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Acoustics — Determination of acoustic properties in impedance tubes —

Part 2:
Two-microphone technique for normal sound absorption coefficient and normal surface impedance

Acoustique — Détermination des propriétés acoustiques aux tubes d'impédance —

Partie 2: Méthode à deux microphones pour le coefficient d'absorption acoustique normal et l'impédance de surface normale

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Contents

Page

Foreword

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This document was prepared by Technical Committee ISO/TC 43 *Acoustics*, Subcommittee SC 2, *Building acoustics,* in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 126, *Acoustics properties of building products and of buildings,* in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This second edition cancels and replaces the first edition (ISO 10534-2:1998), which has been technically revised.

The main changes are as follows:

— the introduction of the measurement procedure to estimate the characteristic properties of porous materials (characteristic impedance, wavenumber, dynamic mass density, dynamic bulk modulus) in an informative annex. The signal processing techniques have been updated since the first version of this document.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Acoustics — Determination of acoustic properties in impedance tubes —

Part 2:
Two-microphone technique for normal sound absorption coefficient and normal surface impedance

1 Scope

This test method covers the use of an impedance tube, two microphone locations and a frequency analysis system for the determination of the sound absorption coefficient of sound absorbing materials for normal incidence sound incidence. It can also be applied for the determination of the acoustical surface impedance or surface admittance of sound absorbing materials. As an extension, it can also be used to assess intrinsic properties of homogeneous acoustical materials such as their characteristic impedance, characteristic wavenumber, dynamic mass density and dynamic bulk modulus.

The test method is similar to the test method specified in ISO 10534-1[1] in that it uses an impedance tube with a sound source connected to one end and the test sample mounted in the tube at the other end. However, the measurement technique is different. In this test method, plane waves are generated in a tube by a sound source, and the decomposition of the interference field is achieved by the measurement of acoustic pressures at two fixed locations using wall-mounted microphones or an in-tube traversing microphone, and subsequent calculation of the complex acoustic transfer function and quantities reported in the previous paragraph. The test method is intended to provide an alternative, and generally much faster, measurement technique than that of ISO 10534-1[1].

Normal incidence absorption coefficients coming from impedance tube measurements are not comparable with random incidence absorption coefficients measured in reverberation rooms according to ISO 354[2]. The reverberation room method will (under ideal conditions) determine the sound absorption coefficient for diffuse sound incidence. However, the reverberation room method requires test specimens which are rather large. The impedance tube method is limited to studies at normal and plane incidence and requires samples of the test object which are of the same size as the cross-section of the impedance tube. For materials that are locally reacting only, diffuse incidence sound absorption coefficients can be estimated from measurement results obtained by the impedance tube method (see Annex E).

Through the whole document, a $e^{+j\omega t}$ time convention is used.

2 Normative references

There are no normative references in this document.

3 Terms, definitions and symbols

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at https://www.iso.org/obp
- IEC Electropedia: available at https://www.electropedia.org/

3.1
sound absorption coefficient at normal incidence

α_n

ratio of the sound power dissipated inside the test object to the incident sound power for a plane wave at normal incidence

Note 1 to entry: "Plane wave" here describes a wave whose value, at any moment, is constant over any plane perpendicular to its direction of propagation. "Normal incidence" describes the direction of the longest axis of the impedance tube.

3.2
sound pressure reflection coefficient at normal incidence

r

complex ratio of the reflected wave sound pressure amplitude to that of the incident wave in the reference plane for a plane wave at normal incidence

3.3
reference plane

cross-section of the impedance tube for which the reflection factor r or the impedance Z or the admittance G are determined and which is usually the surface of the test object, if flat

Note 1 to entry: The reference plane is assumed to be at $x = 0$.

3.4
normal-incidence surface impedance

Z

ratio of the complex sound pressure $p(x = 0)$ to the normal component of the complex sound particle velocity $v(x = 0)$ at an individual frequency in the reference plane defined as $x = 0$

Note 1 to entry: The particle velocity vector has a positive direction pointing towards the interior of the tested object.

Note 2 to entry: Z is expressed in newton second per cubic meter (Ns/m^3)

3.5
normal-incidence surface admittance

G

inverse of the normal-incidence surface impedance Z

Note 1 to entry: G is expressed in cubic meter per newton per second (m^3/N/s)

3.6
wave number in air

k_0

variable, expressed in radian per metre, defined by

$$k_0 = \omega / c_0 = 2\pi f / c_0 = 2\pi / \lambda_0$$

where

ω is the angular frequency,

f is the frequency,

c_0 is the speed of sound in the air,

λ_0 is the wavelength in air.

Note 1 to entry: In general, the wave number is complex, so that $k_0 = k_0' - jk_0''$ where k_0' is the real component and k_0'' is the imaginary component (which is the attenuation constant).

Note 2 to entry: k_0' is expression in radian per metre.

3.7
material characteristic wave number

k_c

variable, expressed in radian per meter, defined by

$$k_c = \omega / c = 2\pi f / c = \omega \sqrt{\rho_{eq} / K_{eq}}$$

where

c is the speed of sound inside the material;

ρ_{eq} is the material dynamic mass density (defined in 3.9);

K_{eq} is the material bulk modulus (defined in 3.10)

3.8
material characteristic impedance

Z_c

variable, expressed in Newton second per cubic metre, defined by

$$Z_c = \sqrt{\rho_{eq} K_{eq}}$$

3.9
material dynamic mass density

ρ_{eq}

variable describing the visco-inertial dissipation inside the tested material.

Note 1 to entry: The dynamic mass density can differ from the static (volume-averaged) value.

Note 2 to entry: It is expressed in kg/m^3.

3.10
material dynamic bulk modulus

K_{eq}

variable describing the thermal dissipation inside the tested material.

Note 1 to entry: The dynamic bulk modulus can differ from the static (volume-averaged) value.

Note 2 to entry: It is expressed in N/m^2 (or equivalently in pascal).

3.11
complex sound pressure

p

frequency-domain spectrum of the sound pressure time signal

3.12
cross spectrum

S_{12}

product $p_2 \, p_1{}^*$, determined from the complex sound pressures p_1 and p_2 at two microphone positions

Note 1 to entry: * means the complex conjugate.

3.13
cross spectrum

S_{21}

product $p_1\ p_2$*, determined from the complex sound pressures p_1 and p_2 at two microphone positions

Note 1 to entry: * means the complex conjugate.

3.14
auto spectrum

S_{11}

product $p_1\ p_1$*, determined from the complex sound pressure p_1 at microphone position one

Note 1 to entry: * means the complex conjugate.

Note 2 to entry: S_{22} denotes the auto spectrum for pressure p_2 at microphone position two.

3.15
transfer function

H_{12}

transfer function from microphone position one to two, defined by the complex ratio $p_2 / p_1 = S_{12} / S_{11}$ or S_{22} / S_{21}, or $[(S_{12} / S_{11})(S_{22} / S_{21})]^{1/2}$

3.16
calibration factor

H_c

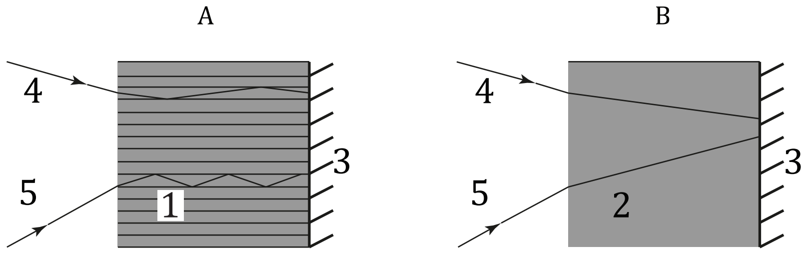
factor used to correct for amplitude and phase mismatches between the microphones

Note 1 to entry: See 8.5.2.

3.17
local reacting material

material for which the pressure and velocity fields at a given point on the surface are independent on the behaviour at other points of the surface is called a locally reacting material

Note 1 to entry: This local reaction behaviour infers specific properties for a material: its surface impedance is independent on the incidence angle of a plane wave impinging the material. Homogeneous honeycomb structures and perforated plates are examples of possible locally reacting materials (see Figure 1, a). For a locally reacting material, its absorption coefficient depends on the angle of incidence as its reflection coefficient does as well



Key

1	locally reacting material sample	4	plane wave impinging the sample
2	non-locally reacting material sample	5	plane wave impinging the sample with a different angle
3	rigid and impervious backing	A	locally reacting material sample
		B	non-locally reacting material sample

Figure 1 — Propagation of plane waves inside a locally reacting material sample and comparison to a non-locally reacting material sample

3.18
bulk or extended reaction material

material for which the reaction does not occur only normal to the surface.

Note 1 to entry: The reaction in each point of the material is hence dependent on the reaction of the neighbouring points. Examples of materials experiencing bulk reactions are foams made of multiple pores and fibrous with fibres not parallel to each other's (see Figure 1 b).

4 Principle

The test sample is mounted at one end of a straight, rigid, smooth and airtight impedance tube. Plane waves are generated in the tube by a sound source emitting a signal such as a random noise, pseudo-random sequence, or a deterministic signal such as a chirp signal, and the sound pressures are measured at two locations near to the sample. The complex acoustic transfer function of the two microphone signals is determined and used to compute the normal-incidence complex reflection coefficient (see Annex C), the normal-incidence absorption coefficient, and the normal incidence surface impedance of the test material. From two distinct measurements, the intrinsic properties of the material (characteristic wave number, characteristic impedance, dynamic mass density and dynamic bulk modulus) can be assessed assuming this material is homogeneous.

The quantities are determined as functions of the frequency (or frequency bands as detailed in ISO 266[3]) with a frequency resolution which is determined from the sampling frequency and the record length of the digital frequency analysis system used for the measurements. The usable frequency range depends on the lateral dimensions or diameter of the tube and the spacing between the microphone positions. An extended frequency range may be obtained from the combination of measurements with different lateral dimensions (or diameter) and spacings.

The measurements may be performed by employing one of two techniques:

a) two-microphone method (using two microphones in fixed locations);

b) one-microphone method (using one microphone successively in two locations).

Technique 1: requires a pre-test or in-test correction procedure to minimize the amplitude and phase difference characteristics between the microphones; however, it combines speed, high accuracy, and ease of implementation. Technique 1 is recommended for general test purposes.

Technique 2: has particular signal generation and processing requirements and may necessitate more time; however, it eliminates phase mismatch between microphones and allows the selection of optimal microphone locations for any frequency. Technique 2 is recommended for measurements with higher precision, and its requirements are described in more detail in Annex B.

5 Test equipment

5.1 Construction of the impedance tube

The apparatus is essentially a tube with a test sample holder at one end and a sound source at the other. Microphone ports are usually located at two or three locations along the wall of the tube (depending on the chosen microphone spacing).

The impedance tube shall be straight with a uniform cross-section (diameter or cross dimension within ±0,2 %) and with rigid, smooth, non-porous walls without holes or slits (except for the microphone positions) in the test section. The walls shall be heavy and thick enough so that they are not excited to vibrations by the sound signal and show no vibration resonances in the working frequency range of the tube. For metal walls, a thickness of about 5 % of the diameter is recommended for circular tubes. For rectangular tubes, the corners shall be made rigid enough to prevent distortion of the side wall plates.

It is recommended that the side wall thickness be about 10 % of the cross dimension of the tube. Tube walls made of concrete shall be sealed by a smooth adhesive finish to ensure air tightness. The same holds for tube walls made of wood; these should be reinforced and damped by an external coating of steel or lead sheets.

The shape of the cross-section of the tube is arbitrary, in principle. Circular or rectangular (if rectangular, then preferably square) cross-sections are recommended.

If rectangular tubes are composed of plates, care shall be taken that there are no air leaks (e.g. by sealing with adhesives or with a finish). Tubes should be sound and vibration isolated against external noise or vibration.

5.2 Working frequency range

The working frequency range is given by Formula (1):

$$f_\mathrm{l} < f < f_\mathrm{u} \qquad (1)$$

where

f_l is the lower working frequency of the tube;

f is the operating frequency;

f_u is the upper working frequency of the tube.

f_l is limited by the uncertainty of the signal processing equipment and the spacing between the two microphone positions.

f_u is chosen to avoid the occurrence of non-plane wave mode propagation. The condition for f_u given by Formula (2):

$$d < 0{,}58\ \lambda_\mathrm{u} : \ f_\mathrm{u} \cdot d < 0{,}58\ c_0 \qquad (2)$$

for circular tubes with the inside diameter d in metres and f_u in Hertz, given by Formula (3) is used:

$$d < 0{,}50\ \lambda_\mathrm{u} : \ f_\mathrm{u} \cdot d < 0{,}50\ c_0 \qquad (3)$$

for rectangular tubes with the maximum side length d in metres; c_0 is the speed of sound in metres per second given by Formula (4.

The spacing s in metres between the microphones shall be chosen to avoid singularities when the distance of the two microphone positions is equal to a multiple of half the operating wavelength. The first singularity is avoided when ensuring that

$$f_\mathrm{u} \cdot s < 0{,}45\ c_0 \qquad (4)$$

The lower frequency limit is dependent on the spacing between the microphones and the uncertainty of the analysis system but, as a general guide, the microphone spacing should exceed 1,5 % of the wavelength corresponding to the lower frequency of interest, provided that the requirements of Formula (4) are satisfied. A larger spacing between the microphones enhances the accuracy of the measurements for these low frequencies but reduces the value of the upper working frequency.

Different microphone spacings can be used to cover a wider frequency range than the one allowed for a single spacing. In this case, the working frequency ranges shall overlap by about one octave (as described in ISO 266[3]). The averaging technique used to obtain the averaged and combined result should be at least mentioned.

Different impedance tubes can also be used to cover a wider frequency range than the one allowed for a single tube (see Clause 10 i).

5.3 Length of the impedance tube

The tube should be long enough to cause plane wave development between the source and the sample. Microphone measurement points shall be in the plane wave field.

The loudspeaker generally will produce non-plane waves besides the plane wave. They will die out within a distance of about maximum three tube diameters or three times the lateral dimensions of rectangular tubes for frequencies below the lower cut-off frequency of the first higher mode. Thus, it is recommended that microphones be located no closer to the source than three tube diameters or three times the lateral dimensions.

Test samples will also cause proximity distortions to the acoustic field. It is recommended to have a minimum spacing between microphone and sample of ½ diameter or ½ maximum lateral dimension, but this spacing should be increased to 2 diameters or 2 times the maximum lateral dimension for non-planar materials or materials with a few small perforations (as perforated plates with a single millimetric perforation).

5.4 Microphones

Microphones of identical type shall be used in each location. When side-wall-mounted microphones are used, the diameter of the microphones shall be small compared to c_0 / f_u.

For side-wall mounting, it is recommended to use microphones of the pressure type. For in-tube microphones, it is recommended to use microphones of the free-field type.

5.5 Positions of the microphones

When side-wall-mounted microphones are used, each microphone shall be mounted with the diaphragm flush with the interior surface of the tube. A small recess is often necessary to prevent the microphone to be inserted inside the tube (see Figure 2); the recess should be kept small and be identical for both microphone mountings. The microphone grid shall be sealed tight to the microphone housing and there shall be a sealing between the microphone and the mounting hole.

a) Rectangular cross-section **b) Circular cross-section**

Key

1 microphone

2 sealing

Figure 2 — Examples of typical microphone mounting for a tube

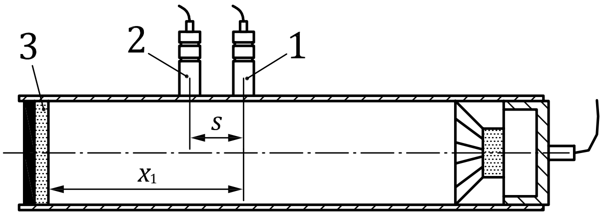
When using a single microphone in two successive wall positions, the microphone position not in use shall be sealed to avoid air leaks and to maintain a smooth surface inside the tube.

When using side-vented microphones, it is important that the pressure equalization vents are not blocked by the microphone mounting.

All fixed microphone locations shall be known to a tolerance of ±0,2 mm or better, and their spacing s (see Figure 3) shall be recorded.

Traversing microphone positions shall be known to a tolerance of ±0,5 mm or better.

Finally, it is recommended to set the microphone positions to a distance not larger than 250 mm $(x_1 < 250\ \text{mm})$ from the rigid backing of the impedance tube (i.e. the opposite end to the loudspeaker) to reduce the impact of the first acoustic resonances in the tube on the microphone measurements.



Key

1	microphone A
2	microphone B
3	test specimen
s	spacing between the two microphones
x_1	distance between the surface of the test specimen and the microphone closest to the sound source

Figure 3 — Microphone positions and distances

5.6 Acoustic centre of the microphone

For the determination of the acoustic centre of a microphone, or minimizing errors associated with a difference between the acoustic and geometric centres of the microphones, see A.2.2.

5.7 Test sample holder

The test sample holder is either integrated into the impedance tube or is a separate unit, which is tightly fixed to one end of the tube during the measurement. The length of the sample holder shall be large enough to install test objects with air spaces behind them if required.

If the sample holder is a separate unit, it shall comply in its interior dimensions with the impedance tube to within ±0,2 %. The mounting of the tube shall be tight, without insertion of elastic gaskets (petroleum jelly or thread seal tape is recommended for sealing).

For rectangular tubes, it is recommended to integrate the sample holder into the impedance tube and to make the installation section of the tube accessible by a removable cover for mounting the test sample. The contact surfaces of this removable cover with the tube shall be carefully finished and the use of a sealant (like a petroleum jelly or a thread seal tape) is recommended in order to avoid small leaks.

For circular tubes, it is recommended to make the test object accessible from both the front and the back end of the sample holder. It is then possible to check the position and flatness of the front surface and the back position.

Generally, in connection with rectangular tubes, it is recommended to install the test object from the side into the tube (instead of pushing it axially into the tube). It is then possible to check the fitting and the position of the test object in the tube, to check the position and the flatness of the front surface, and to reposition the reference plane precisely in relation to the front surface. A sideways insertion also avoids compression of soft materials.