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**Acoustics — Determination of airflow  
resistance —**

**Part 2:  
Alternating airflow method**

*Acoustique — Détermination de la résistance à l'écoulement de l'air —  
Partie 2: Méthode avec écoulement d'air alternatif*

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## Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see [www.iso.org/directives](http://www.iso.org/directives)).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see [www.iso.org/patents](http://www.iso.org/patents)).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see [www.iso.org/iso/foreword.html](http://www.iso.org/iso/foreword.html).

This document was prepared by Technical Committee ISO/TC 43, *Acoustics*, Subcommittee SC 2, *Building acoustics*.

This first edition of ISO 9053-2, together with ISO 9053-1:2018, cancels and replaces ISO 9053:1991, which has been technically revised.

The main changes compared to the previous edition are as follows:

- the former method B in ISO 9053:1991 has been transferred to this document;
- the requirement to the dimensions of the test specimen have been updated;
- a correction for heat conduction has been added.

A list of all parts in the ISO 9053 series can be found on the ISO website.

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](http://www.iso.org/members.html).

# Acoustics — Determination of airflow resistance —

## Part 2: Alternating airflow method

### 1 Scope

This document specifies an alternating airflow method for the determination of the airflow resistance<sup>[5], [6]</sup> of porous materials for acoustical applications.

Determination of the airflow resistance based on static flow is described in ISO 9053-1.

### 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/IEC Guide 98-3, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

### 3 Terms and definitions

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

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

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

#### 3.1

#### airflow resistance

$R$

quantity defined by

$$R = \frac{\Delta p}{q_v}$$

where

$\Delta p$  is the RMS air pressure difference, across the test specimen, due to the alternating airflow, in pascals;

$q_v$  is the RMS volumetric airflow rate, passing through the test specimen, in cubic metres per second.

Note 1 to entry: Airflow resistance is expressed in pascals seconds per cubic metre.

### 3.2

#### specific airflow resistance

$R_s$

quantity defined by

$$R_s = R \cdot A$$

where

$R$  is the airflow resistance of the test specimen, in pascals seconds per cubic metre;

$A$  is the cross-section area of the test specimen, perpendicular to the direction of flow, in square metres.

Note 1 to entry: Specific airflow resistance is expressed in pascals seconds per metre.

### 3.3

#### airflow resistivity

$\sigma$

quantity defined by the following formula if the material is considered as being homogeneous

$$\sigma = \frac{R_s}{d}$$

where

$R_s$  is the specific airflow resistance of the test specimen, in pascals seconds per metre;

$d$  is the thickness of the test specimen, in the direction of flow, in metres.

Note 1 to entry: Airflow resistivity is expressed in pascals seconds per square metre.

### 3.4

#### airflow velocity

$v$

quantity defined by

$$v = \frac{q_v}{A}$$

where

$q_v$  is the RMS volumetric airflow rate, passing through the test specimen, in cubic metres per second;

$A$  is the cross-sectional area of the test specimen, perpendicular to the direction of flow, in square metres.

Note 1 to entry: Airflow velocity is expressed in metres per second.

### 3.5

#### sound pressure level

$L_p$

ten times the logarithm to the base 10 of the ratio of the time average of the square of the sound pressure,  $p(t)$ , during a stated time interval of duration,  $T$  (starting at  $t_1$  and ending at  $t_2$ ), to the square of a reference value,  $p_0$ :

$$L_p = 10 \lg \left( \frac{\frac{1}{T} \int_{t_1}^{t_2} p^2(t) dt}{p_0^2} \right) \text{dB}$$

where the reference value,  $p_0$ , is 20  $\mu\text{Pa}$

Note 1 to entry: The sound pressure level is expressed in decibels.

## 4 Symbols

|           |                                                                                                                  |
|-----------|------------------------------------------------------------------------------------------------------------------|
| $A$       | cross-section area of the test specimen, in square metres;                                                       |
| $A_p$     | cross sectional area of the piston, in square metres;                                                            |
| $b$       | thickness of the thermal boundary layer, in metres;                                                              |
| $C_p$     | specific heat capacity at constant pressure, in joules per kilogram and degree kelvin;                           |
| $c_0$     | speed of sound, in metres per second;                                                                            |
| $d$       | thickness of the test specimen, in the direction of flow, in metres;                                             |
| $f$       | frequency of the piston movement, in hertz;                                                                      |
| $h$       | amplitude of the stroke of the piston, in metres;                                                                |
| $h_s$     | amplitude of the stroke of the piston when the measurement cell with the test specimen is mounted, in metres;    |
| $h_t$     | amplitude of the stroke of the piston when the air cavity is closed by the airtight termination, in metres;      |
| $j$       | $\sqrt{-1}$                                                                                                      |
| $k_a$     | thermal conductivity, in joules per meter, second and degree kelvin;                                             |
| $L_p$     | sound pressure level, in decibels;                                                                               |
| $L_{p,b}$ | background sound pressure level, in decibels;                                                                    |
| $L_{p,s}$ | sound pressure level in the air cavity when the measurement cell with the test specimen is mounted, in decibels; |
| $L_{p,t}$ | sound pressure level in the air cavity with the airtight termination, in decibels;                               |
| $l_h$     | characteristic thermal diffusion length, in metres;                                                              |
| $N$       | acoustic compliance, in cubic metres per pascal;                                                                 |
| $P_s$     | static pressure, in pascals;                                                                                     |

|            |                                                                                                                     |
|------------|---------------------------------------------------------------------------------------------------------------------|
| $p$        | sound pressure, in pascals;                                                                                         |
| $p_s$      | sound pressure when the test cell with the test specimen is mounted, in pascals;                                    |
| $p_t$      | sound pressure when the air cavity is closed by the airtight termination, in pascals;                               |
| $p_0$      | sound pressure reference value, 20 $\mu\text{Pa}$ ;                                                                 |
| $q_s$      | rms value of the volume flow when the test cell with the test specimen is mounted, in cubic metres per second;      |
| $q_t$      | rms value of the volume flow when the air cavity is closed by the airtight termination, in cubic metres per second; |
| $q_v$      | rms volumetric airflow rate, passing through the test specimen, in cubic metres per second;                         |
| $R$        | airflow resistance of the test specimen, in pascals seconds per cubic metre;                                        |
| $R_s$      | specific airflow resistance of the test specimen, in pascals seconds per metre;                                     |
| $r$        | ratio between the stroke amplitudes;                                                                                |
| $r_r$      | radius of the perforations in the specimen support ( <a href="#">Annex D</a> ), in metres;                          |
| $S$        | total area, in square metres;                                                                                       |
| $U$        | expanded uncertainty;                                                                                               |
| $u$        | standard uncertainty;                                                                                               |
| $V$        | volume of the air cavity with the airtight termination, in cubic metres;                                            |
| $v$        | airflow velocity, in metres per second;                                                                             |
| $v_s$      | rms-value of the airflow velocity through the test specimen, in metres per second;                                  |
| $y$        | thickness of the support, in metres;                                                                                |
| $Z_a$      | acoustic impedance of the cavity, in pascals seconds per cubic metres;                                              |
| $\Delta p$ | rms air pressure difference, across the test specimen, due to the alternating airflow, in pascals;                  |
| $\phi$     | perforation rate;                                                                                                   |
| $\eta$     | dynamic viscosity of air, in pascals seconds;                                                                       |
| $\kappa$   | ratio of specific heats for air;                                                                                    |
| $\kappa'$  | effective ratio of specific heats for air;                                                                          |
| $\lambda$  | wavelength, in metres;                                                                                              |
| $\rho_0$   | density of air, in kilograms per cubic metre;                                                                       |
| $\sigma$   | airflow resistivity of the test specimen, in pascals seconds per square metre;                                      |
| $\omega$   | circular frequency, $2 \cdot \pi \cdot f$ , in per second.                                                          |

## 5 Principle

An alternating volume flow with a low frequency,  $f$ , for example of 2 Hz, is generated by a piston or similar device (see [Figure 1](#) and [Figure 2](#)) moving sinusoidally. This volume flow acts on an air cavity that is either closed by an airtight termination or terminated by the test specimen mounted in a measurement cell. The sound pressure level is measured in the air cavity for both cases.

The pressure inside the cavity is the outside atmospheric pressure modulated by the alternating flow generated by the piston. The microphone mounted inside the cavity therefore measures the pressure difference across the specimen when the test cell with the specimen is mounted.

When the air cavity is closed, the volume flow creates a sound pressure in the air cavity that can be calculated from the piston movement, the dimensional information of the cavity and the atmospheric air pressure.

When the measurement cell is mounted, the main part of the generated volume flow passes through the test specimen and a lower sound pressure is observed in the air cavity. The difference between the sound pressure levels when the vessel is closed and when the test cell is mounted is a direct function of the airflow resistivity of the test specimen. By the measurement of the sound pressure differences, the airflow resistance for the test specimen can be computed.

It can be practical to use different piston stroke lengths for the closed vessel and when the measurement cell is mounted.

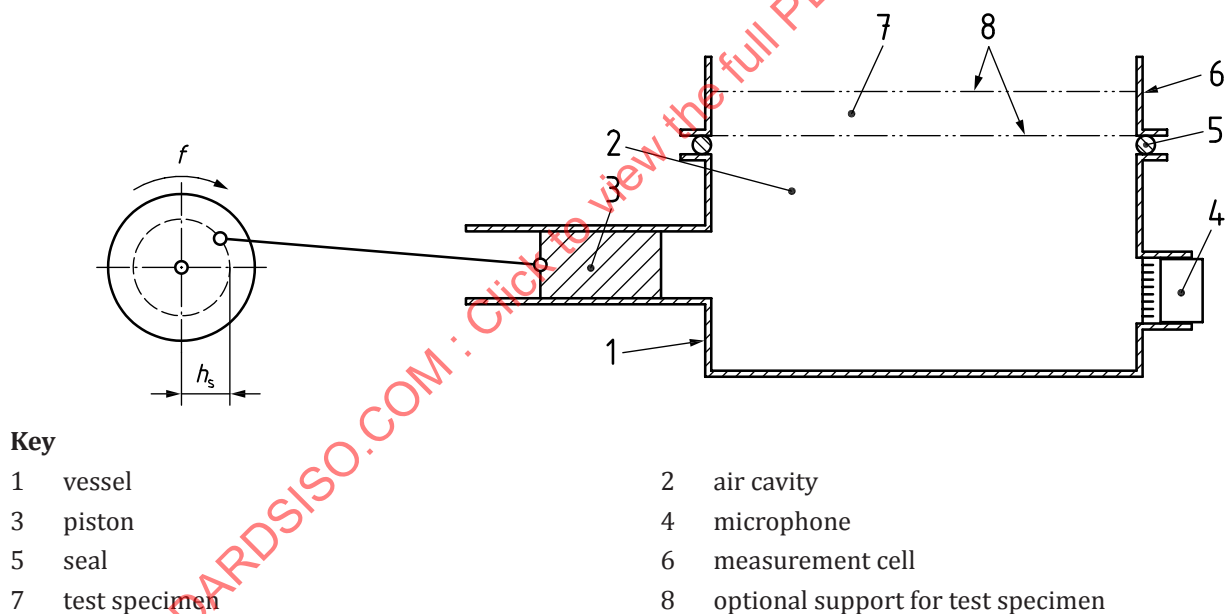
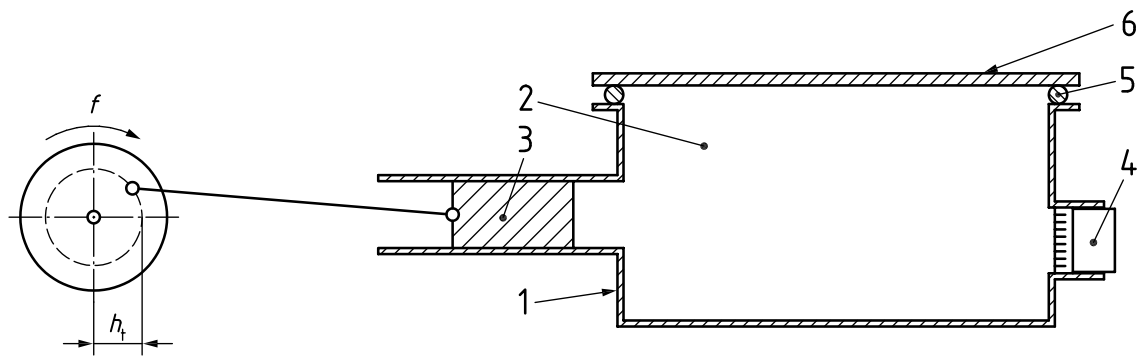


**Figure 1 — Basic principle, termination with the test specimen**



**Key**

- |   |        |   |                      |
|---|--------|---|----------------------|
| 1 | vessel | 2 | air cavity           |
| 3 | piston | 4 | microphone           |
| 5 | seal   | 6 | airtight termination |

**Figure 2 — Basic principle, termination with an airtight seal**

**NOTE** For materials with a visco-inertial transition frequency below 100 Hz, the method described in ISO 9053-1 using a static flow can give a different result. Examples of such materials are: a) fibre materials with large fibres, such as some metal or plant fibres, b) foams with low porosity but big pores, such as some metal foams, c) granular materials with large grains and low porosity, such as road pavements.

## 6 Equipment

### 6.1 General

The equipment shall consist of:

- a) a device for producing the alternating airflow (see 6.2);
- b) a sound level meter or an alternative device for measuring the sound pressure level in a narrow frequency band (e.g. a fractional octave band) around the frequency of the piston (see 6.3);
- c) a vessel (see 6.4)
  - containing the air cavity,
  - allowing connections to the microphone and the source of the alternating airflow, and
  - including an airtight termination and a measurement cell;
- d) a device for measuring the static pressure (see 6.5);
- e) a device for measuring the frequency of the piston (see 6.6);
- f) a device for measuring the thickness of the test specimen when it is positioned for the test.

### 6.2 Device for producing the alternating airflow

The alternating airflow shall be produced by a sinusoidally moving piston. The frequency of the piston movement,  $f$ , shall be in the range of 1 Hz to 4 Hz and known with sufficient accuracy (see Annex C).

The amplitude of the piston stroke,  $h$  (see [Figure 1](#) and [Figure 2](#)), shall be determined, normally by dimensional measurements. The rms-value of the volume flow,  $q_v$ , produced by the moving piston is

$$q_v = \sqrt{2} \cdot \pi \cdot f \cdot h \cdot A_p$$

Different stroke lengths can be applied for the measurement with the airtight termination and the measurement cell with specimen. The two lengths shall be selected to obtain suitable sound pressure levels in both situations as well as to generate the required airflow velocity through the specimen. The use of different piston frequencies and stroke lengths can be used to demonstrate that the obtained airflow resistance is independent of the airflow velocity.

The rms-value of the flow velocity through the test specimen, in metres per second, is calculated according to [Formula \(1\)](#):

$$v_s = \frac{\sqrt{2} \cdot \pi \cdot f \cdot h_s \cdot A_p}{A} \quad (1)$$

It is recommended to use rms-values of the flow velocity between  $5 \cdot 10^{-4} \text{ m s}^{-1}$  and  $4 \cdot 10^{-3} \text{ m s}^{-1}$ .

NOTE 1 A piston with a diameter of 10 mm and stroke lengths of 1,4 mm (airtight termination) and 14 mm (measurement cell with specimen) has proven to be appropriate for a measurement cell diameter of 100 mm and an air cavity with a volume of about  $10^{-3} \text{ m}^3$ .

NOTE 2 The uncertainty analysis shows that the ratio between the different applied stroke lengths is important. The ratio can be verified by using a sound level measuring system that covers the pressures generated by all the applied strokes lengths.

### 6.3 Sound measuring device

The sound measuring device shall be able to measure sound pressures with the piston frequency. The applied sound pressure shall be within the linear measurement range for the device.

The sound measuring device shall have a small bandwidth around the piston frequency for reducing background noise and harmonic distortions.

For all related measurements at a particular piston frequency including measurement of background noise, the bandwidth of the sound measuring device shall not be changed.

The sound measuring device may be a sound level meter, including microphones and cables, conforming to the requirements of IEC 61672-1 class 1 or class 2, and with fractional-octave band filters meeting the requirements of IEC 61260-1 class 1 or class 2.

It is important that the sound measuring device only measure the sound with frequencies close to the frequency of the piston in order to reduce the effect of harmonic distortions and background noise. The band limiting function can be obtained by the use of a fractional-octave band filter or FFT-analyser/technique.

NOTE The sound measuring device is mainly used to determine the difference in sound pressure levels for sound with a constant frequency. Level linearity performance at this frequency is therefore the most important property.

### 6.4 Vessel and measurement cell

The vessel and the measurement cell shall be in the shape of a circular cylinder or a rectangular parallelepiped (preferably with a square cross-section in the latter case). The vessel shall include appropriate seals to enable a leak-free mounting of the airtight termination and the measurement cell. The vessel and the airtight termination shall be sufficiently stiff to avoid volume changes under alternating pressure conditions. The volume,  $V$ , of the air cavity inside the closed vessel with the

airtight termination mounted shall include all connecting pipes, such as to the microphone and to the piston. The piston shall be in centre position when the volume is measured.

The diameter or smallest edge of the measurement cell shall be chosen depending on the specimens to test. In any case, the minimum diameter or smallest edge of the measurement cell shall be 29 mm. Furthermore, the air cavity shall have a cross section that is at least the same as the cross section of the measurement cell. Various measurement cells can be used as long as they fulfil all the requirements of this document.

The vessel and the measurement cell should be made so that the airflow is along the flow direction to be measured. This is normally perpendicular to the surface of the specimen to be measured. The measurement cell may include two grills or perforated plates for keeping the test specimen in position. It is important that the test specimen do not move due to the alternating air flow. The supports shall have an open area of minimum 50 %, evenly distributed. The holes in the support shall have a diameter of not less than 3 mm. The airflow resistance of the support should be less than 1 % of the airflow resistance to be measured. See [Annex D](#) for additional information.

## 6.5 Device for measuring the static pressure

The device for measuring the static pressure shall be capable of performing measurements with a low uncertainty. The uncertainty in the static pressure shall be considered in the uncertainty budget.

## 6.6 Device for measuring the frequency of the piston

The frequency of the piston shall be determined with low uncertainty. The uncertainty in the frequency shall be considered in the uncertainty budget. The frequency may be measured from the microphone signal by the use of a frequency counter or by frequency analysis.

# 7 Test specimens

## 7.1 Homogeneity of test specimen

The test specimen can have different airflow resistivities for different orientations of the specimen relative to the applied direction of airflow. If the specimen is not homogeneous, one or more appropriate orientations shall be selected and described in the test report.

## 7.2 Shape

The test specimen may be circular or rectangular, corresponding to the shape of the measurement cell.

## 7.3 Dimensions

### 7.3.1 Lateral dimensions

The lateral dimensions of a specimen shall contain a minimum of 10 pores for a foam specimen, 10 fibres for a fibrous material specimen, or 10 grains for a granular specimen. In case no information about the microstructure of the material (number of pores, fibres or grains per millimetre) is available, a minimum diameter of 95 mm or a smaller edge of 90 mm minimum is required for the material specimens.

The measurement cell shall have the same lateral dimensions as the material specimen submitted to test. See [8.2](#) to avoid leaks between the measurement cell and the specimen.

Care should be taken to avoid dimensional distortion of the test specimen.

### 7.3.2 Thickness

The thickness of the test specimen shall be chosen to obtain a measurable sound pressure level above self-noise in the instrument and noise in the environment.

The test specimen shall be mounted in the measurement cell in a way to prevent altering the thickness of the specimen.

If the test specimens available are not sufficiently thick to produce a suitable sound pressure level, test specimens chosen in the same way may be superimposed if this does not modify the material microscopic structure. In particular, when test specimens of fibrous materials or non-woven textiles are superimposed, the same orientation of the fibres shall be used for the individual superimposed specimens. For perforated plates or woven textiles, holes or patterns should all be superimposed.

### 7.4 Number of test specimens

The required number of test specimens depends on the type of the material and is commonly defined in product standards. Usually three to six samples are required.

## 8 Test procedure

**8.1** Place the test specimen, prepared as described in [Clause 7](#), in the measurement cell.

**8.2** Ensure that the edges are properly sealed. A thin layer of petroleum jelly, thread seal tape or rings may be used to seal the edges of specimens. When using petroleum jelly, care should be taken to avoid penetration of the petroleum jelly inside the material specimen.

**8.3** Bring the device for measuring the thickness of the test specimens into contact with the upper surface of the test specimens, compressing it lightly if necessary.

**8.4** Note the thickness and use this measurement to determine the free or the compressed volume and, from this, derive the free or the compressed density of the test specimen when in position.

**8.5** Measure the static pressure,  $P_s$ . Adjust the volume flow source to the piston stroke length,  $h_s$ . Set the source in motion and measure:

- a) the frequency of the piston movement,  $f$ ;
- b) the background sound pressure level,  $L_{p,b}$ , with acting source and neither test cell nor airtight termination mounted;
- c) the sound pressure level in the air cavity, when the measurement cell with the test specimen is mounted,  $L_{p,s}$  (see [Figure 1](#)).

**8.6** Replace the measurement cell with the airtight termination. Adjust the volume flow source to the piston stroke length,  $h_t$ . Set the source in motion and ensure that the frequency of the piston movement is unchanged. Then, measure the sound pressure level in the air cavity with the airtight termination,  $L_{p,t}$  (see [Figure 2](#)).

**8.7** The airflow resistance is then calculated from the measured quantities as given in [Formula \(2\)](#):

$$R = \frac{\kappa' \cdot P_S}{2 \cdot \pi \cdot f \cdot V} \cdot \frac{h_t}{h_s} \cdot 10^{\frac{L_{p,s} - L_{p,t}}{20 \text{ dB}}} \quad (2)$$

The effective ratio of specific heat,  $\kappa'$ , shall be determined by the method given in [Annex A](#) or another method to determine the effect of heat conduction.

[Formula \(2\)](#) gives valid results when the requirements in [Formula \(3\)](#) and [\(4\)](#) are both met:

$$\frac{h_t}{h_s} \cdot 10^{\frac{L_{p,s} - L_{p,t}}{20 \text{ dB}}} < 0,3 \quad (3)$$

and

$$L_{p,s} - L_{p,b} > 10 \text{ dB} \quad (4)$$

If the requirements are not met, a change of the specimen length, specimen diameter, cavity volume, piston frequency or piston stroke length can be appropriate.

[Formula \(2\)](#) shows that the airflow resistance is a function of the difference between two sound pressure levels, measured at the same frequency. An absolute calibration of the sound measuring device is therefore not needed. Further, the frequency response of the device is not critical. The important function is level linearity.

If the requirement in [Formula \(4\)](#) is satisfied, the influence of the background noise on the level  $L_{p,s}$  is less than 0,4 dB assuming uncorrelated noise. If the noise is correlated with the piston movement, a larger difference can be required for the stated accuracy.

The requirement in [Formula \(3\)](#) is explained in [Annex B](#).

## 9 Uncertainty

The uncertainty of the measured airflow resistance shall be estimated according to ISO/IEC Guide 98-3 and shall contain at least the following uncertainty components:

- effective ratio of specific heats;
- static pressure;
- frequency;
- volume;
- ratio between stroke amplitudes;
- difference in sound pressure levels.

In addition, the uncertainty may include contributions from air leakage and from sample dimensions and mounting.

[Annex C](#) contains some guidelines of how [Formula \(2\)](#) can be used for the uncertainty estimation.

NOTE Reference [7] shows an example of uncertainty analysis based on the method according to ISO/IEC Guide 98-3. The relative standard uncertainty turned out to be 9 %, excluding uncertainties due to specimen mounting and specimen preparation.

## 10 Test report

The test report shall include the following information:

- a) a reference to this document (i.e. ISO 9053-2:2020);
- b) information identifying and describing the test specimen;
- c) the environmental conditions during the test: temperature, humidity and air pressure;
- d) the date of the measurement/test report;
- e) the results, including a reference to the clause which explains how the results were calculated;
- f) the flow velocities used to determine the airflow resistance;
- g) the test conditions used, particularly the shape and dimensions of the measurement cell;
- h) the method of preparation of the test specimen;
- i) the number of test specimens and their lateral dimensions;
- j) if relevant, the orientation of the axis of the test specimens with respect to the principal axes of symmetry;
- k) if applicable, the presence and nature of any skin;
- l) relevant information related to density of the material as tested in the measurement cell;
- m) any deviation from the procedures specified in this document that can have influenced the results;
- n) any unusual features observed.

## Annex A (normative)

### Effective ratio of specific heats for air

#### A.1 Adiabatic compression

When a sinusoidal motion of a piston is acting as a source of alternating air flow into a closed air cavity, a sound pressure is generated in the cavity. If the dimensions of the cavity are small compared to the wavelength of sound in air corresponding to the applied frequency, the sound pressure is the same in all places within the volume, and a simple model can be used for describing the sound pressure.

If the compression of the air in the cavity is adiabatic, the rms-value of the sound pressure,  $p$ , is given by [Formula \(A.1\)](#):

$$p = \frac{\kappa \cdot P_s}{V} \cdot A_p \cdot \frac{h_t}{\sqrt{2}} \quad (\text{A.1})$$

Due to heat conduction and other losses, the compression of the air in the cavity is not fully adiabatic.

#### A.2 Correction for heat conduction

The acoustic pressure is calculated from an evaluation of the acoustic impedance of the cavity and the volume displacement of the piston.

The acoustic impedance,  $Z_a$ , of a cavity is the complex constant of proportionality between the acoustic pressure,  $p$ , and the volume flow driving the cavity. In the case of a rigid piston, the rms-value of the volume flow is given by [Formula \(A.2\)](#):

$$q_v = j \cdot \omega \cdot A_p \cdot \frac{h}{\sqrt{2}} \quad (\text{A.2})$$

where  $j = \sqrt{-1}$  and  $\omega = 2 \cdot \pi \cdot f$ .

The rms-value of the sound pressure is calculated according to [Formula \(A.3\)](#):

$$p = Z_a \cdot j \cdot \omega \cdot A_p \cdot \frac{h}{\sqrt{2}} \quad (\text{A.3})$$

where  $Z_a$  is the acoustic impedance of the cavity.

In several cases, the acoustic impedance of a closed cavity can be evaluated theoretically. In a closed cavity, heat conduction between the air and the cavity walls results in a departure from adiabatic conditions. As the frequency decreases, there is a transition from adiabatic to isothermal conditions. The exact nature of this transition as a function of frequency depends on the dimensions of the cavity. In addition, any in-plane particle velocity at the cavity walls results in viscous losses that alter the acoustic pressure.

The “small cavity” formulation<sup>[8]</sup> for determining the acoustic pressure takes into account the heat conduction effects and can be expressed independently of the specific geometry of the cavity if the characteristic dimensions of the cavity are large compared to the thickness of the thermal boundary layer, and small compared to the wavelength.

The thickness of the thermal boundary layer,  $b$ , is given by [Formula \(A.4\)](#):

$$b = \sqrt{\frac{2 \cdot c_0 \cdot l_h}{\omega}} \quad (\text{A.4})$$

where  $l_h$  is the characteristic thermal diffusion length and calculated by [Formula \(A.5\)](#):

$$l_h = \frac{k_a}{\rho_0 \cdot c_0 \cdot C_p} \quad (\text{A.5})$$

The acoustic impedance of the air cavity,  $Z_a$ , is then given by [Formula \(A.6\)](#):

$$Z_a = \frac{\kappa \cdot P_S}{j \cdot \omega \cdot V} \cdot \frac{1}{1 + \frac{1-j}{\sqrt{2}} \cdot (\kappa-1) \cdot \frac{S}{V} \cdot \sqrt{\frac{c_0 l_h}{\omega}}} \quad (\text{A.6})$$

where  $S$  is the total area of the internal surface of the air cavity.

IEC 61094-2:2009, Annex F, provides a method for the calculation of physical properties of air.

By comparing the [Formulae \(A.6\)](#), [\(A.1\)](#) and [\(2\)](#), and considering the magnitude of the complex quantity from [Formula \(A.6\)](#), an approximate value for the effective ratio of specific heats to be applied in [Formula \(2\)](#) is given by [Formula \(A.7\)](#):

$$\kappa' = \frac{\kappa}{\sqrt{1 + (\kappa-1) \cdot \frac{S}{V} \cdot b + \frac{1}{2} \left( (\kappa-1) \cdot \frac{S}{V} \cdot b \right)^2}} \quad (\text{A.7})$$

### A.3 Calculated example

The air cavity is assumed to be a closed cylinder with height and diameter both equal to 100 mm. The volume and internal surface is then:

$$V = 7,854 \cdot 10^{-4} \text{ m}^3$$

$$S = 0,0471 \text{ m}^2$$

The following physical properties for air, valid at 23 °C, 101,325 kPa and 50 % RH, are used for the calculation (values from IEC 61094-2:2009):

$$c_0 = 345,9 \frac{\text{m}}{\text{s}}$$

$$\rho_0 = 1,186 \frac{\text{kg}}{\text{m}^3}$$

$$\kappa = 1,4008$$

$$k_a = 0,02355 \frac{\text{J}}{\text{s} \cdot \text{m} \cdot \text{K}}$$

$$c_p = 938,7 \frac{\text{J}}{\text{kg} \cdot \text{K}}$$

Based on these values, the following values are calculated for the frequency  $f = 2 \text{ Hz}$  :

$$\lambda = \frac{c_0}{f} = 172,9 \text{ m}$$

$$b = 1,83 \cdot 10^{-3} \text{ m}$$

$$\kappa' = \kappa \cdot 0,978 = 1,370$$

The corrected value for the ratio of specific heats corresponds to a lowering of the sound pressure level by 0,19 dB compared to the uncorrected value given by [Formula \(A.1\)](#).

The assumptions for the calculation,  $\lambda \gg \sqrt[3]{V}$  and  $b \ll \sqrt[3]{V}$ , are both satisfied.

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## Annex B (informative)

### Acoustic model of the flow

[Formula \(2\)](#) assumes a linear relationship between the airflow resistance and the sound pressure in the vessel. However, as the resistance increases from a low value, the outgoing airflow through the test-specimen is reduced and is lower than the airflow generated by the piston. In the condition with the airtight termination, the outgoing flow is reduced to zero. This annex describes the transition between the ranges. If not otherwise specified, the symbols in this annex are as defined in [Clause 4](#).

[Figure B.1](#) shows a simplified lumped parameter model of the relation between the flow and the pressure in the vessel. The vessel with volume,  $V$ , is modelled as an acoustic compliance,  $N$ , given by [Formula \(B.1\)](#):

$$N = \frac{V}{\kappa' \cdot P_S} \quad (\text{B.1})$$

The corrected value for the ratio of specific heats,  $\kappa'$ , as given in [Annex A](#), is used in the model.

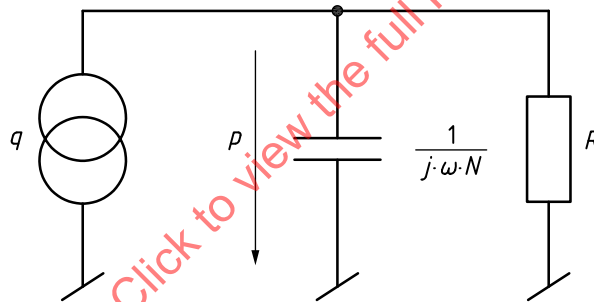


Figure B.1 — Lumped parameter model

The magnitude of the sound pressure is given by the product of the airflow and the magnitude of the impedance given by the compliance and the airflow resistance as given in [Formula \(B.2\)](#):

$$p_s = \frac{R}{\sqrt{1 + (2 \cdot \pi \cdot f \cdot R \cdot N)^2}} \cdot q_s \quad (\text{B.2})$$

When the vessel is closed, the airflow resistance is infinite and [Formula \(B.2\)](#) can be simplified to give the sound pressure,  $p_t$ , in the closed vessel as given in [Formula \(B.3\)](#):

$$p_t = \frac{q_t}{2 \cdot \pi \cdot f \cdot N} = \frac{q_t \cdot \kappa' \cdot P_s}{2 \cdot \pi \cdot f \cdot V} \quad (\text{B.3})$$

The airflow is scaled with the stroke of the piston as given in [Formula \(B.4\)](#):

$$\frac{q_t}{q_s} = \frac{h_t}{h_s} \quad (\text{B.4})$$

By combining the [Formulae \(B.2\)](#), [\(B.3\)](#) and [\(B.4\)](#), the following ratio is obtained, see [Formula \(B.5\)](#):

$$\frac{p_t}{p_s} = \frac{h_t}{h_s} \cdot \sqrt{1 + \frac{1}{(2 \cdot \pi \cdot f \cdot N \cdot R)^2}} \quad (\text{B.5})$$

This formula can be solved for  $R$  as given in [Formula \(B.6\)](#):

$$R = \frac{1}{2 \cdot \pi \cdot f \cdot N} \cdot \frac{h_t}{h_s} \cdot \frac{p_s}{p_t} \cdot \frac{1}{\sqrt{1 - \left( \frac{h_t}{h_s} \cdot \frac{p_s}{p_t} \right)^2}} \quad (\text{B.6})$$

The ratio of the sound pressures can be described by the sound pressure levels, see [Formula \(B.7\)](#):

$$\frac{p_s}{p_t} = 10^{\frac{L_{p,s} - L_{p,t}}{20 \text{ dB}}} \quad (\text{B.7})$$

By using the information in [Formula \(B.1\)](#), [Formula \(B.6\)](#) can be written as [Formula \(B.8\)](#):

$$R = \frac{\kappa' \cdot P_s}{2 \cdot \pi \cdot f \cdot V} \cdot \frac{h_t}{h_s} \cdot 10^{\frac{L_{p,s} - L_{p,t}}{20 \text{ dB}}} \cdot \frac{1}{\sqrt{1 - \left( \frac{h_t}{h_s} \cdot 10^{\frac{L_{p,s} - L_{p,t}}{20 \text{ dB}}} \right)^2}} \quad (\text{B.8})$$

If the condition required in [Formula \(3\)](#) (see [8.7](#)) is satisfied, [Formula \(B.8\)](#) can be approximated by [Formula \(2\)](#) with an error of less than 5 %.