term "frequency response function" arises from more general linear system theory (**1**).[4] This test method shall retain the use of the former term. Users should be aware that modern FFT analyzers might employ the latter terminology.

$j = \sqrt{-1}$

$k = 2\pi f/c$; wave number in air, m^{-1}.

NOTE 2—In general the wave number is complex where $k' = k^r - jk^i$. k^r is the real component, $2\pi\, f/c$, and k^i is the imaginary component of the wave number, also referred to as the attenuation constant, nepers/m. This accounts for the effects of viscous and thermal dissipation in the oscillatory, thermoviscous boundary layer that forms on the inner surface of the duct, (**2**). The wave number k' of the propagating wave interior to the material being tested is generally different from that in air, and may be calculated in certain cases from the acoustic transfer matrix.

d = thickness of the specimen in meters; see Fig. 1.

11, 12 = distance in meters from the reference plane (test sample front face) to the center of the nearest microphone on the upstream and downstream side of the specimen; see Fig. 1.

$s1$, $s2$ = center-to-center spacing in meters between microphone pairs on the upstream and downstream side of the specimen; see Fig. 1.

R = complex acoustic reflection coefficient.

α = normal incidence sound absorption coefficient.

TL_n = normal incidence transmission loss.

k' = complex wavenumber of propagation in the material, m^{-1}.

Z = characteristic impedance of propagation in the material, rayls.

3.3 *Subscripts, Superscripts, and Other Notation*—The following symbols, which employ the variable X for illustrative purposes, are used in Section 8:

Xc = calibration.

XI, XII = calibration quantities measured with microphones placed in the standard and switched configurations, respectively.

$\bar{X}$ = measured quantity prior to correction for amplitude and phase mismatch.

$|X|$ = magnitude of a complex quantity.

φ = phase of a complex quantity in radians.

Xi = imaginary part of a complex quantity.

[4] The boldface numbers in parentheses refer to the list of references at the end of this standard.

Xr = real part of a complex quantity.

3.4 *Summary of Complex Arithmetic*—The quantities in this standard, especially the transfer function spectra, are complex-valued in general. The following may be useful in evaluating the defining equations:

$$e^{j\omega} = \cos(\omega) + j\sin(\omega)$$
$$(A+jB) \times (C+jD) = (AC+BD) + j(AD+BD)$$
$$1/(A+jB) = A/(A^2+B^2) - jB/(A^2+B^2)$$

4. Summary of Test Method

4.1 This test method is similar to Test Method E1050 in that it also uses a tube with a sound source connected to one end and the test sample mounted in the tube. For transmission loss, four microphones, at two locations on each side of the sample, are mounted so the diaphragms are flush with the inside surface of the tube perimeter. Plane waves are generated in the tube using a broadband signal from a noise source. The resulting standing wave pattern is decomposed into forward- and backward-traveling components by measuring sound pressure simultaneously at the four locations and examining their relative amplitude and phase. The acoustic transfer matrix is calculated from the pressure and particle velocity, or equivalently the acoustic impedance, of the traveling waves on either side of the specimen. The transmission loss, as well as several other important acoustic properties of the material, including the normal incidence sound absorption coefficient, is extracted from the transfer matrix.

5. Significance and Use

5.1 There are several purposes of this test:

5.1.1 For transmission loss: *(a)* to characterize the sound insulation characteristics of materials in a less expensive and less time consuming approach than Test Method E90 and ISO 140-3 ("reverberant room methods"), *(b)* to allow small samples tested when larger samples are impossible to construct or to transport, *(c)* to allow a rapid technique that does not require an experienced professional to run.

5.1.2 For transfer matrix: *(a)* to determine additional acoustic properties of the material; *(b)* to allow calculation of acoustic properties of built-up or composite materials by the combination of their individual transfer matrices.

5.2 There are significant differences between this method and that of the more traditional reverberant room method. Specifically, in this approach the sound impinges on the specimen in a perpendicular direction ("normal incidence") only, compared to the random incidence of traditional methods. Additionally, revereration room methods specify certain minimum sizes for test specimens which may not be practical for all materials. At present the correlation, if any, between the two methods is not known. Even though this method may not replicate the reverberant room methods for measuring the transmission loss of materials, it can provide comparison data for small specimens, something that cannot be done in the reverberant room method. Normal incidence transmission loss may also be useful in certain situations where the material is placed within a small acoustical cavity close to a sound source, for example, a closely-fitted machine enclosure or portable electronic device.

5.3 Transmission loss is not only a property of a material, but is also strongly dependent on boundary conditions inherent in the method and details of the way the material is mounted. This must be considered in the interpretation of the results obtained by this test method.

5.4 The quantities are measured as a function of frequency with a resolution determined by the sampling rate, transform size, and other parameters of a digital frequency analysis system. The usable frequency range depends on the diameter of the tube and the spacing between the microphone positions. An extended frequency range may be obtained by using tubes with various diameters and microphone spacings.

5.5 The application of materials into acoustical system elements will probably not be similar to this test method and therefore results obtained by this method may not correlate with performance in-situ.

6. Apparatus

6.1 The apparatus is a set of two tubes of equal internal area that can be connected to either end of a test sample holder. The number of sets of tubes depends on the frequency range to be tested. A wider frequency range may require multiple measurements on a set of several tubes. At one end of one tube is a loudspeaker sound source. Microphone ports are mounted at two locations along the wall of each tube. A two- or four-channel digital frequency analysis system, or a computer that can effectively do the same calculations, is used for data acquisition and processing.

6.2 *Tube:*

6.2.1 *Construction*—The interior section of the tube may be circular or rectangular and shall have a constant cross-sectional dimension from end-to-end. The tube shall be straight and its inside surface shall be smooth, nonporous, and free of dust, in order to maintain low sound attenuation. The tube construction shall be sufficiently massive so sound transmission through the tube wall is negligible compared with transmission though the sample. See Note 3. Compliant feet or mounts must be used to attenuate extraneous vibration entering the tube structure from the work surface.

NOTE 3—The tube can be constructed from materials including metal, plastic, concrete, or wood. It may be necessary to seal the interior walls with a smooth coating in order to maintain low sound attenuation for plane waves.

6.2.2 *Working Frequency Range*—The working frequency range is:

$$f_l < f < f_u \quad (1)$$

where:

f = operating frequency, Hz,
f_l = lower working frequency of the tube, Hz, and
f_u = upper working frequency of the tube, Hz.

6.2.3 The lower frequency limit f_l is determined by the spacing of the microphones and the accuracy of the analysis