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Acoustics — Measurements on silencers *in situ*

Acoustique — Mesurages sur silencieux in situ

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Contents

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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.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 11820 was prepared by Technical Committee ISO/TC 43, *Acoustics*, Subcommittee SC 1, *Noise*.

Annexes A to C of this International Standard are for information only.

Introduction

This International Standard gives a method for evaluating the acoustic performance of silencers under plant-operating conditions. The attenuation losses determined express the extent to which the level of sound power passing through a duct, or across the internal cross-section of an aperture or opening (e.g. in an enclosure or a building) is reduced by the use of a silencer. Sound transmission via flanking elements is attributed to the silencer performance unless the flanking element is not a part of the silencer or of the related duct walls. The influences of flow noise and of alterations to the operating conditions with and without a silencer are included.

In laboratory measurements on ducted silencers in accordance with ISO 7235, insertion losses, static pressure losses and regenerated sound (flow noise) are determined under well-defined conditions. In practical applications both the sound field and flow field are less uniformly distributed. This can lead to different attenuations and greater pressure losses. In addition, sound levels and rates of flow are mutually dependent. Therefore, in this International Standard the regenerated sound is not measured separately but is treated as a property of the silencer in its operating installation which limits the degree of attenuation in the particular application.

Acoustics — Measurements on silencers *in situ*

1 Scope

1.1 This International Standard specifies measurements on silencers *in situ*. It is applicable to measurements on silencers in practical applications for acoustic analysis, acceptance tests and similar evaluations. Results obtained in accordance with this International Standard cannot be compared to performance data obtained from laboratory measurements on ducted silencers in accordance with ISO 7235, partly because of different test conditions (such as sound field distribution, flow, temperature and mounting conditions) and partly because of different definitions.

Depending on the method used, the measurement is either of

— insertion loss D_{is}, or

— transmission loss D_{ts}.

The measurement method depends upon the type of silencer and the installation conditions (e.g. insertion loss measurements must be carried out for blowdown silencers).

NOTE 1 The subscripts denote the practical application of the silencer and the particular installation and operating conditions: "s" stands for "*in situ*", "t" for transmission, and "i" for insertion.

Additional characteristic quantities, which could include measurements taken using artificial sound sources or measurements taken to determine the directivity of sound propagation from the silencer, may be agreed upon in accordance with this International Standard.

1.2 This International Standard is applicable to

a) silencers which are installed either as a whole or in the form of individual baffles in the propagation path of sound (e.g. openings of ducts) originating from a sound source (machine, building, plant such as a gas turbine generator, scrubbing plant, cooling tower, heating ventilation and air conditioning (HVAC) plant, exhaust stack, air intake duct, weapon, internal combustion engine, compressor, etc.);

b) all types of passive silencers (absorptive, reactive, reflection and blowdown silencer);

c) active silencers (involving amplifiers and loudspeakers) as far as the insertion loss of passive silencers is equivalent to the off/on conditions of active devices; and

d) other measures or means of effecting acoustic attenuation in air or other gases (e.g. components installed in ducting, louvres, grilles and deflector hoods).

Additionally, this International Standard is applicable to the determination of the effect of cleaning or refurbishing silencers.

This International Standard is not applicable to closed high-pressure systems (e.g. silencers in closed pipes) since measurements of structure-borne sound are not anticipated.

1.3 Quantities to be measured include the following:

a) sound pressure levels in octave bands with centre frequencies at least from 63 Hz to 4 kHz and, if possible and required, from 31,5 Hz to 8 kHz or in one-third-octave bands with centre frequencies from 50 Hz to 5 kHz and, if possible and required, from 25 Hz to 10 kHz
   - at a point or points on the source side of a silencer,
   - at a point or points on the receiver side of a silencer;

b) static and dynamic pressures, flow velocities and temperatures at selected positions.

Operating data to be determined include flow rate, pressure and speed, which define the operating conditions of the machine or plant to be silenced.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 3744:1994, *Acoustics — Determination of sound power levels of noise sources using sound pressure — Engineering method in an essentially free field over a reflecting plane.*

ISO 5221:1984, *Air distribution and air diffusion — Rules to methods of measuring air flow rate in an air handling duct.*

IEC 651:1979, *Sound level meters.*

IEC 651:1979/Amd.1:1993, *Amendment No. 1.*

IEC 804:1985, *Integrating-averaging sound level meters.*

IEC 804:1985/Amd.1:1989, *Amendment No. 1.*

IEC 804:1985/Amd.2:1993, *Amendment No. 2.*

3 Definitions

For the purposes of this International Standard, the following definitions apply.

3.1 transmission sound pressure level difference, D_{tps}: Difference, in decibels, between the mean sound pressure levels on the source and receiver side of a silencer:

$$D_{tps} = \overline{L_{p2}} - \overline{L_{p1}} \qquad \dots (1)$$

where

$\overline{L_{p1}}$ is the mean sound pressure level (ref. 20 µPa), in decibels (in one-third-octave or octave bands, see IEC 1260), on the receiver side of the silencer, for all measuring points used to determine the airborne sound within the duct or propagated from the aperture and external surfaces of the silencer;

$\overline{L_{p2}}$ is the mean sound pressure level (ref. 20 µPa), in decibels (in one-third-octave or octave bands), on the source side of the silencer, for all measuring points used to determine the airborne sound reaching the silencer.

NOTE 2 D_{tps} is not self-standing but is an intermediate step towards determining the transmission loss (see 9.1.3).

Mean sound pressure levels $\overline{L_p}$ are defined by

$$\overline{L_p} = 10 \lg \left(\frac{1}{N} \sum_{j=1}^{N} 10^{0,1 L_{pj}} \right) \text{ dB} \qquad \dots (2)$$

where

L_{pj} is the individual level;

N is the number of measuring points.

3.2 insertion sound pressure level difference, D_{ips}: Difference, in decibels, in sound pressure levels measured at a point or averaged over a small measurement area before and after installation of a silencer:

$$D_{ips} = L_{pII} - L_{pI} \qquad \dots (3)$$

where

L_{pI} is the sound pressure level (ref. 20 µPa), in decibels (in one-third-octave or octave bands, see IEC 1260), of the sound source(s) measured at a point or averaged over a small measurement area, after installation of the silencer;

L_{pII} is the sound pressure level (ref. 20 µPa), in decibels (in one-third-octave or octave bands), occurring at the same measuring point or over a small measurement area due to the sound source(s) to which the silencer is to be attached, before installation of the silencer.

NOTE 3 As opposed to D_{tps}, D_{ips} is restricted to a point or a small area where certain directivity indices of sound radiation with and without the silencer are effective. The reference to a small area with a diameter of about half a wavelength rather than a point may be useful to avoid strong effects of interference between direct and reflected waves which may occur at certain points.

3.3 transmission loss, D_{ts}: Difference, in decibels, between the levels of the sound power incident upon and transmitted from the silencer:

$$D_{ts} = L_{W2} - L_{W1} \quad \ldots (4)$$

where

L_{W1} is the level (ref. 1 pW), in decibels (in one-third-octave or octave bands), of the sound power propagated through the silencer into an attached duct, into a room or into free space, to be determined from

$$L_{W1} = \overline{L_{p1}} + 10 \lg \left(S_1/S_0\right) \text{ dB} + K_1 \quad \ldots (5)$$

in which, depending on the installation conditions (see clause 5 and 9.1):

S_1 is the area of the measurement surface on the receiver side of the silencer corresponding to the mean sound pressure level $\overline{L_{p1}}$, or

S_1 is one-quarter of the absorption A in a reverberant receiving room, where Sabine's formula applies so that

$$S_1 = (6 \ln 10)V/(cT_1) \quad \ldots (6)$$

in which

V is the volume of the room;

c is the speed of sound (for air at room temperature c = 340 m/s);

T_1 is the reverberation time;

S_0 = 1 m²;

K_1 is the correction, in decibels, for the field distribution in the transmitted sound field on the receiver side of the silencer (see annex A);

L_{W2} is the level (ref. 1 pW), in decibels (in one-third-octave or octave bands), of the sound power incident upon the silencer, to be determined from

$$L_{W2} = \overline{L_{p2}} + 10 \lg \left(S_2/S_0\right) \text{ dB} + K_2 \quad \ldots (7)$$

in which, depending on the installation conditions (see clause 5 and 9.1):

S_2 is the area of the measurement surface on the source side of the silencer corresponding to the mean sound pressure level $\overline{L_{p2}}$, or

S_2 is one-quarter of the total silencer intake area in a reverberant source room, where Sabine's formula applies and sound pressure levels L_{p2} are measured at various positions in the room but not very close to the silencer or to any sound source;

S_0 = 1 m²;

K_2 is the correction, in decibels, for the field distribution in the incident and reflected sound field on the source side of the silencer (see annex A).

NOTE 4 The definitions of the areas S_1 and S_2 include basic field corrections so that the corrections K_1 and K_2 are generally small, typically less than 3 dB in absolute value.

3.4 insertion loss, D_{is}: Difference, in decibels, between the levels of the transmitted sound power with and without a silencer:

$$D_{is} = L_{WII} - L_{WI} \quad \ldots (8)$$

where

L_{WI} is the sound power level (ref. 1 pW), in decibels (in one-third-octave or octave bands) with the silencer installed, to be determined from

$$L_{WI} = \overline{L_{pI}} + 10 \lg \left(S_I/S_0\right) \text{ dB} + K_I \quad \ldots (9)$$

in which

$\overline{L_{pI}}$ is the mean sound pressure level (ref. 20 µPa), in decibels (in one-third-octave or octave bands) with the silencer installed, averaged over all measurement points for airborne sound carried by the duct or propagated from the aperture; and depending on the installation conditions (see clause 5 and 9.1):

S_I is the area of the measurement surface behind the silencer corresponding to the mean sound pressure level, $\overline{L_{pI}}$, or

S_I is one-quarter of the absorption A in a reverberant receiving room, where Sabine's formula applies so that

$$S_I = (6 \ln 10)V/(cT_I) \quad \ldots (10)$$

in which T_I is the reverberation time, and V and c are as defined in 3.3;

S_0 = 1 m²;

K_I is the correction, in decibels, for the sound field distribution behind the silencer (see annex A);

L_{WII} is the sound power level (ref. 1 pW), in decibels (in one-third-octave or octave bands) without the silencer, to be determined from

$$L_{WII} = \overline{L_{pII}} + 10 \lg (S_{II}/S_0) \text{ dB} + K_{II} \quad (11)$$

in which

$\overline{L_{pII}}$ is the mean sound pressure level (ref. 20 µPa), in decibels (in one-third octave or octave bands) without the silencer installed, averaged over all measurement points for airborne sound carried by the duct or propagated from the aperture; and depending on the installation conditions (see clause 5 and 9.1):

S_{II} is the area of the measurement surface corresponding to the mean sound pressure level $\overline{L_{pII}}$, or

S_{II} is one-quarter of the absorption A in a reverberant receiving room, where Sabine's formula applies so that

$$S_{II} = (6 \ln 10) V/(c T_{II}) \quad \ldots (12)$$

in which T_{II} is the reverberation time, and V and c are as defined in 3.3;

S_0 = 1 m²;

K_{II} is the correction, in decibels, for the sound field distribution in the duct or in front of the aperture without the silencer installed (see annex A).

NOTE 5 In most cases the areas S_I and S_{II} are equal and the corrections K_I and K_{II} are similar so that these terms cancel each other in the evaluation of the insertion loss D_{is}. For special cases, see annex A.

3.5 total pressure loss of silencer, Δp_T: Difference, between the mean total pressure upstream, $\overline{p_{Tu}}$, and downstream, $\overline{p_{Td}}$, of the silencer:

$$\Delta p_T = \overline{p_{Tu}} - \overline{p_{Td}} \quad \ldots (13)$$

Where the inlet and outlet areas of a ducted silencer are equal and there are no significant changes in temperature or density of the gas along the silencer, the total pressure loss is equal to the static pressure difference.

Where a silencer is inserted between two rooms or in a duct of large cross-sectional area, and where the flow velocities are negligible in these, the total pressure loss approximately equals the static pressure difference between these rooms or the duct sections.

Where the cross-section of the silencer does not equal that of the duct or aperture in which the silencer is installed and transition elements are part of the silencer, the pressure measurements are carried out beyond the transition sections.

3.6 static pressure difference, Δp_S: Where the inlet and outlet areas of a ducted silencer differ, but the temperature of the gas does not vary markedly, the static pressure difference Δp_S is related to the total pressure loss Δp_T by

$$\Delta p_S = \Delta p_T - \frac{\rho q_V^2}{2}\left(\frac{1}{S_u^2} - \frac{1}{S_d^2}\right) \quad \ldots (14)$$

where

ρ is the density of the gas, in kilograms per cubic metre;

q_V is the volume flow of the gas, in cubic metres per second;

S_u is the silencer upstream cross-sectional area, in square metres;

S_d is the silencer downstream cross-sectional area, in square metres.

4 Corrections for background noise

4.1 Transmission sound pressure level difference (see 3.1)

Correct the measured sound pressure levels for background noise (i.e. sound not coming from the source and the duct or the aperture for which the silencer will operate) according to table 1. If the measuring conditions are such that a correction of 3 dB is not sufficient, then $\overline{L_{p1}}$ cannot be determined using the method described in this International Standard. It is then only possible to state that

$$\overline{L_{p1}} < \overline{L'_{p1}} - 3 \text{ dB}$$

where $\overline{L'_{p1}}$ is the measured mean sound pressure level (in one-third-octave or octave bands) on the receiver side of the silencer.

Table 1 — Corrections for background noise

Values in decibels

Difference between sound pressure level measured with sound source operating and background sound pressure level alone	Corrections to be subtracted from sound pressure level measured with sound source operating to obtain sound pressure level due to sound source alone
< 3	measurements invalid
3	3
4	2
5	2
6	1
7	1
8	1
9	0,5
10	0,5
> 10	0

4.2 Insertion sound pressure level difference (see 3.2)

Correct the measured sound pressure levels for background noise (i.e. sound not coming from the source and the duct or the aperture for which the silencer will operate) according to table 1. If the measuring conditions are such that a correction of 3 dB is not sufficient, then D_{ips} cannot be determined using the method described in this International Standard. It is then only possible to ascertain that

$$D_{ips} > L'_{pII} - L'_{pI}$$

where

L'_{pI} is the sound pressure level (in one-third-octave or octave bands, see IEC 1260) with the silencer installed, under the influence of the extraneous sound;

L'_{pII} is the sound pressure level (in one-third-octave or octave bands) without the silencer, under the influence of the same extraneous sound.

NOTE 6 The background noise defined in 3.12 of ISO 7235:1991 includes regenerated sound, while the extraneous sound considered in this International Standard excludes the regenerated sound.

5 Installation conditions

Potential installation conditions in which either the transmission loss or the insertion loss may be determined are schematically illustrated in figure 1. This figure shows 16 different installation configurations for transmission loss measurements and 4 for insertion loss measurements. The source side may be

— a duct,

— a room with a diffuse sound field,

— a room with a non-diffuse sound field, or

— a space with an acoustically free field.

The receiver side may be

— a duct,

— a room with a diffuse sound field,

— a room with a non-diffuse sound field, or

— a space with an acoustically free field.

When a silencer acceptance test is to be based on this International Standard, agreement shall be reached between interested parties on the type of installation conditions to be considered, on the measurement positions, and on the magnitude of the field correction terms K to be applied.

NOTE 7 Results obtained for a situation corresponding to No. 6 of figure 1 may be different from those determined in accordance with ISO 140-10, and results obtained for a situation corresponding to No. 8 of figure 1 may be different from those determined in accordance with ISO 140-5, depending on the measurement surfaces chosen.

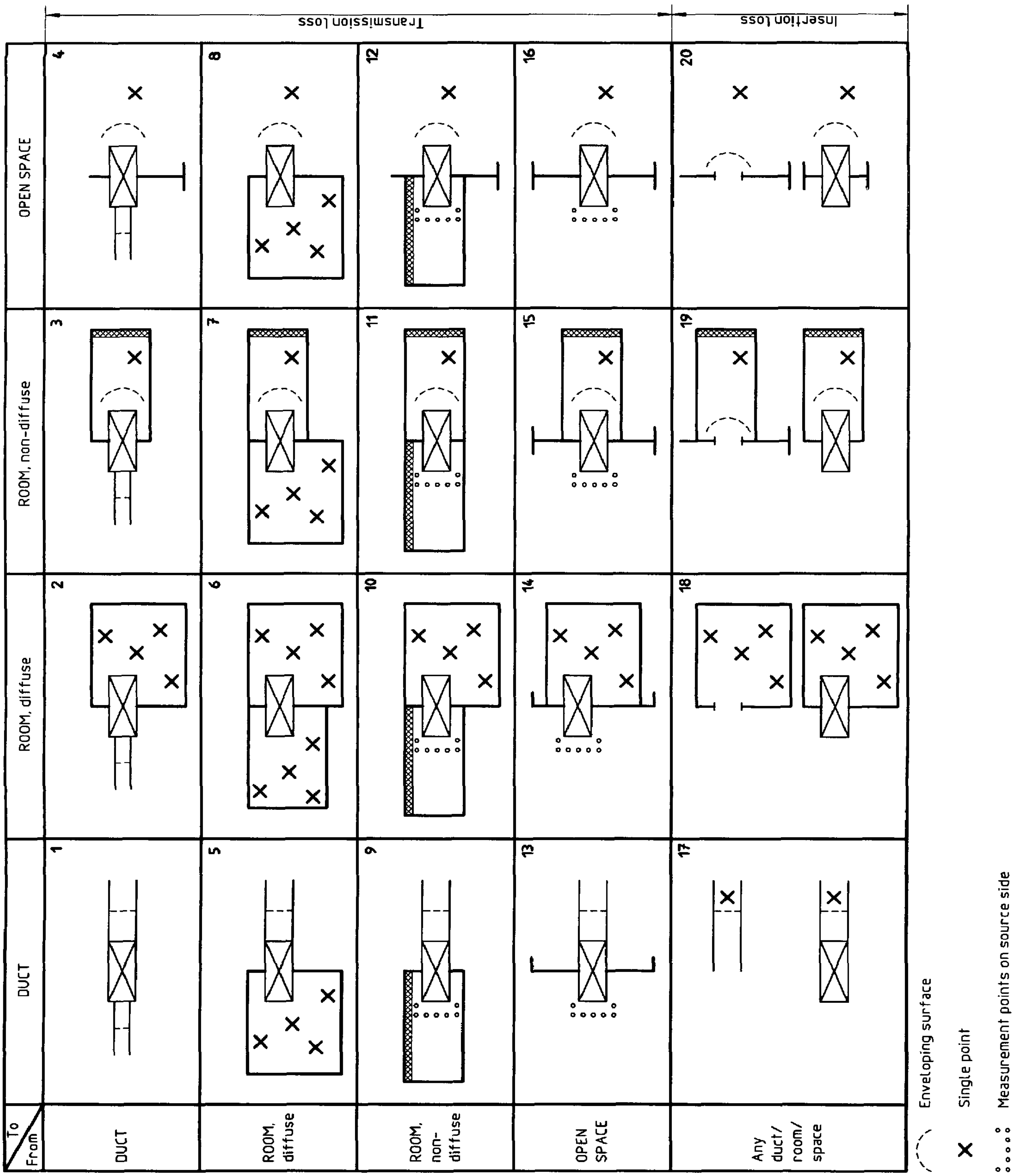
In special situations, where measurements cannot be made during operation of the actual sound source and an artificial sound source is used instead, the type and installation of this source shall be specified. For better comparison with actual source spectra, the measurements shall be carried out in one-third-octave bands. Special correction terms K must be defined considering the effects of different sound field distributions, temperatures and flow conditions.

NOTE 8 The actual correction terms depend on the particular situation. Their determination requires the use of complex theoretical models beyond the scope of this International Standard.

6 Measuring instruments

6.1 Acoustic instruments

The instrumentation shall comply with the requirements of ISO 3744. Use class 1 sound level meters as specified in IEC 651 and IEC 804. Directional micro-



NOTE — The sound source is always on the left-hand side of the silencer; the flow direction is arbitrary.

Figure 1 — General scheme for transmission and insertion loss measurements of silencers

phones may be used in particular cases (see 8.2.3) if all requirements of these standards, apart from those on directivity, are met.

In general, the measurement system including the recording equipment shall be calibrated.

NOTE 9 In cases where the same measuring equipment is used on the source and receiver side and the sound pressure level differences are evaluated, and in cases where directional microphones are used which are calibrated under laboratory conditions as described in annex B, it is not necessary to calibrate the microphone in the field but it is advisable and good practice to use a calibrator for checking the measurement system performance.

The noise caused by flow past the microphone shall be suppressed by appropriate devices.

NOTE 10 One of the following may be used:

— a foam ball windscreen,

— a nose cone, provided the direction of flow is known to an accuracy of approximately ± 15°, or

— a Friedrich tube or turbulence screen for use as described in ISO 5136.

6.2 Air flow, static pressure and temperature measuring devices

The procedures described in ISO 5221 shall be used for measurements of flow velocity and static or dynamic pressure, if practicable.

Pitot static tubes and manometers or pressure transducers are most useful to determine pressure differences. When the pressure difference is less than about 10 Pa or the angle of incidence of flow on the Pitot static tube is greater than 10°, major inaccuracies may occur. In cases of flow without significant fluctuation or rotational components, vane anemometers can be applied to determine velocity distributions.

Any type of thermometer capable of measuring the temperature to within ± 5 °C is acceptable.

7 Test object and measuring conditions

The test object is a silencer installed (or intended for installation) in a duct or at an opening in a machine or plant or in the wall of an enclosed space. The effect of the silencer shall be measured either

— under the existing operating conditions of the plant or equipment, which gives rise to a certain flow rate and sound level, or

— with artificial sound generation (e.g. a loudspeaker) with the plant inoperative and without flow.

Measurement under existing operating conditions is the preferred method.

Different results are to be expected for the differing acoustic excitations which can arise under different operating conditions and under artificial excitation. Influencing factors include the sound field distribution, regenerated sound, flow gradients, temperature, turbulence and flanking transmission. The attenuation losses measured in accordance with this International Standard are only valid in conjunction with the relevant operating conditions during the measurement period. These shall be determined and reported.

For acceptance tests on the silencer, agreement shall be reached on the nominal operating conditions or operation under normal conditions for the sound source if these conditions are relevant for typical or particularly frequent sounds produced under operating conditions.

If a machine is covered by a specific International Standard, then the main state of operation specified therein shall be chosen.

8 Measurement procedures

8.1 General

Before application of the procedures described in this International Standard, agreement shall be reached between the interested parties concerning the measuring conditions. These include the operating state of the plant into which the silencer is installed or is to be installed, as well as the positions of the measuring points. In addition to sound propagated through openings, sound may also be radiated from the external surfaces of the silencer. Both sound components can be taken into consideration by means of an appropriate selection of measuring points. It is not sufficient for the clear specification of measurement results merely to refer to this International Standard without including details of such agreements.

8.2 Acoustic measurements

8.2.1 Measurements in ducts

For transmission loss measurements, locate the microphone close to the silencer but preferably not closer than 1 m. Ensure that the measurements are not influenced by the gas flow. Avoid locations close to the source or to bends or obstructions in the duct, if practicable.

A measurement surface is usually defined as a surface oriented perpendicular to the direction of sound propagation or parallel to the entrance cross-section of the silencer [see figure 2a)]. A number of measurement positions are required to determine the average sound pressure level.

NOTE 11 The number depends on the size of the duct and the measurement conditions (e.g. access and temperature).

Locate the measuring points evenly distributed on or close to (within an eighth of a wavelength for the lowest frequency of interest) the measurement surface, but not all in the plane of the measurement surface.

Preferably distribute the measuring points equally over the duct cross-section and at locations where the flow profile is uniform, and avoid positions in the boundary layer close to the duct walls.

For insertion loss measurements, place the microphone at the same locations with and without the silencer in position. The locations need not be distributed uniformly over the duct cross-section.

It is advisable to move the microphone over a small area both across and along the duct in order to reduce the effects of standing waves.

Align microphones fitted with a nose cone or turbulence screen with the direction of flow.

Where high flow velocity conditions (e.g. > 30 m/s) and high sound pressure levels [e.g. > 120 dB (ref. 20 μPa)] are present within the duct, it is permissible to mount the microphone flush with the wall.

NOTES

12 In the design of the duct system, consideration should be given to the provision of access for the microphones. Care should be taken to seal the access holes to prevent generation of secondary sound by the ingress/exit of gas to/from the duct.

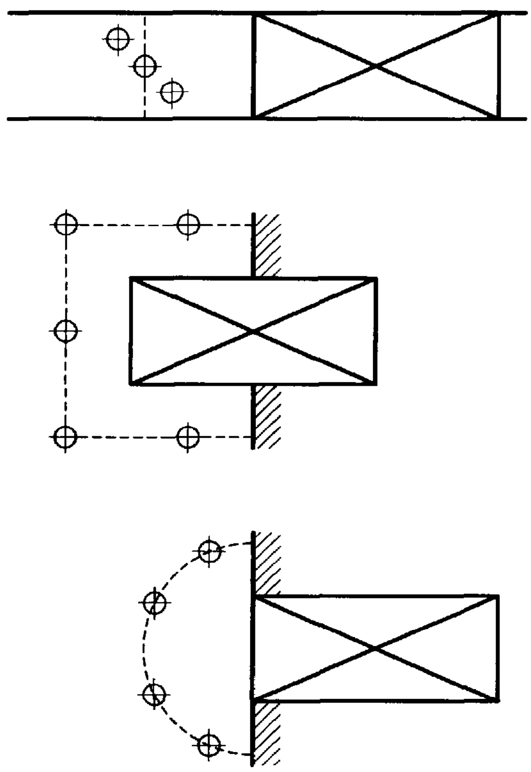
13 Rods supporting the microphone may generate secondary sound.

Make the measurement time at each microphone location about equal and sufficiently long to ensure that the energy equivalent sound pressure level can be determined within an uncertainty of not more than 1 dB.

NOTES

14 Where high temperature conditions exist and measurement time is short, it may be useful to record the microphone signal.

15 Accuracy may be reduced for fluctuating signals.



a) Plane surface inside a duct

b) Box-shaped surface in front of a silencer

c) Spherical surface in front of a silencer

NOTE — Measurement surfaces are indicated by dashed lines.

Figure 2 — Examples of measurement surfaces

8.2.2 Measurements in rooms or plenum chambers

For transmission and insertion loss measurements, the choice of microphone positions depends on the room dimensions and on the distribution of sound-absorptive and -reflective surfaces within the room.

In rooms where the ratio of length or width to height is less than 3:1 and where relatively little sound absorption is uniformly distributed over the room surfaces, distribute measurement positions evenly throughout the room. Use at least three positions, if practicable. Choose no position closer than 0,5 m from the sources, walls or silencer opening(s). The preferred minimum distance is 1 m.

Otherwise, choose measurement positions so that they lie on a surface which partially envelops the silencer and/or silencer opening(s). Avoid positions closer than 0,5 m from the sources, walls or silencer opening(s). The preferred minimum distance is 1 m. The enveloping surface may be box-shaped, part of a sphere or part of a cylinder [see figure 2 b) and c)].

Measurements of the insertion sound pressure level difference are taken at specified positions, such as the operator's position.

Use an omnidirectional microphone. In general, the use of a foam ball windscreen is recommended to protect the microphone from airflow. Do not use turbulence screens or directional microphones.

8.2.3 Measurements in open spaces

Four measurement regions are identified. These are

a) positions at immission points remote from the silencer for measurements of the insertion sound pressure level difference;

b) positions on the path from the source to the immission point;

c) positions on an enveloping surface around the silencer for transmission or insertion loss measurements; and

d) positions in the entrance or exit plane of the silencer for transmission or insertion loss measurements.

Measurement positions remote from the silencer are recommended only if the silencer opening is the dominant sound source in the neighbourhood. Directional microphones may be employed to minimize the influence of other sources of sound. For calibration of directional microphones, see annex B. To reduce the influence of ground interference, it is recommended that the microphone be located at least 4 m above the ground. The location should be selected so that the influence of sound reflections from buildings or other obstacles is less than 1 dB.

Where the influence of other sources cannot be reduced at the immission point, a substitute measurement position may be chosen on the path from the source to the immission point.

Generally, measurement positions should be chosen so that they lie on a surface which partially envelops the silencer opening. Normally, positions should be at a distance of about 1 m from the silencer opening. The enveloping surface may be box-shaped, part of a sphere or part of a cylinder [see figure 2 b) and c)]. In general, the use of a foam ball windscreen is recommended to protect the microphone from airflow. Align microphones fitted with a nose cone with the flow direction. A turbulence screen may be used if the insertion sound pressure level difference is to be determined.

In cases of high background noise, it may be useful to measure directly in the opening plane of the silencer. In such cases the measurement surface is defined as the free cross-sectional area, S_f, of the silencer. Since the sound pressure level measured is highly sensitive to the location of the microphone in the direction of the flow, the measurement position shall be accurately located on the measurement plane.

8.3 Flow, pressure and temperature measurements

8.3.1 Measurement surfaces

Define two measurement surfaces, one upstream and the other downstream of the test object, both perpendicular to the direction of the main airstream. If possible, locate the upstream measurement surface at a distance d_u from a ducted silencer under test:

$$d_u = 1{,}5\sqrt{\frac{4S_u}{\pi}} \qquad \ldots (15)$$

where S_u is the cross-sectional area of the upstream measurement surface.

Also, if possible, locate the downstream measurement surface at a distance d_d from the ducted silencer under test:

$$d_d = 12\sqrt{S_d} - 10\sqrt{S_f} \qquad \ldots (16)$$

where

S_d is the cross-sectional area of the downstream measurement surface;

S_f is the free cross-sectional area of the silencer.

In cases where this is not possible, agreement shall be reached between interested parties about the distances of the measurement surfaces from the entrance and the exit of the silencer.

8.3.2 Pressure difference

Report all pressures as the difference between absolute pressure and the ambient atmospheric pressure p_a. For the purposes of this International Standard, measurement of the ambient atmospheric pressure is not required.

Measure the total pressure p_T and the static pressure p_S in a number of positions on both measurement surfaces, if practicable, but not within a distance of 15 mm from any duct wall if a Pitot static tube is used.

NOTE 16 For more detailed investigations, a survey of both pressures should, if possible, be carried out along a pair of mutually perpendicular axes or, in the case of a splitter-type silencer, along two parallel axes perpendicular to the splitters.

8.3.3 Flow velocities

For measurements of local flow velocities (e.g. airway velocities), calibration of instruments is not required.

NOTE 17 It may be useful to determine data at various positions (e.g. at the entrance and the exit of a splitter-type silencer) in order to determine the flow distribution. In cases of uneven distribution, an increase in pressure loss and flow noise may occur.

8.3.4 Temperature

Measure (and monitor for the time of flow and sound measurements) the gas temperature θ at a position on the upstream measurement surface. If the temperature downstream of the silencer is considerably different from that temperature or from ambient temperature, measure it also.

9 Evaluation

9.1 Evaluation of sound pressure measurements

The various case numbers refer to the numbers shown in figure 1.

9.1.1 Transmission sound pressure level difference

Cases 1 to 4: From sound pressure levels L_{pj} measured at a number of positions close to the measurement surface on the source side of the silencer, as described in 8.2.1, determine the mean sound pressure level $\overline{L_{p2}}$ according to equation (2).

Cases 5 to 8: From sound pressure levels L_{pj} measured at a number of positions in the reverberant room on the source side of the silencer, as described in 8.2.2, determine the mean sound pressure level $\overline{L_{p2}}$ according to equation (2).

Cases 9 to 16: From sound pressure levels L_{pj} measured at a number of positions on a surface enveloping the source side of the silencer, as described in 8.2.2 and 8.2.3, determine the mean sound pressure level $\overline{L_{p2}}$ according to equation (2).

Cases 1 to 16: If it is possible to determine the contribution of extraneous sound separately, make appropriate corrections to the sound pressure levels measured at J points on the receiver side of the silencer using table 1 or the relationship

$$\overline{L_{p1}} = 10 \lg \left[\frac{1}{J} \sum_{j=1}^{J} \left(10^{0,1L_{pj}} - 10^{0,1L_{ej}} \right) \right] \text{ dB} \quad \ldots (17)$$

where L_{ej} is the extraneous sound pressure level.

If it is possible to turn off the sound source(s) affected by the silencer and to ignore flanking transmission, take measurements at the same microphone positions to determine the extraneous sound pressure level. The maximum correction is 3 dB.

Calculate the transmission sound pressure level difference D_{tpS} from equation (1).

9.1.2 Insertion sound pressure level difference

Case 17: From sound pressure levels L_{pj} measured at a number of positions in the duct cross-section without the silencer, as described in 8.2.1, determine the mean sound pressure level L_{pII} if the measurement positions were close to each other, or $\overline{L_{pII}}$ if the measurement positions were equally spaced, according to equation (2).

Case 18: From sound pressure levels L_{pj} measured at a number of positions in the reverberant room without the silencer, as described in 8.2.2, determine the mean sound pressure level $\overline{L_{p\text{II}}}$ according to equation (2).

Cases 19 and 20: From sound pressure levels L_{pj} measured at a number of positions close to each other in a non-diffuse room or in open space without the silencer, as described in 8.2.2 and 8.2.3, determine the mean sound pressure level $\overline{L_{p\text{II}}}$ according to equation (2). From sound pressure levels L_{pj} measured at a number of equally spaced positions on a measurement surface enveloping the aperture without the silencer, determine the mean sound pressure level $\overline{L_{p\text{II}}}$ according to equation (2).

Cases 17 to 20: If it is possible to determine the contribution of extraneous sound separately, make appropriate corrections to the sound pressure levels measured at N points close to each other with the silencer in position using table 1 or the relationship

$$\overline{L_{p\text{I}}} = 10 \lg \left[\frac{1}{N} \sum_{j=1}^{N} \left(10^{0,1 L_{pj}} - 10^{0,1 L_{\text{e}j}} \right) \right] \text{dB} \quad \ldots (18)$$

where $L_{\text{e}j}$ is the extraneous sound pressure level.

In cases where the measurement positions are equally spaced over the duct cross-section, in the reverberant receiver room or over the enveloping surface on the receiver side of the silencer, determine the mean sound pressure level $\overline{L_{p\text{I}}} = L_{p\text{I}}$.

If it is possible to turn off the sound source(s) affected by the silencer and to ignore flanking transmission, take measurements at the same microphone positions to determine the extraneous sound pressure level. The maximum correction is 3 dB.

The insertion sound pressure level difference D_{ips} is calculated from equation (3).

9.1.3 Transmission loss

Calculate the silencer transmission loss D_{ts} from the transmission sound pressure level difference D_{tps}, the area ratio S_2/S_1, and the difference between the field corrections from either end of the silencer, $K_2 - K_1$:

$$D_{\text{ts}} = D_{\text{tps}} + 10 \lg \left(S_2/S_1 \right) \text{dB} + K_2 - K_1 \quad \ldots (19)$$

Cases 1 to 4: S_2 is the area of the measurement surface in the duct cross-section on the source side of the silencer.

Cases 5 to 8: S_2 is one-quarter of the area of the total cross-section of the silencer on the source side.

NOTE 18 The area of the total silencer intake cross-section should be clearly distinguished from the free cross-sectional area S_f of the silencer.

Cases 9 to 16: S_2 is one-half of the area of the total silencer intake cross-section.

Cases 1, 5, 9 and 13: S_1 is the area of the measurement surface in the duct cross-section behind the silencer.

Cases 2, 6, 10 and 14: S_1 is one-quarter of the absorption of the receiver room (see 3.3).

Cases 3, 4, 7, 8, 11, 12, 15 and 16: S_1 is the area of the measurement surface enveloping the end of the silencer.

Unless otherwise stated on the basis of special considerations outlined in annex A, the field corrections K_1 and K_2 account for markedly different temperatures on both sides of the silencer only:

$$K_2 - K_1 = 5 \lg \left(\frac{273 + \theta_1}{273 + \theta_2} \right) \text{dB} \quad \ldots (20)$$

where

- θ_1 is the temperature, in degrees Celsius, on the receiver side;
- θ_2 is the temperature, in degrees Celsius, on the source side.

The different temperatures determine different sound velocities which result in different conversion factors from squared sound pressure to sound power.

9.1.4 Insertion loss

Calculate the silencer transmission loss D_{is} from the difference in mean sound pressure levels $\overline{L_{p\text{II}}} - \overline{L_{p\text{I}}}$, the area ratio $S_{\text{II}}/S_{\text{I}}$, and difference between the field corrections $K_{\text{II}} - K_{\text{I}}$, without and with the silencer:

$$D_{\text{is}} = \overline{L_{p\text{II}}} - \overline{L_{p\text{I}}} + 10 \lg \left(S_{\text{II}}/S_{\text{I}} \right) \text{dB} + K_{\text{II}} - K_{\text{I}} \quad (21)$$

Case 17: S_{II} is the area of the measurement cross-section in the duct without the silencer, and S_I is the area of the measurement cross-section in the duct with the silencer installed. If possible, choose the same cross-section before and after insertion of the silencer.

Case 18: S_{II} is one-quarter of the absorption in the reverberant room without the silencer (see 3.4) and S_I is one-quarter of the absorption in the reverberant room with the silencer. If possible, leave the absorption of the reverberant room unchanged before and after insertion of the silencer.

Cases 19 and 20: S_{II} is the area of the measurement surface enveloping the aperture in a wall without the silencer, and S_I is the area of the measurement surface enveloping the open end of the silencer. If possible, choose the enveloping surfaces so that both areas have the same size.

Unless otherwise stated on the basis of special considerations outlined in annex A, the field corrections K_I and K_{II} account for markedly different temperatures for the cases with and without the silencer only:

$$K_{II} - K_I = 5 \lg \left(\frac{273 + \theta_I}{273 + \theta_{II}} \right) \text{ dB} \qquad \ldots (22)$$

where

θ_I is the temperature, in degrees Celsius, with the silencer;

θ_{II} is the temperature, in degrees Celsius, without the silencer.

For an explanation, see 9.1.3.

9.1.5 Conversion of one-third-octave band data to octave band data

Conversion of measured one-third-octave band data to octave band data is permissible for measured sound pressure levels only, but not for level differences.

9.2 Evaluation of flow measurements

From total pressures $p_{Tu,j}$ and static pressures $p_{Su,j}$ measured at a number N of positions upstream of the silencer, as described in 8.3.2, determine the mean upstream pressures, $\overline{p_{Tu}}$ and $\overline{p_{Su}}$, as

$$\overline{p_{Tu}} = \frac{1}{N} \sum_{j=1}^{N} p_{Tu,j} \qquad \ldots (23)$$

$$\overline{p_{Su}} = \frac{1}{N} \sum_{j=1}^{N} p_{Su,j} \qquad \ldots (24)$$

From total pressures $p_{Td,j}$ and static pressures $p_{Sd,j}$ measured at a number N of positions downstream of the silencer, as described in 8.3.2, determine the mean downstream pressures, $\overline{p_{Td}}$ and $\overline{p_{Sd}}$, as

$$\overline{p_{Td}} = \frac{1}{N} \sum_{j=1}^{N} p_{Td,j} \qquad \ldots (25)$$

$$\overline{p_{Sd}} = \frac{1}{N} \sum_{j=1}^{N} p_{Sd,j} \qquad \ldots (26)$$

Then determine the total pressure loss Δp_T of a ducted silencer (case 1 in figure 1) from equation (13).

Calculate upstream or downstream flow velocities w from respective velocity pressures p_v defined by

$$p_v = p_T - p_S \qquad \ldots (27)$$

Calculate the upstream flow velocity w_u from

$$w_u = \sqrt{\frac{2 p_{vu}}{\rho_u}} \qquad \ldots (28)$$

where ρ_u denotes the density of the gas upstream of the silencer which for the purposes of this International Standard can be determined from

$$\rho_u = \frac{M \cdot p_{amb}}{R(273 + \theta_u)} \qquad \ldots (29)$$

where

R is the universal gas constant [= 8 314,4 N·m/(kmol·K)];

M is the molar mass, in kilograms per kilomole;

R/M = 287 N·m/(kg·K) for air;

p_{amb} is the ambient static pressure (= 100 kPa);

θ_u is the temperature, in degrees Celsius, upstream of the silencer.

The downstream flow velocity w_d is calculated from a similar set of equations (the subscript "u" is replaced by the subscript "d" for conditions downstream of the silencer).

From flow velocities w_j determined for a number N of positions upstream or downstream of the silencer, the mean flow velocity, $\overline{w_u}$ or $\overline{w_d}$, is calculated as

$$\overline{w} = \frac{1}{N}\sum_{j=1}^{N} w_j \qquad \dots (30)$$

If the flow velocities w_{uj} close to the entrance of the silencer deviate from the mean flow velocity $\overline{w_d}$ by more than 10 %, or if the results of flow velocity measurements according to 8.3.3 show a comparably non-uniform distribution, report the actual distribution, since increased pressure losses and regenerated sound may result from such conditions.

The mean flow velocity $\overline{w_f}$ inside the silencer can be calculated from

$$\overline{w_f} = \frac{S_u}{S_f} \cdot \overline{w_u} \qquad \dots (31)$$

where S_u is the measurement cross-section area of the duct upstream of the silencer.

10 Information to be recorded

For all measurements made in accordance with the requirements of this International Standard, record the following information, when applicable.

10.1 Description of the tested silencer:

a) type of silencer and its application;
b) mounting conditions of silencer;
c) dimensions of inlet and outlet sections;
d) length of silencer;
e) direction of flow;
f) potential flanking sound transmission and means for reduction;
g) potential sound radiating surfaces other than inlet or outlet areas;
h) active devices (if used);
i) further relevant construction parameters;
j) diagrams showing silencer location in relation to sound source and discharge opening.

10.2 Description of the operating conditions:

a) date and time of measurements;
b) type of gas;
c) mean flow velocity upstream of the silencer or without the silencer;
d) mean flow velocity downstream of the silencer or with the silencer;
e) mean flow velocity in the silencer;
f) strong deviations from uniform flow distributions (to help find possible sources of regenerated sound);
g) total pressure loss across the silencer;
h) temperature of the gas;
i) operating conditions of the sound source;
j) environmental conditions.

10.3 Description of the test method:

a) acoustical installation conditions as described by a case number in figure 1;
b) location of measurement surfaces and points used for sound and flow measurements (drawing);
c) list of measurement equipment employed including, when available, makes, model numbers and serial numbers;
d) type and use of windscreens;
e) artificial sound source (if used).

10.4 Acoustical test results:

10.4.1 In the case of measurements on either side of the silencer:

a) transmission loss D_{ts};
b) difference between the field corrections $(K_2 - K_1)$ applied;
c) corrections applied for extraneous sound.

10.4.2 In the case of measurements with and without a passive silencer or on/off conditions of an active silencer:

a) insertion sound pressure level difference D_{ips};
b) insertion loss D_{is} (if applicable);
c) difference between the field corrections $(K_{II} - K_I)$ applied;
d) corrections applied for extraneous sound.

10.4.3 In the case of excitation with an artificial sound source:

a) method of conversion of one-third-octave band data to octave band data, if applied.

10.5 Further information:

a) name and address of the test institute;

b) identification number of the test report;

c) date and signature.

In addition to tabular listings of data, present the one-third-octave band spectra or full-octave band spectra of transmission loss or insertion loss in a graphical form with 15 mm on the abscissa for one octave band and 20 mm on the ordinate for 10 dB, or with a common reduction factor for both coordinates.

11 Information to be reported

Include in the test report all the relevant information recorded and any other factors which may have affected the result. State that the results have been obtained in compliance with the requirements of this International Standard.

As a minimum, report the information of subclauses 10.3 a), 10.4 and 10.5 a).

Annex A
(informative)

Field corrections

In practical cases, it is hardly ever possible to determine the true values of the field corrections K_1, K_2, K_I or K_{II}. This annex contains come information for engineering estimates within the accuracy of typically ± 3 dB. The interested parties should agree upon the values of K, preferably prior to the measurement.

On the source side of the silencer, the field correction K_2 accounts for

a) the direction of sound incidence, which can be

1) normal to the cross-sectional intake surface (as in ducts below the cut-on frequency f_c of higher-order modes

— in rectangular ducts, $f_c = 0{,}5c/a$, where c is the speed of sound at operating temperature and a is the length of the larger side of the rectangle;

— in circular ducts, $f_c = 0{,}59c/d$, where d is the diameter of the duct);

2) oblique to that surface (as in ducts with higher-order modes or close to a source in a room);

3) randomly distributed over a partial space (as for a duct entrance in a corner, in an edge, in the wall, or far from the walls of a reverberant room);

b) the size of the silencer opening relative to the wavelength of sound;

c) reflections from the open intake of the silencer due to impedance mismatch.

In general, the field correction depends on the frequency of sound. Resonances of the intake duct may result in large corrections. However, in most practical cases, the absolute value is limited to about 3 dB due to the following baseline considerations of this International Standard (cases refer to numbers in figure 1).

a) In ducts (cases 1 to 4), plane waves are assumed. This holds for low frequencies $f < f_c$ only. For high frequencies, K_2 approaches − 3 dB.

b) In reverberant rooms (cases 5 to 8), random sound incidence on a small aperture in a wall is assumed. If the aperture is far from the wall or not small in diameter as compared to the wavelength of sound, $K_2 = -3$ dB. A small aperture in the edge or the corner of a reverberant room yields at low frequencies field corrections of 3 dB and 6 dB, respectively.

c) In non-diffuse rooms (cases 9 to 12) and open spaces (cases 13 to 16), oblique sound incidence is assumed resulting in an intermediate situation between ducts and reverberant rooms.

On the receiver side of the silencer, the field correction K_1 accounts for

a) the field distribution (as in ducts, cases 1, 5, 9 and 13);

b) the diffusiveness of the receiver room (cases 2, 6, 10 and 14);

c) the proximity of walls or reflecting objects to the measurement surface (cases 3, 4, 7, 8, 11, 12, 15 and 16);

d) the size of the aperture relative to the size of the measurement surface.

Aside from special situations, where a pronounced frequency dependence can play a role, in most practical cases the absolute value of K_1 is limited to about 3 dB due to the following baseline considerations of this International Standard.

a) In ducts (cases 1, 5, 9 and 13), plane waves are assumed. This holds for low frequencies only. For high frequencies, K_1 approaches − 3 dB. If the ducts on either side of the silencer are comparable in cross-sectional size, the difference in field corrections $K_2 - K_1$ is small.

b) In reverberant rooms (cases 2, 6, 10 and 14), the absorption is closely, but not accurately, described by Sabine's formula. Deviation by more than a factor of 2 (corresponding to a field correction $|K_1| = 3$ dB) is rarely found.

c) In most other rooms (cases 3, 7, 11 and 15), it should be possible by appropriate definition of the measurement surface to include major reflections from nearby surfaces and to exclude the reverberant field.

d) Openings of silencers into rooms or open spaces (cases 3, 4, 7, 8, 11, 12, 15 and 16), which are not small compared to the measurement surface, may result in a field correction K_1 up to − 3 dB due to random rather than perpendicular sound incidence on the measurement surface.

In principle, the field corrections K_I and K_{II} should be equal and cancel each other in the evaluation of insertion loss measurements. There may be exceptions, however, as follows.

a) The silencer may act as a modal filter so that the field correction in the attached duct is modified (case 17).

b) The absorption or the fittings of the reverberant receiving room may have changed with insertion of the silencer (case 18).

c) The measurement surface may be shifted or enlarged after insertion of the silencer (cases 19 and 20).

Annex B
(informative)

Calibration of directional microphones and microphones equipped with a turbulence windscreen

Based on practical experience, the following free-field comparison method is recommended for the calibration of directional microphones in the frequency range from 50 Hz to 5 kHz. A microphone of known free-field sensitivity and the directional microphone should be mounted close to each other (at a distance of about 0,1 m) on a 5 m high tripod. The directional microphone should point to a loudspeaker located at the same height above the ground and at a distance of about 5 m (for instance in an open window). The loudspeaker may be driven by broad-band or one-third-octave band noise, depending on background noise. The microphone signals should be analysed by a dual channel one-third-octave band analyser.

The level differences $\Delta L_{1/3}$ determined in one-third-octave bands between the signals from the calibrated microphone and the directional microphone may be converted to octave band level differences $\Delta L_{1/1}$ by use of the relationship

$$\Delta L_{1/1} = -10 \lg \left(\frac{1}{3} \sum_{j=1}^{3} 10^{-0,1 \Delta L_{1/3,j}} \right) \text{ dB}$$

where the subscript j refers to the individual one-third octaves within one octave band. Such corrections are added to the sound pressure levels measured with the directional microphone under free-field conditions.

Annex C
(informative)

Bibliography

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1) To be published. (Revision of ISO 140-5:1978)

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