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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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ISO 11820:1996
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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.

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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.

ISO 11820:1996
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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.

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ISO 11820:1996
https://standards.iteh.ai/catalog/standards/sist/29eff1ed-f326-4a41-850d-1ff84124d283/iso-11820-1996

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.

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Depending on the method used, the measurement is either of

ISO 11820:1996
https://standards.iteh.ai/catalog/standards/sist/29e...-4a41-850d-1ff84124d283/iso-11820-1996

— 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.*

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(standards.iteh.ai)
ISO 11820:1996
https://standards.iteh.ai/catalog/standards/sist/29eff1ed-f326-4a41-850d-1ff84124d283/iso-11820-1996

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:

$$D_{tps} = \overline{L_{p2}} - \overline{L_{p1}} \quad \ldots (1)$$

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

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

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:

$$D_{ips} = L_{pII} - L_{pI} \quad \ldots (3)$$

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

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ISO 11820:1996
https://standards.iteh.ai/catalog/standards/sist/29eff1ed-f326-4a41-a3ed-1ff84124d283/iso-11820-1996

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

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

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

S_0 = 1 m^2;

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.

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ISO 11820:1996
https://standards.iteh.ai/catalog/standards/sist/29eff...
1f84134d283/iso-11820-1996

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-

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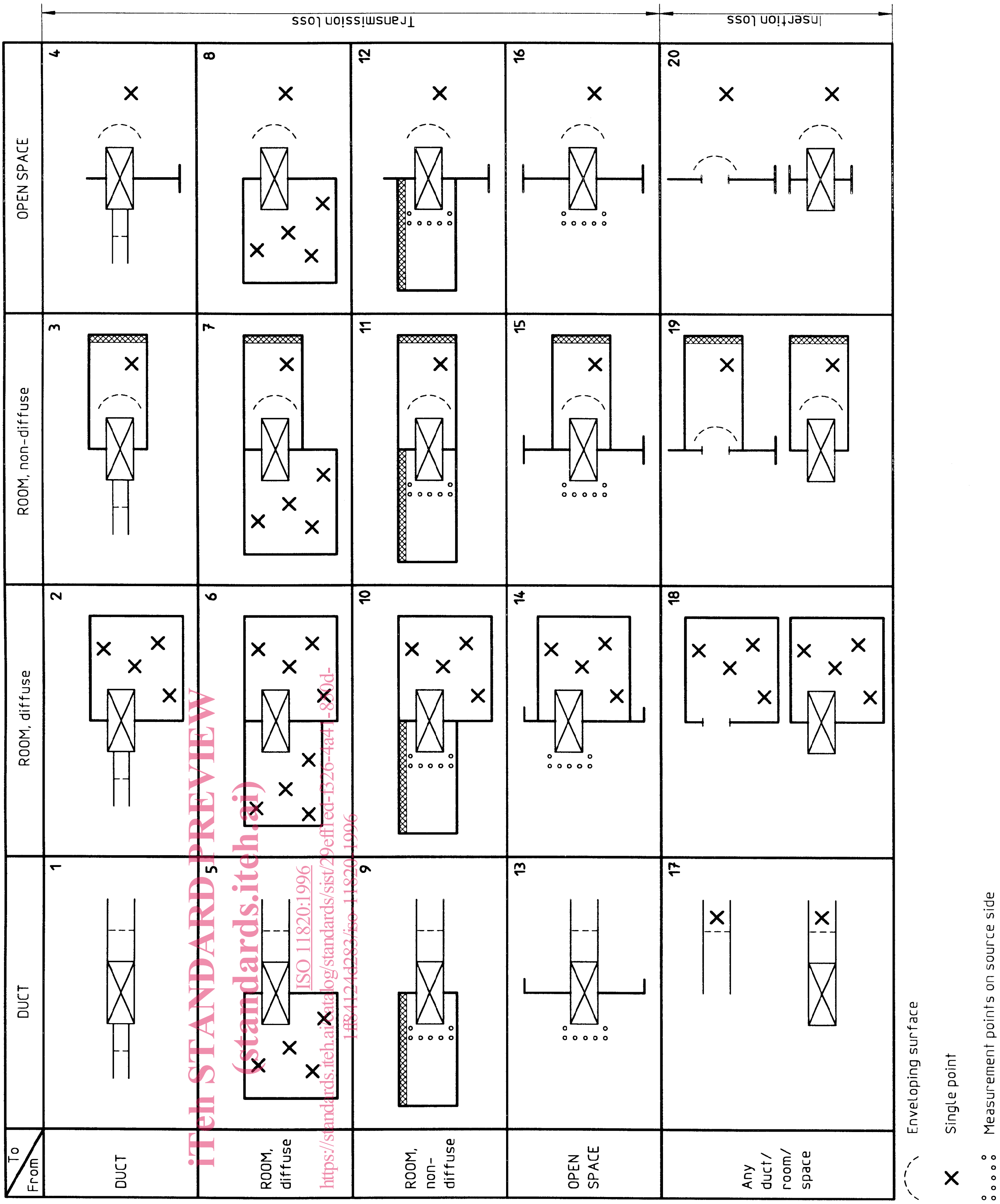

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ISO 11820:1996
https://standards.iteh.ai/catalog/standards/sist/29eff1ed-f326-4a41-88dd-1884124d4283/iso-11820-1996

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.

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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.

ISO 11820:1996
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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.