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Acoustics — Laboratory measurement procedures for ducted silencers and air-terminal units — Insertion loss, flow noise and total pressure loss

Acoustique — Modes opératoires de mesure en laboratoire pour silencieux en conduit et unités terminales — Perte d'insertion, bruit d'écoulement et perte de pression totale

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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. 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.

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.

ISO 7235 was prepared by Technical Committee ISO/TC 43, *Acoustics*, Subcommittee SC 1, *Noise*.

This second edition cancels and replaces the first edition (ISO 7235:1991), which has been technically revised.

Introduction

This International Standard specifies the substitution method for determining the insertion loss of ducted silencers and a method for determining the transmission loss of air-terminal units.

In the substitution method, the sound pressure level of the transmitted wave is first determined for the test object and then when the test object has been replaced by the substitution duct. The sound pressure level of the transmitted wave can be measured

— in a reverberation room,

— in a test duct after the silencer, or

— in an essentially free field.

The methods are listed in order of preference.

The acoustic performance of silencers depends on the modal composition of the sound field at the inlet and on reflections at the outlet side, on flanking transmission and on level differences between signals and flow noise (or regenerated sound).

This International Standard describes configurations at the inlet side providing for a predominant fundamental mode that suffers the least attenuation. For the outlet side, it describes anechoic terminations and measurement procedures which are not sensitive to reflections or which allow for specified corrections. Furthermore, this International Standard gives guidance on the suppression of flanking transmission and noise signals.

The transmission loss of an air-terminal unit is determined from the results of measurements in a reverberation room and theoretical reflection coefficients of a substitution duct.

The insertion loss of a silencer is generally affected by the airflow. The insertion loss is therefore preferably measured with superimposed airflow if the silencer is to be used in ducts with high flow velocity.

For absorptive silencers where the maximum internal flow velocity falls short of 20 m/s, the flow will hardly have an effect on the insertion loss. In practice, non-uniform flow distributions will occur. Therefore, the limit velocity of 20 m/s may correspond to a design velocity of 10 m/s to 15 m/s.

An airflow through a silencer regenerates noise. This flow noise (or regenerated sound) establishes the lowest sound pressure level that can be achieved after the silencer. It is, therefore, necessary to know the sound power level of the flow noise (or regenerated sound) behind the silencer. This is preferably determined in a reverberation room connected to the object via a transmission element.

In accordance with this International Standard, the total pressure loss of a silencer to be used with flow is to be determined. It is, therefore, useful to equip the test facility with the instruments and devices necessary for the determination of the total pressure loss.

Acoustics — Laboratory measurement procedures for ducted silencers and air-terminal units — Insertion loss, flow noise and total pressure loss

1 Scope

This International Standard specifies methods for determining

— the insertion loss, in frequency bands, of ducted silencers with and without airflow,

— the sound power level, in frequency bands, of the flow noise (or regenerated sound) generated by ducted silencers,

— the total pressure loss of silencers with airflow, and

— the transmission loss, in frequency bands, of air-terminal units.

The measurement procedures are intended for laboratory measurements at ambient temperature. Measurements on silencers *in situ* are specified in ISO 11820.

It is to be noted that the results determined in a laboratory according to this International Standard will not necessarily be the same as those obtained *in situ* (installation), as different sound and flow fields will yield different results. For example, the pressure loss will be lower under laboratory conditions than *in situ*, but will be comparable between different laboratories.

This International Standard is applicable to all types of silencer including silencers for ventilating and air-conditioning systems, air intake and exhaust of flue gases, and similar applications. Other passive air-handling devices, such as bends, air-terminal units or T-connectors, can also be tested using this International Standard.

This International Standard is not applicable to reactive silencers used for motor vehicles.

NOTE 1 Annex A specifies the sound field excitation equipment. Annex B gives requirements for the transition element. Annex C gives details of duct walls and limiting insertion loss. Annex D specifies how to convert one-third-octave band attentuation values to octave band values. Annex E gives requirements for measurements on large parallel-baffle silencers. Annex F specifies a test of longitudinal attenuation. Annex G gives guidelines on anechoic terminations and Annex H shows examples of measurement arrangements.

NOTE 2 Acoustic testing of air-terminal devices and fan-coil units is to be carried out as described for air-terminal units.

NOTE 3 Sound power measurements on air-terminal units are specified in ISO 5135. Measurements of the pressure loss of air-terminal units are described in EN 12238, EN 12239 and EN 12589.

2 Normative references

The following referenced documents are indispensable for the application 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 3741:1999, *Acoustics — Determination of sound power levels of noise sources using sound pressure — Precision methods for reverberation rooms*

ISO 3746, *Acoustics — Determination of sound power levels of noise sources using sound pressure — Survey method using an enveloping measurement surface over a reflecting plane*

ISO 5167-1, *Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full — Part 1: General principles and requirements*

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

ISO 9614-3, *Acoustics — Determination of sound power levels of noise sources using sound intensity — Part 3: Precision method for measurement by scanning*

IEC 60651:2001, *Sound level meters*

IEC 60804:2000, *Integrating-averaging sound level meters*

IEC 60942:1997, *Electroacoustics — Sound calibrators*

IEC 61260, *Electroacoustics — Octave-band and fractional-octave-band filters*

3 Terms and definitions

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

3.1
insertion loss
D_i
⟨of the test object⟩ reduction in the level of the sound power in the duct behind the test object due to the insertion of the test object into the duct in place of a substitution duct, given by the equation

$$D_\mathrm{i} = L_{W\mathrm{II}} - L_{W\mathrm{I}} \quad (1)$$

where

$L_{W\mathrm{I}}$ is the level of the sound power in the frequency band considered, propagating along the test duct or radiating into the connected reverberation room when the test object is installed;

$L_{W\mathrm{II}}$ is the level of the sound power in the frequency band considered, propagating along the test duct or radiating into the connected reverberation room when the substitution duct replaces the test object.

NOTE 1 The insertion loss is expressed in decibels (dB).

NOTE 2 For measurements according to this International Standard, the insertion loss of a silencer equals its transmission loss.

3.2
transmission loss
D_t
⟨of an air-terminal unit⟩ difference between the levels of the sound powers incident on and transmitted through the test object

NOTE 1 The transmission loss is expressed in decibels (dB).

NOTE 2 Adapted from ISO 11820:1996.

3.3
face velocity
v_f
velocity in front of the test object

$$v_f = \frac{q_V}{S_1} \qquad (2)$$

where

q_V is the volume flow rate, in cubic metres per second (m^3/s);

S_1 is the inlet (or face) cross-sectional area of the test object, in square metres (m^2)

NOTE The face velocity is expressed in metres per second (m/s).

3.4
total pressure loss
Δp_t
⟨of the test object⟩ difference between the total pressures upstream and downstream of the test object

NOTE The total pressure loss is expressed in pascals (Pa).

3.5
total pressure loss coefficient
ζ
total pressure loss divided by the face velocity pressure upstream of the test object, given by the formula

$$\zeta = \frac{\Delta p_t}{\frac{1}{2}\rho_1 {v_f}^2} \qquad (3)$$

where

Δp_t is the total pressure loss, in pascals (Pa);

ρ_1 is the air density upstream of the silencer, in kilograms per cubic metre (kg/m^3);

v_f is the face velocity, in metres per second (m/s) (see 3.3)

3.6
front
position relative to the direction of the sound propagation of the sound signal to be measured, corresponding to the “source side”

3.7
behind
position relative to the direction of the sound propagation of the sound signal to be measured, corresponding to the “receiving side”

3.8
test duct
straight, rigid duct of constant cross section in front of and behind the test object

3.9
transition
duct element which connects two duct sections with different duct cross sections to each other

NOTE Transitions which are part of a silencer as supplied by the manufacturer/supplier are considered part of the test object.

3.10
anechoic termination
device intended to reduce sound reflections at the receiving-side end of the test duct

3.11
transmission element
connection from the test duct behind the test object to a reverberation room, transmitting a certain fraction of the sound energy from the duct into the room

3.12
substitution duct
rigid, non-absorbing duct element and having the same length and the same connecting cross sections as the test object

3.13
reverberation room
test room meeting the requirements of ISO 3741

[ISO 3741:1999]

3.14
regenerated sound
flow noise
noise caused by the flow conditions in the test object

NOTE Adapted from ISO 14163:1998.

3.15
background noise level
sound pressure level at the indicating instrument when measurements are made with the substitution duct in place and the loudspeaker is switched off

NOTE 1 The background noise level is expressed in decibels (dB).

NOTE 2 Adapted from ISO 11200:1995.

NOTE 3 The main elements in background noise are

— flow noise from the fan,

— flow noise generated at the microphone,

— flow noise from the duct system,

— structure-borne sound from the fan propagating along the duct walls to the measurement position,

— airborne sound radiated from the fan or from the loudspeaker equipment into the test room and transmitted through the duct walls to the microphone, and

— electrical noise in the measurement equipment.

NOTE 4 Flanking transmission of sound from the loudspeaker or of flow noise generated by the test object is not part of the background noise, but determines the limiting insertion loss.

3.16
reflection coefficient
r
ratio of the reflected sound pressure amplitude to the sound pressure amplitude of the sound wave incident on the reflecting object

NOTE Adapted from ISO 5136:1990.

3.17
frequency range of interest
one-third-octave bands with centre frequencies from 50 Hz to 10 000 Hz

NOTE For certain applications, it may be sufficient to measure in the frequency range between 100 Hz and 5 000 Hz.

3.18
limiting insertion loss
maximum insertion loss which can be determined in a given test installation without flow

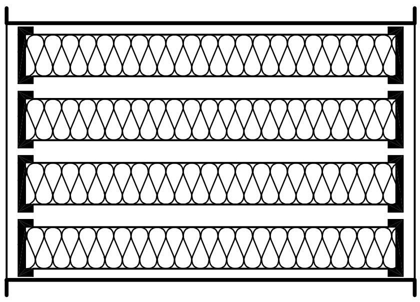
NOTE 1 The limiting insertion loss is expressed in decibels (dB).

NOTE 2 The limiting insertion loss is generally determined by the flanking transmission along the duct walls.

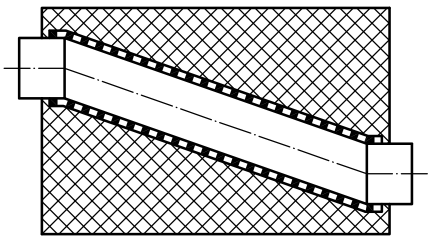
3.19
test object
complete silencer, as supplied by the manufacturer/supplier, one or several parallel baffles installed in a substitution duct, or an air-terminal unit, ready for installation in the test facility, including its housing and its inlet and outlet openings to be connected to ducts

NOTE 1 Examples of silencers are given in Figure 1 and Annex E. Other elements to which the method of this International Standard is applicable are listed in Clause 1.

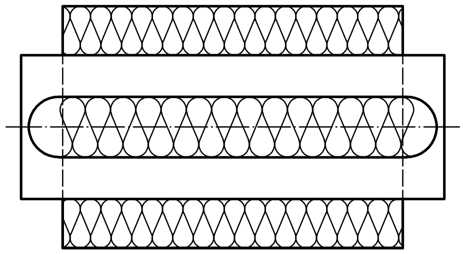
NOTE 2 For "parallel baffles", the term "splitters" is also common.



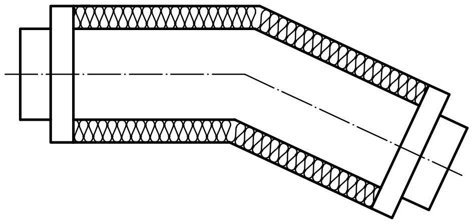
a) Parallel-baffle silencer without transitions



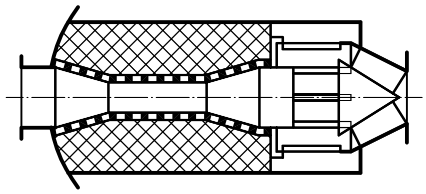
b) Off-set silencer



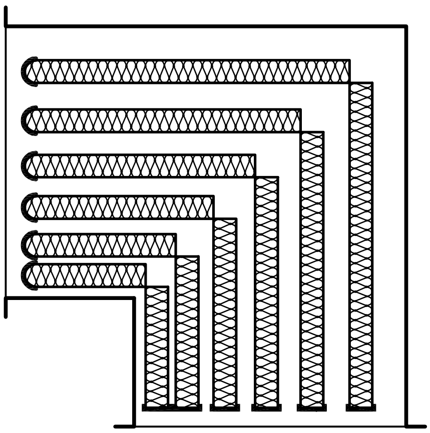
c) Circular silencer with concentric pod



d) Flexible silencer



e) Silencer with spark arrestor



f) Elbow silencer

NOTE A centreline is only drawn for test objects with a rotationally symmetrical airway cross section.

Figure 1 — Examples of silencers

4 Symbols

Symbols are listed in Table 1. The meanings of indices used in this International Standard are explained in Table 2.

Table 1 — Symbols

Symbol	Definition	Unit	Reference
C	difference in level between the sound power radiated into the reverberation room and the average sound pressure level in the reverberation room	dB	6.4
c	speed of sound	m/s	5.2.2.3, B.3
D_a	propagation loss	dB/m	Annex F
D_i	insertion loss	dB	3.1, 6.2, 6.3, A.4
D_t	transmission loss	dB	3.2, 6.3
D_td	transmission loss of open end of test object	dB	6.3, 6.4, B.3
d	diameter of duct	m	5.2.2.3, G.1.4
d_e	equivalent diameter	m	6.5.2.2.1
f	frequency	Hz	B.3
f_C	cut-on frequency of higher-order modes in the duct	Hz	B.2.2, G.2.2, G.2.3.7
f_Cd	cut-on frequency of higher-order modes in duct with circular cross section	Hz	5.2.2.3
f_CH	cut-on frequency of higher-order modes in duct with rectangular cross section	Hz	5.2.2.3
H	height (of silencer or model)	m	5.2.2.3, Annex E
l_min	minimum length of transition	m	5.4.2.3, Figure 7
L_p	sound pressure level	dB	6.2, 6.3, 6.4
L_W	sound power level	dB	3.1, 6.4
p	pressure	Pa	Figure 6, Table 4, 6.5.2.1, 6.5.2.2.1, 6.5.2.2.2, Figure 9, 6.5.2.2.3
q_m	mass flow rate	kg/s	5.4.2.2, 6.5.1
q_V	volume flow rate	m^3/s	3.3, Table 3, 6.5.1, 6.5.2.1, 6.5.2.2.1, 6.5.2.2.2, Figure 9, 6.5.2.2.3
R	specific gas constant for air, R = 287 N·m/kg·K	N·m/kg·K	6.5.2.1, 6.5.2.2.3
r	reflection coefficient	1	3.16, 5.4.2.6, Table 5, B.2.1, B.3, G.2.1, G.2.3.6
r_t	turning radius	m	5.2.2.4.3, Figure 4
S	cross-sectional area, general	m^2	6.5.2.1, B.3, Annex E

Table 1 — Symbols *(continued)*

Symbol	Definition	Unit	Reference
S_1	test duct cross-sectional area, inlet	m^2	3.3, Figure 6, Figure 7, 6.5.2.1, 6.5.2.2.2, 6.5.2.2.3
S_2	test duct cross-sectional area, outlet	m^2	Figure 7, 6.5.2.1
S_T	test object cross-sectional area	m^2	Figure 6
s	gap width in baffle silencer	m	Annex E
t_b	baffle thickness	m	Figure 6, Annex E
v_f	face velocity	m/s	3.3, 3.5
w	width (of silencer or model)	m	Annex E
ΔL	difference between maximum and minimum sound pressure levels of a standing wave in the duct	dB	B.2.1, G.2.1, G.2.3.6
Δp	pressure difference	Pa	3.4, 3.5, 6.5.2.1, 6.5.2.2.2, Figure 6
ζ	total pressure loss coefficient	1	3.5, 6.5.2.1, 6.5.2.2.2, 6.5.2.2.3, 7.8
θ_1	temperature upstream of test object	°C	6.5.2.1, 6.5.2.2.1, 6.5.2.2.3
ρ_1	air density upstream of test object	kg/m^3	3.5, 6.5.1, 6.5.2.2.3
σ_{Ri}	standard deviation of reproducibility of insertion loss	dB	7.9, Table 7
σ_{RI}	standard deviation of reproducibility of intensity level	dB	7.9, Table 7
σ_{Rt}	standard deviation of reproducibility of transmission loss	dB	7.9, Table 7
Ω	solid angle of sound radiation at the duct end	sr	B.3

Table 2 — Indices

Index	denotes
a	ambient
d	dynamic
i	insertion
I	intensity
n	referring to the airflow rate in the middle of the range of interest
R	receiving-side equipment
R	reproducibility
S	sound-source equipment
s	static
t	transmission
T	test object
tot	total
I	with test object installed
II	with test object replaced by substitution duct

5 Test facilities and requirements for instrumentation

5.1 Purpose and types of test facilities

Different test facilities are specified, depending on the task, as follows.

a) Acoustic testing without airflow is applied to determine the insertion loss of a complete silencer ready for installation in the test facility, which can be replaced by a substitution duct (or a set of baffles in the substitution duct which shall have a minimum height of one baffle thickness) when the effect of airflow on the test result is negligible (e. g. for absorptive silencers with an airway flow velocity of less than 20 m/s).

b) Acoustic testing without airflow is also applied to determine the transmission loss of an air-terminal unit, which may be mounted inside or outside a reverberation room and may contain a flow-rate controller (an aerodynamically, electrically or pneumatically actuated damper) and a distribution box with spigots and dampers.

c) Flow testing is applied to determine the total pressure loss of the test object and the sound power level of flow noise (or regenerated sound).

d) Dynamic testing with airflow is applied to determine the insertion loss of a complete silencer or a set of baffles when the effect of airflow on the test result is not negligible (e. g. for certain types of reactive silencers and for high flow velocities).

Acoustic testing (as compared to dynamic testing) allows for easier connection of the sound source to the test object and does not require high sound power levels to overcome the level of flow noise (or regenerated sound). Major requirements for flow and dynamic testing result from the need for a quiet inflow.

5.2 Equipment for acoustic testing of silencers

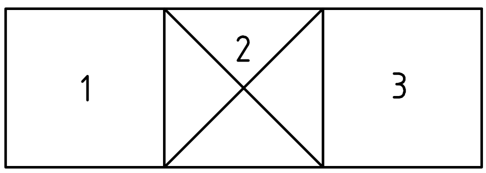
5.2.1 Equipment sets

The test set-up for acoustic testing comprises (see Figure 2)

— the sound source equipment (see 5.2.2),

— the test object, and

— the receiving-side equipment (see 5.2.4).



Key

1 sound-source equipment

2 test object

3 receiving-side equipment

Figure 2 — Test set-up for acoustic testing (schematic)

5.2.2 Sound-source equipment

5.2.2.1 Components

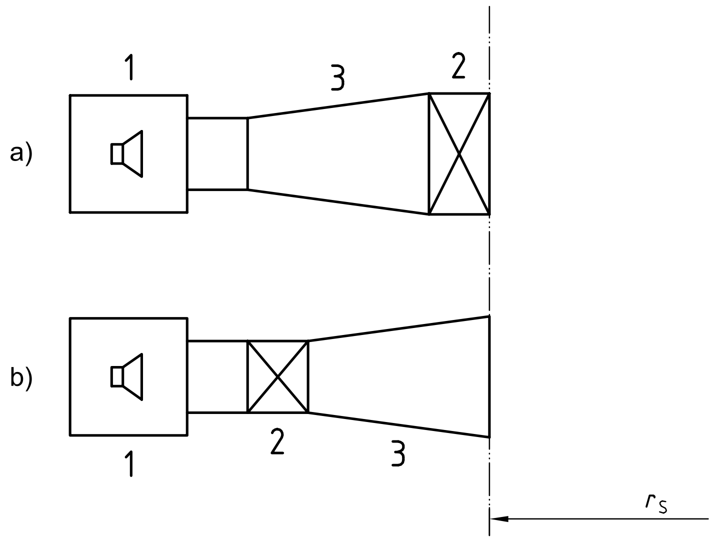
The sound-source equipment is used to excite a sound field with dominating plane-wave mode in front of the test object, and shall comprise (see Figure 3)

— electronic equipment and a loudspeaker unit (see 5.2.2.2),

— a modal filter (see 5.2.2.3), and

— a transition element between the loudspeaker and the test object (see 5.2.2.4).

Resonances in the duct in front of the test object shall be avoided (see 5.2.2.5).



Key

1 loudspeaker unit

2 modal filter

3 transition element

r_S is the reflection coefficient referring to this plane.

Figure 3 — Examples of possible sound source arrangements (schematic)

5.2.2.2 Electronic equipment and loudspeaker unit

A random-noise generator and an amplifier shall drive one or more loudspeakers in an acoustically sealed box (see Figure A.1). Box resonances shall be suppressed by a sound-absorbent lining. Care shall be taken to ensure that the loudspeaker unit does not transmit unwanted structure-borne sound to the connected duct and that the transmission of airborne sound through the walls of the box is sufficiently low.

To avoid damage to the loudspeaker unit during flow tests, openings for pressure equalisation shall be provided.

The sound power produced by this equipment shall be sufficient to ensure that, in the frequency range of interest and at every measurement point, the sound pressure level is at least 6 dB and preferably 10 dB above the level of the background noise.

5.2.2.3 Modal filter

The modal filter is a duct with absorptive or reactive elements providing for a small attenuation of the fundamental mode and for substantial attenuation of higher-order modes of axial sound propagation. In addition, the modal filter is employed to decouple the sound source from the test object/substitution duct. For this purpose, it shall provide a minimum longitudinal attenuation of the fundamental mode of 3 dB at the low-frequency end and of 5 dB above the cut-on frequency of higher-order modes in the connected ducts.

NOTE 1 For example, a short silencer similar to the test object may be used as a modal filter.

NOTE 2 In a duct of circular cross section, the cut-on frequency for the first higher-order mode is

$$f_{\mathrm{Cd}} = \frac{0{,}59c}{d} \tag{4}$$

where

c is the speed of sound;

d is the duct diameter.

In a rectangular duct with larger dimension H,

$$f_{\mathrm{CH}} = \frac{0{,}5c}{H} \tag{5}$$

Tests for determining the longitudinal attenuation are specified in Annex F.

5.2.2.4 Transition element

5.2.2.4.1 General

The transition element shall be rigid to avoid breakout noise transmitted through the duct walls. It may be positioned either between the loudspeaker and the modal filter or between the modal filter and the test object (see Figure 3).

To suppress higher-order modes generated in the transition, it should be positioned between the loudspeaker and the modal filter [see Figure 3a)]. However, consideration shall be given to the fact that the performance of a modal filter can be limited in any position due to the recombination of partial waves at its end.

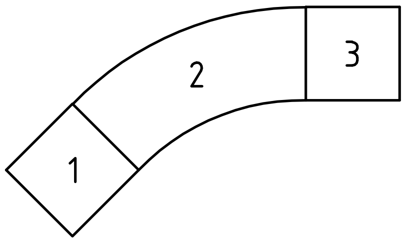
5.2.2.4.2 Straight test objects

In addition to the requirements in 5.2.2.4.1, for straight silencers, the transition shall be straight and coaxial.

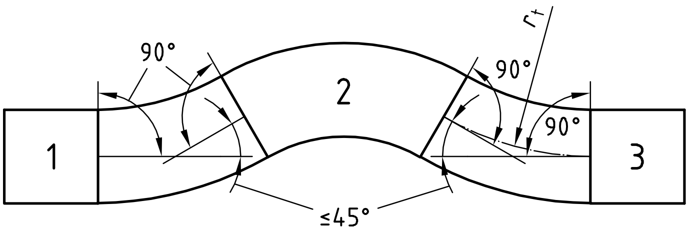
5.2.2.4.3 Bent test objects

It is generally preferable to use straight transitions as specified in 5.2.2.4.2. In the case of bent test objects, this implies that the sound source equipment in front of the test object shall be rotated by the angle between the inlet and outlet axes of the test object [see Figure 4 a)].

If this is not done, two transitions bent by an angle of up to 45° each (elbows) are permitted. The turning radius r_{t} shall not be smaller than the cross-sectional dimension of the duct [see Figure 4 b)].



a)



b)

Key

1 sound-source equipment

2 test object

3 receiving-side equipment

Figure 4 — Test set-ups for bent test objects (schematic)

5.2.2.5 Overall performance requirements below the cut-on frequency of higher-order modes

The reflection coefficient, r_S, of the sound source equipment shall not exceed a value r_S = 0,3 as seen from the position of the test object (see Figure 3) when the loudspeaker is switched off. Qualification is verified by measuring the standing-wave ratio for pure tones in a test duct replacing the test object, which is excited at the opposite side at frequencies below the cut-on frequency of higher-order modes in the test duct [see B.2 and Equations (4) and (5)].

The sound-source equipment is qualified for one-third-octave bands in which the requirements for the longitudinal attenuation of the modal filter are met and the maxima of the standing waves exceed the minima by less than 5 dB in level at the band centre frequencies within the frequency range of interest below the cut-on frequency of higher-order modes.

5.2.3 Substitution duct

The walls of the substitution duct shall be non-absorbent and designed to avoid breakout of airborne sound and transmission of structure-borne sound (see Annex C).

The geometry of the substitution duct shall be recorded and reported.

In the case of a complete silencer ready for installation, use the empty housing of the test object as the substitution duct, if possible and if it fulfils the requirements. If it is not possible to use the empty housing of the test object, the substitution duct shall be matched in size and shape to its inlet and outlet. Differences in linear dimensions of less than 5 % are permissible.

The walls of the substitution duct for a straight test object shall be straight and smooth.

If the connection planes of the test object are not parallel (as in an elbow silencer), the substitution duct section shall be

a) the empty housing of the test object, if possible and if it fulfils the requirements,

b) a smoothly curved bend with as large as possible a curvature radius in the case of a smoothly curved test object, or

c) an elbow duct section similar in geometry to that of the test object in the case of an elbow silencer.

5.2.4 Receiving-side equipment

5.2.4.1 Objectives, alternative configurations and instrumentation

The receiving-side equipment shall permit sound pressure measurements for determining the insertion loss of the test object. For this purpose, pronounced interferences at the microphone positions and flanking transmission of sound shall be avoided. Three alternative configurations may be applied (see Figure 5):

a) a reverberation room and a transmission element connecting the test object to it (see 5.2.4.2);

b) a test duct with anechoic termination (see 5.2.4.3);

c) essentially free-field conditions close to the open end of the test object/substitution duct (see 5.2.4.4).

In addition, any environment complying with ISO 9614-3 is allowed when sound intensity measurements are carried out (see 5.2.4.5).

For bent test objects, the requirements of 5.2.2.4.3 apply.

5.2.4.2 Reverberation room and transmission element

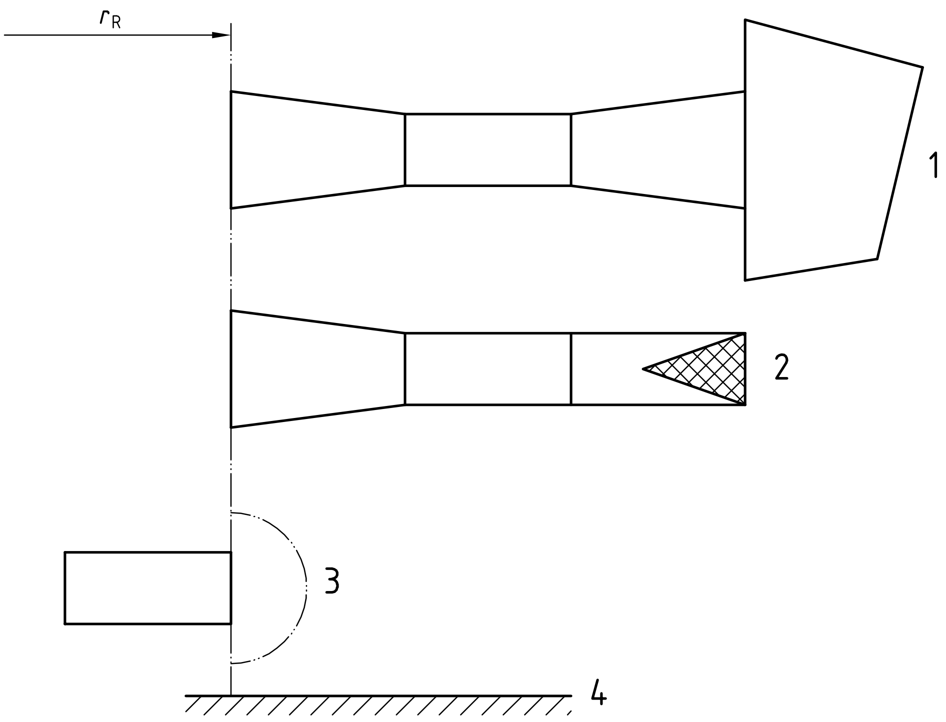
Measurement in a reverberation room complying with the requirements of ISO 3741 is the preferred method of acoustic testing. The room shall be qualified at least down to the one-third-octave band centred at 125 Hz. Reverberation room volumes larger than 300 m³ are permitted. For the purposes of this International Standard, the measurements in accordance with ISO 3741 may be extended down to the one-third-octave band centred at 50 Hz.

The transmission element connecting the receiving side of the test object/substitution duct to the reverberation room may have a constant cross-section or may be fitted with conical elements on either end. For the testing of reactive silencers, the duct shall be equipped with an absorptive silencer providing an insertion loss of at least 3 dB in the frequency range below the cut-on frequency of higher-order modes [see Equations (4) and (5)].

NOTE Reflections that occur at the open end of the duct in a similar way both with and without the test object do not affect insertion loss measurements in the reverberation room. Reflections at the test object are small for absorptive silencers. Reflections at the open end of the substitution duct are small when the requirement for the reflection coefficient, $r_S < 0{,}3$, is met (see 5.2.2.5). With reactive silencers, problems can arise from multiple reflections at both ends of a duct with a constant cross section. These refelections are suppressed when some attenuation is effective in the duct.

5.2.4.3 Test duct with anechoic termination

Measurements inside a test duct on the receiving side are preferred when a reverberation room is not available.



Key

1 reverberation room

2 test duct with absorbent wedge

3 essentially free field

4 floor

r_R is the reflection coefficient referring to this plane.

Figure 5 — Examples of possible receiving-side arrangements (schematic)

The test duct may be attached to the test object/substitution duct either directly or via a conical transition element (see Figure 5). The test duct shall have rigid walls and an anechoic termination. The test duct shall be straight and of either rectangular or circular cross section. Its length shall at least be half the wavelength corresponding to the centre frequency of the lowest frequency band of the frequency range of interest, and not less than four times the maximum duct cross dimension. Examples of suitable designs for the anechoic termination are described in Annex G.

The reflection coefficient, r_R, of the complete receiving-side system (including, if used, a transition element) shall not exceed the value r_R = 0,3. Qualify the system by measuring the standing-wave ratio for pure tones in the substitution duct and in the test duct at frequencies below the cut-on frequency of higher-order modes [see B.2 and Equations (4) and (5)].

The system is qualified for one-third-octave bands in which the maxima of the standing waves exceed the minima by less than 5 dB in level at the band centre frequencies.

The obstruction caused by the microphone and its fixtures shall not exceed 5 % of the test duct cross-sectional area. A device shall be available to move the microphone, either stepwise or continuously, along a straight line inclined with respect to the duct axis and extending over at least one-quarter of the wavelength corresponding to the centre frequency of the lowest one-third-octave band in the frequency range of interest (see Figure 8).

5.2.4.4 Essentially free-field conditions

Such conditions at the microphone positions can be assumed when the direct sound from the open end of the test object or of the substitution duct exceeds the strongest reflection from any nearby surface by at least 10 dB in level for each frequency band within the frequency range of interest. This requirement is met when the distance from the open end to the reflecting surface is more than twice the distance from the open end to the microphone.

Measurements under essentially free-field conditions require duct walls of the sound source equipment with a sufficient sound insulation (or transmission loss). This requirement is met when the limiting insertion loss obtained with the substitution duct, sealed as described in C.2.2, is at least 10 dB higher than the insertion loss of the test object for each frequency band within the frequency range of interest.

Possible ways to increase the limiting insertion loss are to mount elastic gaskets before and after the test object, to line the external duct walls with materials having high internal losses (such as sandwich structures), or to use heavier duct walls.

Measurements under essentially free-field conditions are not permitted when breakout noise penetrating through the walls of the test object or environmental noise has a noticeable effect on the sound pressure level at the microphone positions. This condition is checked by measuring the sound pressure level with and without the duct behind the test object sealed as described in C.2.2. If the difference in level is less than 10 dB in any frequency band within the frequency range of interest, free-field measurements are not permissible.

5.2.4.5 Sound intensity measurements

Sound intensity measurements may be useful to distinguish between sound radiated from the open end of the test object (or of the connected duct) and the breakout sound, or for the suppression of sound transmitted via flanking paths. The effective level of background noise may be reduced by up to 15 dB.

The selection of measurement positions shall comply with ISO 9614-3.

5.2.4.6 Instrumentation

The instrumentation for sound measurements shall consist at least of the following elements:

a) a microphone;

b) a one-third-octave-band filter complying with IEC 61260;

c) a sound level meter or sound intensity meter.

The instrumentation system, including cables, shall meet the requirements for a Type 1 instrument as specified in IEC 60651:2001 or, in the case of integrating-averaging sound level meters, the requirements of IEC 60804:2000.

Equipment for sound intensity measurements shall comply with ISO 9614-3.

5.3 Equipment for acoustic testing of air-terminal units

5.3.1 Sound-source equipment

The sound-source equipment for testing shall be as specified in 5.2.2, except that no modal filter is required. It shall be mounted outside a reverberation room and connected to the high-pressure side of the test object. If the test object is mounted inside the reverberation room, that part of the duct connecting the high-pressure side of the test object to the sound source (outside) shall be acoustically lagged. Spigots and dampers shall be open during testing.

5.3.2 Receiving-side equipment

The receiving-side equipment comprises a reverberation room complying with the requirements of ISO 3741 and, if the test object is mounted outside the reverberation room, a transmission element connecting the test object to the reverberation room. This element may be adjusted in shape to openings available in the wall of the reverberation room as long as its cross-sectional area is kept unchanged. The protrusion of this element into the reverberation room shall be recorded as described in ISO 5135.

For the instrumentation requirements, see 5.2.4.6.

If the test object can only be attached to the transmission element outside of the reverberation room, a secondary transmission element (having the same cross-sectional dimensions and/or area as the outlet of the test object) shall be attached; this secondary transmission element protrudes into the reverberation room.

5.4 Equipment for flow testing

5.4.1 Equipment sets

5.4.1.1 Total pressure loss

NOTE Measurements of the flow rate and pressure loss of air-terminal units are specified in EN 12238, EN 12239 and EN 12589.

The test set-up for measurements of the total pressure loss comprises (see Figure 6)

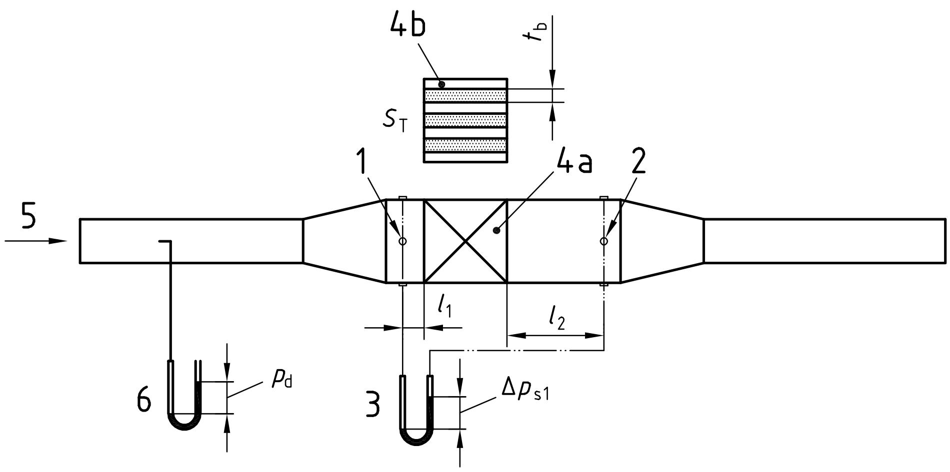
— a fan to produce an airflow without substantial swirl at different flow rates (see 5.4.2.1),

— a device for measuring the flow rate (see 5.4.2.2),

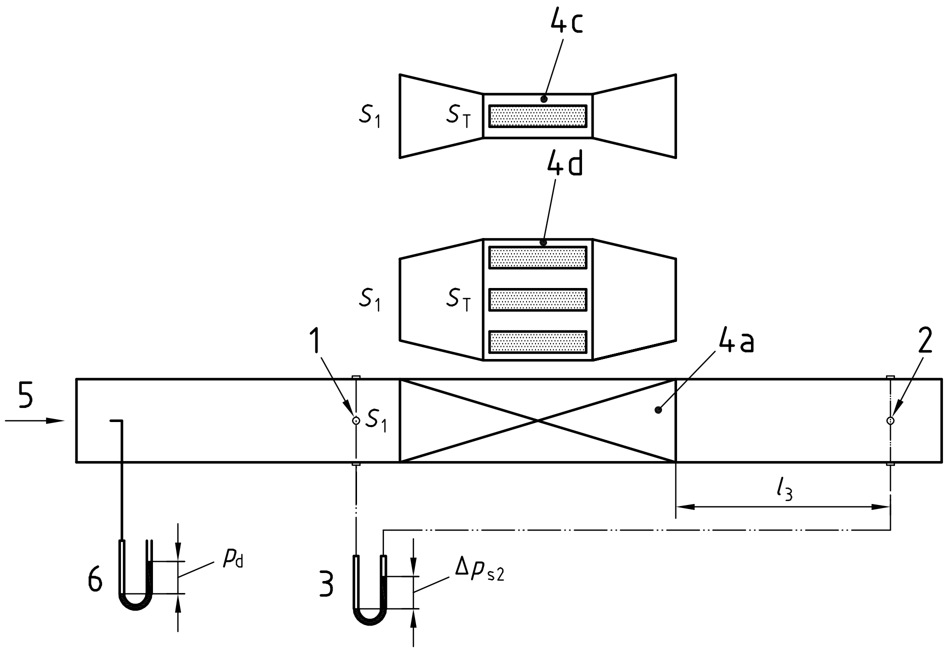
— the test object/substitution duct (see 5.2.3),

— test ducts with aerodynamic transition elements, if needed, on either side of the test object (see 5.4.2.3), and

— a device for measuring the difference in mean static pressure upstream and downstream of the test object (see 5.4.2.4).



a) Silencers without integrated transitions



b) Silencers with integrated transitions

Key

1 upstream static pressure measurement

2 downstream static pressure measurement (either in the reverberation room or in the test duct using four static pressure taps connected by a piezometric ring)

3 manometer

4a substitution duct

4b parallel-baffle silencer

4c test object with integrated diffuser

4d test object with integrated confusor

5 direction of flow

6 flow rate measurement

t_b is the baffle thickness

l_1 is the distance between upstream pressure tap and test object, $l_1 > 0{,}5\ t_b$

l_2 is the distance between downstream pressure tap and test object, $l_2 > 6\ t_b$

l_3 is the distance between downstream pressure tap and test object in case of a test object with diffuser, $l_3 \geqslant 8\left(\sqrt{S_1} - \sqrt{S_T}\right)$

S_1 is the test duct cross-sectional area

S_T is the test object cross-sectional area

Δp_{s1} is the static pressure difference in the case of a test duct with transitions

Δp_{s2} is the static pressure difference in the case of a test object with transitions

p_d is the dynamic pressure

Figure 6 — Typical test arrangements for flow rate and pressure loss

5.4.1.2 Flow noise (or regenerated sound)

The test set-up for measurements of flow noise (or regenerated sound) comprises

— a silenced fan to produce quiet airflow at different flow rates (see 5.4.2.1),

— a device for measuring the flow rate (see 5.4.2.2),

— the test object/substitution duct (see 5.2.3),

— aerodynamic transition elements, if needed, on either side of the test object (see 5.4.2.3), and

— a transmission element (see 5.4.2.6) and a reverberation room complying with the requirements of ISO 3741.

The flow noise (or regenerated sound) of the test object always occurs in combination with sound regenerated in the connected ducts, particularly on the receiving side. For suppressing the latter, the highest flow velocity in the test object shall be larger than the flow velocity in the duct to the reverberation room. This condition determines the choice of the duct cross-sectional area and shape.

Note that swirl and turbulence tend to increase flow noise.

5.4.1.3 Further parameters

The ambient pressure shall be measured to a precision of 1 000 Pa (10 hPa) using a calibrated manometer.

The ambient temperature shall be measured to a precision of ±1 K using a calibrated thermometer.

5.4.2 Components

5.4.2.1 Fan and connected components

The fan should preferably be adjustable in speed to allow variations of the flow rate. It shall be vibration-isolated from the duct.

For measurements of flow noise (or regenerated sound), the attached duct shall be equipped with a silencer to reduce the fan noise in the reverberation room to at least 10 dB below the level of the sound regenerated by the test object in each frequency band within the frequency range of interest.

A flow straightener may be needed to prevent any substantial swirl upstream of the device for measuring the flow rate and of the test object.

The airflow shall not hit any object within 1 m from the opening leading into the reverberation room.

5.4.2.2 Device for measuring the flow rate

ISO 5221 gives several methods for measuring the airflow rate in an airtight duct section, the cross section of which may be circular or (excluding Pitot-static tubes) rectangular.

NOTE From measurements made with this device complying with ISO 5221, the assessment of the mass flow rate will be obtained so that if the air density upstream of the test object is known, either the air volume or the mean flow velocity through the inlet of the test object can be calculated.

The device for measuring the flow rate should not interfere with the sound measurement.

The measurement of fluid flow by means of pressure differential devices (e.g. orifice plates, Venturi tubes, nozzles) inserted in circular-cross-section conduits running full is described in ISO 5167-1.

The mass flow rate, q_m, shall be measured using instruments in accordance with ISO 5221 or ISO 5167-1.

All flow meters shall have the minimum accuracy specified in Table 3.

Table 3 — Relative error of airflow meters

Volume flow rate, q_V m^3/s	**Relative error** %
$0{,}07 < q_V \leqslant 7$	± 2,5
$0{,}007 < q_V \leqslant 0{,}07$	± 5,0

Flow meters may be calibrated by means of the Pitot static tube traverse described in ISO 3966.

Flow meters shall be calibrated at appropriate intervals but these shall not exceed 12 months.

5.4.2.3 Test ducts and aerodynamic transition elements

The test ducts on either side of the test object shall be straight and of constant and equal cross sections.

It is preferable that the cross dimensions of test ducts and the test object be the same. If transition elements are needed to connect mismatching cross sections of the test object and the test ducts on either side, they shall be aerodynamically designed as follows:

— for conical elements: with an enclosed angle of approximately 10°;

— for arbitrary transitions: with a minimum length l_{min} depending on the cross-sectional areas S_1 and S_2 at the ends of the transitions as specified in Figure 7.

This area ratio is limited between 1 to 4 and 4 to 1 for both ends of the transition elements.

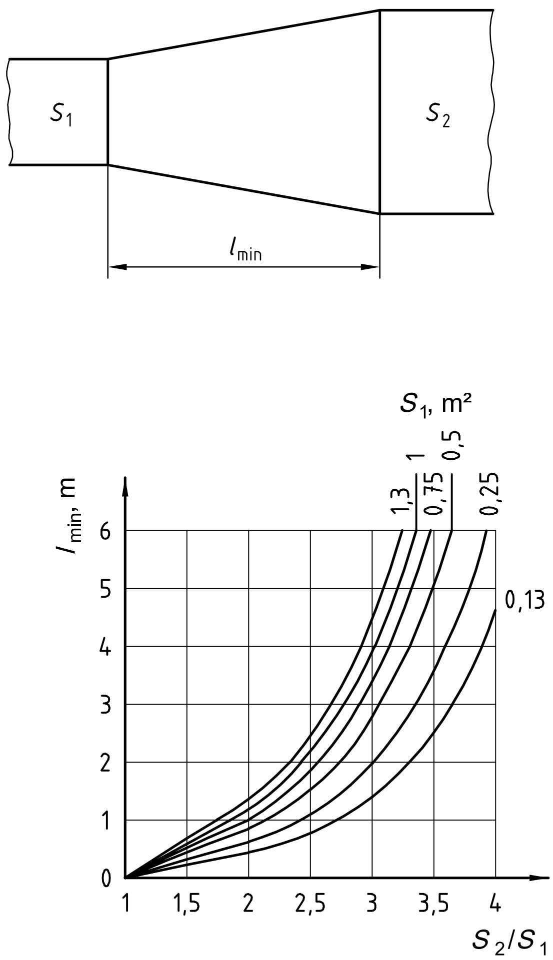


Figure 7 — Minimum length of transitions as a function of area ratio S_2/S_1

5.4.2.4 Pressure loss

The arrangement and device for measuring the mean static pressure on either side of the test object and the total pressure loss across the test object shall comply with Figure 6.

5.4.2.5 Pressure measurement

Pressure in the duct shall be measured with a calibrated manometer.

The maximum scale interval shall not be greater than the characteristics listed for the accompanying range of manometer shown in Table 4.

Table 4 — Maximum scale intervals for the range of manometers

Pressure range p Pa	**Maximum scale interval** Δp Pa
$p \leqslant 25$	1,0
$25 < p \leqslant 250$	2,5
$250 < p \leqslant 500$	5,0
$p > 500$	25

For airflow measurement, the minimum pressure differential shall be

a) 25 Pa with an inclined-tube manometer or micromanometer, or

b) 500 Pa with a vertical-tube manometer.

Calibration standards shall be

a) for instruments with a range of up to 25 Pa, a micromanometer accurate to ± 0,5 Pa,

b) for instruments with a range of up to 100 Pa, a micromanometer accurate to ± 1,0 Pa, or

c) for instruments with a range of over 100 Pa, a micromanometer accurate to ± 1 % of reading.

5.4.2.6 Transmission element

The transmission element connecting the test object and the reverberation room shall be designed to inhibit pronounced resonances behind the test object, and it shall not have any significant absorption in the duct.

It is then sufficient to determine the end reflection coefficient r by the measurement method described in B.2 or the calculation method described in B.3, if applicable. If reflections at the receiver side of the test object are not weak, the end-reflection coefficient, r, should not exceed the maximum values specified in Table 5. The reflection coefficient of the test object, r_T, is determined from measurements of the standing-wave ratio in a test duct replacing the transmission element, when the test duct is excited at the open end at frequencies below the cut-on frequency of higher-order modes [see Equations (4) and (5)].

NOTE Absorptive silencers generally provide weak reflections.

If reflections at the receiver side of the test object are weak, as they are for a reflection coefficient of the transmission element, $r_T < 0,3$, they may be neglected.

Table 5 — Maximum values of the reflection coefficient for a transmission element

Centre frequency of the frequency band Hz	Maximum value of reflection coefficient r
50	0,7
63	0,6
80	0,5
100	0,4
125	0,3
> 160	0,2

NOTE These values will be obtained using a test duct with a cross-sectional area of at least 2 m^2 (without a transmission element).

5.5 Equipment for dynamic testing

5.5.1 Equipment sets

The test set-up for dynamic testing comprises (see Figure H.2)

- a fan to produce a variable airflow (see 5.4.2.1),
- a device for measuring the flow rate (see 5.4.2.2),
- a special sound-source equipment (see 5.5.2),
- the test object/substitution duct (see 5.2.3),
- aerodynamic transition elements on either side of the test object (see 5.4.2.3), and
- a special receiving-side equipment (see 5.5.3).

5.5.2 Sound-source equipment for dynamic testing

In addition to complying with the requirements in 5.2.2.1, the sound-source equipment shall produce a sound power sufficient to ensure that, in the frequency range of interest and at every measurement point, the sound pressure level is at least 10 dB above the level of the flow noise (or regenerated sound).

The signal-to-noise ratio can be improved by using a band-limited signal, either octave or one-third octave.

Examples of an appropriate design for the loudspeaker unit, together with a qualification procedure, are given in Annex A.

5.5.3 Receiving-side equipment for dynamic testing

If sound measurements are to be made in a test duct with anechoic termination, the flow noise (or regenerated sound) of the anechoic termination shall not influence the acoustic measurement. Suitable designs are described in Annex G and in ISO 5136. It may be necessary to suppress the air-flow-induced microphone signal (i.e. generated by turbulent pressure fluctuations) by using appropriate wind screens (e. g. nose cone, foam ball or sampling tube) in order to obtain a sufficient signal-to-noise ratio. The difference in level between the sound pressure generated by the sound source and attenuated by the test object and the flow noise (or regenerated sound) generated by turbulent flow over the microphone shall be at least 10 dB in each frequency band within the frequency range of interest.

NOTE If a sampling tube complying with ISO 5136 is used, problems can arise as a result of the directivity of the sampling tube.

If sound measurements are to be made in the reverberation room, the transmission element shall be designed to provide a level difference of at least 10 dB in each frequency band within the frequency range of interest between the sound pressure generated by the sound source and attenuated by the test object and in the transmission elements and the sound pressure regenerated by the flow.

The difference in level between the signal and flow noise (or regenerated sound) may be checked by measurements when the sound source is switched on and off.

6 Test procedures

6.1 General

Determine the reflection coefficients of the components of the test facility from measurements with pure tones of 50 Hz, 63 Hz, etc. at the centre frequencies of the one-third-octave bands up to the cut-on frequency of the first cross-mode in the duct [see B.2 and Equations (4) and (5)].

Carry out measurements for determining the insertion/transmission loss of test objects in one-third-octave bands of random noise excited by the sound source equipment in the frequency range of interest. The flow noise (or regenerated sound) is measured in one-third-octave bands centred at 50 Hz to 10 kHz.

Determine the limiting insertion loss of the test facility from measurements without flow and with the test object replaced by a substitution duct. Carry out the measurements with and without the substitution duct acoustically blocked as described in C.2.2.

The insertion loss and, if necessary, the flow noise (or regenerated sound) and total pressure loss of the test object shall be determined for the range of flow velocities for which measurements are required.

Before and after each series of acoustic measurements, a Type 1 sound calibrator complying with IEC 60942:1997 with a tolerance of ± 0,3 dB shall be applied to the microphone for verifying the calibration of the entire measuring system at one or more frequencies over the frequency range of interest.

6.2 Insertion loss

6.2.1 Sound-pressure measurement

The insertion loss, D_{i}, shall be determined from spatially energy-averaged sound pressure levels $\overline{L_p}$ at identical points or paths

— in the reverberation room complying with ISO 3741, or

— in the test duct behind the test object, or

— on an enveloping surface near the open end of the test object/substitution duct according to ISO 3746.

NOTE Since differences in sound power levels are evaluated from measurements taken at the same positions and since the open ends of the test object and the substitution duct are similar in shape and position, the precision of the measurements is substantially higher than expected for measurements according to ISO 3746.

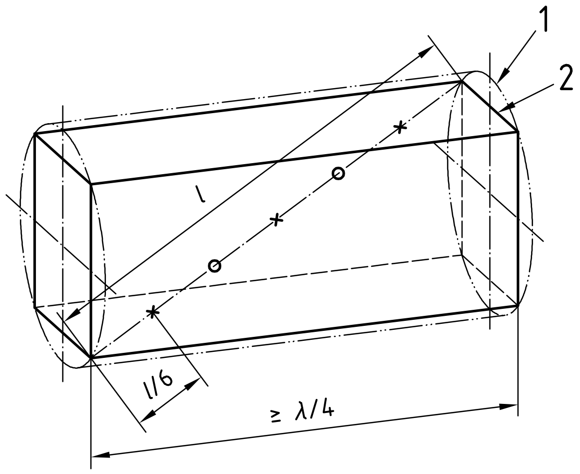
In one test series, $\overline{L_{p\mathrm{I}}}$ shall be determined with the test object installed.

In a further series, $\overline{L_{p\mathrm{II}}}$ shall be determined with the test object replaced by the substitution duct.

The sound signal emitted by the sound source shall be the same with respect to the sound power spectrum for the two test series. The test installation and the test environment shall be unchanged.

If the local sound pressure levels are measured in the reverberation room, the measurements and the averaging shall be made in accordance with ISO 3741.

If the local sound pressure levels are measured in the test duct behind the test object, the spatial average shall be determined from the sound pressure levels measured at least at three key positions equally spaced as shown in Figure 8. The longitudinal span of this line shall be at least as long as one-quarter of a wavelength λ at the centre frequency of the respective one-third-octave band. It should be positioned at about half the length of the test duct. The preferred orientation of the microphone is along the duct axis. If the difference, in decibels, between the highest and the lowest levels of the three measurements exceeds the values given in Table 6, then five positions shall be used. Spatial averaging is also permitted by continuous measurement along the diagonal line across the test duct.



Key

1 circular test duct

2 rectangular test duct

X Key position of microphone

O Additional position of microphone

Figure 8 — Microphone positions

Table 6 — Maximum level differences for three microphone positions in the test duct

Frequency Hz	**Maximum level difference** dB
50	10
63	10
80	8
100	8
125	7
> 160	6

6.2.2 Sound-intensity measurements

Without flow, the insertion loss, D_i, shall be determined from sound-intensity measurements on identical paths on an enveloping surface near the open end of the test object/substitution duct, according to ISO 9614-3, with the test object installed and, in a further series, with the test object replaced by the substitution duct. The insertion loss, D_i, is then calculated from the mean intensities.

6.3 Transmission loss

The transmission loss, D_t, of the test object (air-terminal unit) shall be determined from spatially energy-averaged sound pressure levels, $\overline{L_{p1}}$ and $\overline{L_{p2}}$, in the reverberation room in accordance with ISO 3741 (see 5.3) and from theoretical values of the transmission loss of the open end of the test object, D_{td}, using Equation (6) (see reference [22]). First, the sound radiated through the substitution duct shall be measured without the test object installed ($\overline{L_{p1}}$). Measurements of the reverberation time, T_1, are carried out, if needed. Next, the test object shall be attached to the transmission element leading into the reverberation room and the sound attenuated by the test object shall be measured ($\overline{L_{p2}}$). If the test object is mounted inside the reverberation room, the reverberation time T_2 shall be determined. Otherwise, it may be assumed that $T_2 = T_1$.

$$D_t = D_i + D_{td} \tag{6}$$

where

$$D_i = \overline{L_{p1}} - \overline{L_{p2}} + 10 \lg \frac{T_2}{T_1} \text{ dB}$$

D_{td} is as defined in B.3.

The setting of the flow rate controller shall be recorded.

6.4 Sound power level of the flow noise (or regenerated sound)

The sound power level of the flow noise (or regenerated sound) shall be determined for the flow direction and face velocity corresponding to the intended application of the test object.

It is recommended that the sound power level be determined in a reverberation room in accordance with ISO 3741, connected to the test duct behind the test object. If no reverberation room is available, the in-duct method given in ISO 5136 should be used.

Two measurement series shall be carried out. In the first series, the level of the background noise shall be determined with the substitution duct in place of the test object. In the second series, the sound pressure level of the flow noise of the test object shall be measured. For both series, all other test conditions (flow condition, microphone position, duct system dimensions, etc.) shall be held constant.

The sound power level of the flow noise (or regenerated sound) of the test object, L_W, is calculated in one-third-octave bands from

$$L_W = \overline{L_p} + D_{td} + C \tag{7}$$

where

$\overline{L_p}$ is the spatial energy-average one-third-octave-band sound pressure level, determined according to ISO 3741, but without correction for background noise;

D_{td} is the transmission loss at the open end of the duct attached to the reverberation room;

C is the difference in level between the sound power radiated into the reverberation room and the average sound pressure in the reverberation room, which is determined either from the direct or the indirect method specified in ISO 3741.

For ducts with constant cross section, transmission loss data, D_{td}, are to be obtained as in Equation (B.3).

Sound power levels of the flow noise determined for the test object and for the substitution duct shall be reported without corrections for background noise.

6.5 Volume flow rate and pressure loss coefficient

6.5.1 Inlet volume flow rate

The volume flow rate, q_V, at the inlet of the test object shall be calculated from the following equation:

$$q_V = \frac{q_m}{\rho_1} \tag{8}$$

where

q_m is the mass flow rate, in kilograms per second;

ρ_1 is the air density upstream of the test object, in kilograms per cubic metre.

6.5.2 Average total pressure loss coefficient

6.5.2.1 Simplified method

To determine the pressure loss coefficient, five different airflow rates (q_V) shall be measured. The lowest flow rate in the range shall be such that it produces a pressure difference greater than 10 Pa.

If there are significant differences in the air temperature and static pressure between the flow meter and the test object, so that the air density ratio $\frac{\rho_1}{\rho_2}$ is less than 0,98 or greater than 1,02, the following correction shall be applied:

$$q_V = \frac{q_m}{\rho_{1n}} \tag{9}$$

where

$$\rho_{1n} = \frac{1}{R}\frac{p_{s1} + p_a}{\theta_1 + 273\ °C} \tag{10}$$

and

$$R = 287 \frac{N \cdot m}{kg \cdot K}$$

The total pressure (p_{tot}) in the plane of measurement is equal to the sum of the measured static pressure measured (p_s) and the dynamic pressure (p_d), according to the following formula:

$$p_t = p_s + \frac{\rho}{2}\left(\frac{q_V}{S}\right)^2 \tag{11}$$

The total pressure loss is

$$\begin{aligned} \Delta p_t &= p_{t1} - p_{t2} = (p_{s1} + p_{d1}) - (p_{s2} + p_{d2}) \\ &= \Delta p_s + \Delta p_d \\ &= \Delta p_s + p_{d1}\left(1 - \left(\frac{S_1}{S_2}\right)^2\right) \end{aligned} \tag{12}$$

where

$$p_{d1} = \frac{\rho}{2}\left(\frac{q_V}{S_1}\right)^2 \qquad (13)$$

S_1 is the cross-sectional area of the inlet test duct;

S_2 is the cross-sectional area of the outlet test duct.

The total pressure loss coefficient is

$$\begin{aligned}\zeta &= \frac{\Delta p_t}{p_{d1}} \\ &= \frac{\Delta p_s}{p_{d1}} + 1 - \left(\frac{S_1}{S_2}\right)^2\end{aligned} \qquad (14)$$

NOTE As a rule, $S_1 = S_2$.

The average total pressure loss coefficient shall be calculated as the linear average of all measurements.

6.5.2.2 Fundamental method

6.5.2.2.1 Method and requirements

Determine the average total pressure loss coefficient of the test object using a substitution method. Carry out two test series

— one with the test object installed, and

— another with the test object replaced by the substitution duct.

Each test series shall be carried out at a minimum of five airflow rates distributed evenly throughout the test range of airflow rates.

The upstream test duct shall be straight for a minimum length of $5d_e$ or 2 m, whichever is the greater, where d_e is the equivalent diameter; $d_e = \sqrt{\frac{4S}{\pi}}$ where S is the cross-sectional area of the duct.

The flow in the upstream test duct shall have no substantial swirl (see 5.4.2.1).

The velocity profile near the upstream connection to the test object shall be uniform to ± 10 % of the mean value over the test duct cross section, excluding the area within 15 mm of the duct walls. A velocity survey at ten equally spaced positions along a pair of mutually perpendicular axes about 1,5 d_e from the test object shall be carried out to confirm that the velocity profile is within these limits.

The upstream duct static pressure, p_{s1}, shall be measured by means of four static pressure tapings 1,5 d_e from the upstream connection to the test object. These pressure taps shall, for a rectangular duct, be at the centre of each side and, for a circular duct, equally spaced around the circumference. The pressure taps shall be connected to form a piezometric ring. The upstream static pressure, p_{s1}, shall be measured relative to a pressure downstream of the test object or substitution duct, respectively, either in the downstream test duct or in the connected reverberation room.

For determination of the fluid density, the upstream duct static pressure, $p_{s1(a)}$, shall also be measured relative to the ambient pressure, p_a, when the test object is installed.

The air temperature shall be measured at the flow meter and at a position 2 d_e upstream of the test object, and during the test the temperature variation shall not be greater than 3 K.

The following data shall be recorded:

a) the inlet duct static pressure with the test object installed, $p_{s1(I)}$, in pascals, as measured relative to the downstream pressure;

b) the upstream duct static pressure, $p_{s1(a)}$, in pascals, as measured relative to the ambient pressure;

c) the inlet duct static pressure with the substitution duct installed, $p_{s1(II)}$, in pascals, as measured against the downstream pressure;

d) the ambient pressure, p_a, in pascals;

e) the air temperature at the inlet to the test object, θ_1, in degrees Celsius.

For each test, the volume airflow rate, q_V, according to ISO 5221 or ISO 5167-1 shall be determined as specified in 6.5.1.

6.5.2.2.2 Graphical evaluation procedure for determining the average total pressure loss coefficient

The following graphs shall be plotted on scales:

a) lg $p_{s1(I)}$ against lg q_V;

b) lg $p_{s1(II)}$ against lg q_V;

c) lg $p_{s1(a)}$ against lg q_V.

The best-fit straight lines with a slope of 2 shall then be drawn through that set of data points for which the values of lg p_{s1} lie within ± 5 % of the straight line. See Figure 9.

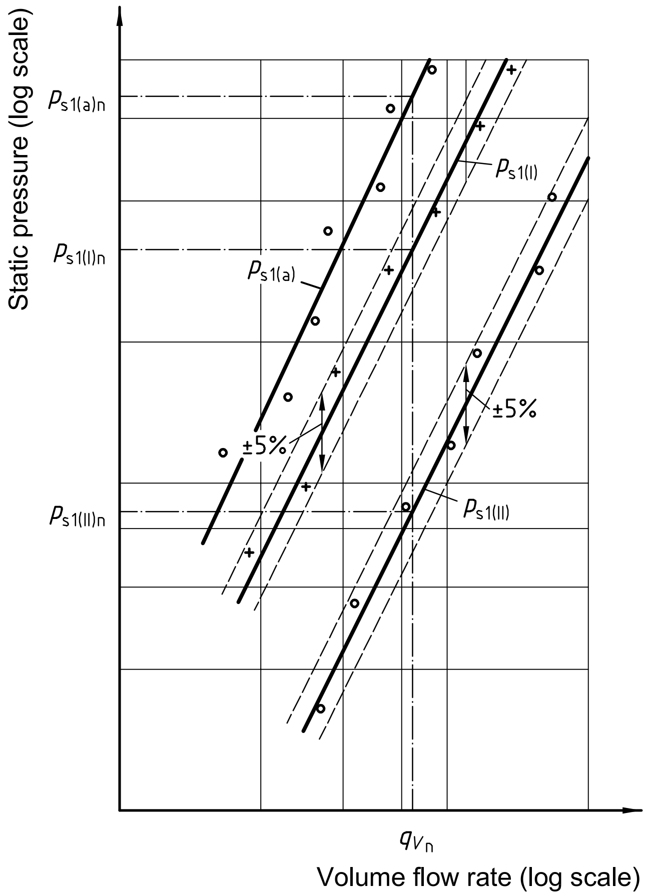


Figure 9 — Flow rate/pressure requirement
(Plot of static pressures and corresponding flow rates in plane 1)

Select a value $q_{V\text{n}}$ of the flow rate in the middle of the range investigated. Calculate the total gauge pressure requirement, $\Delta p_{\text{tot,n}}$, of the test object from the following equation:

$$\Delta p_{\text{tot,n}} = \Delta p_{\text{sn}} = p_{\text{s1(I)n}} - p_{\text{s1(II)n}} \tag{15}$$

Calculate the inlet (or face) velocity pressure, p_{dn}, from the following equation:

$$p_{\text{dn}} = \frac{1}{2}\rho_{\text{1n}}\left(\frac{q_{V\text{n}}}{S_1}\right)^2 \tag{16}$$

where

ρ_{1n} is given by Equation (10);

S_1 is the cross-sectional area of the upstream duct, in square metres.

The total pressure loss coefficient, ζ, averaged over the range of flow velocities, shall be calculated from the following equation:

$$\zeta = \frac{\Delta p_{\text{tot,n}}}{p_{\text{dn}}} \tag{17}$$

All total pressure losses quoted from the test results shall be calculated from the average total pressure loss coefficient.

6.5.2.2.3 Computational evaluation procedure for determining the average total pressure loss coefficient

The following formula may be used:

$$\zeta = \frac{1}{N}\sum_{i=1}^{N}\frac{p_{\text{s1(I)}i}}{p_{\text{d}i}} - \frac{1}{M}\sum_{k=1}^{M}\frac{p_{\text{s1(II)}k}}{p_{\text{d}k}} \quad (18)$$

where

N, M are the numbers of measurements with the test object and with the substitution duct installed, respectively;

$$p_{\text{d}i} = \frac{1}{2}\rho_{1i}\left(\frac{q_{Vi}}{S_1}\right)^2 \quad (19)$$

$$p_{\text{d}k} = \frac{1}{2}\rho_{1k}\left(\frac{q_{Vk}}{S_1}\right)^2 \quad (20)$$

in which

$$\rho_{1i} = \frac{p_{\text{s1(a)}i} + p_{\text{a}}}{R\left(\theta_{1i} + 273\ °\text{C}\right)} \quad (21)$$

$$\rho_{1k} = \frac{p_{\text{s1(a)}k} + p_{\text{a}}}{R\left(\theta_{1k} + 273\ °\text{C}\right)} \quad (22)$$

7 Information to be recorded

7.1 Description of the test object

The following information, when applicable, shall be compiled and recorded:

a) type of test object and its application;

b) dimensions;

c) direction of the flow.

7.2 Instrumentation

All the measuring equipment used, including type and serial numbers and the date of verification of the compliance with relevant standards, shall be recorded.

7.3 Sound-source equipment

The following information, when applicable, shall be compiled and recorded:

a) type and size of the loudspeaker unit;

b) coupling of the loudspeaker unit to the duct in front of the test object;

c) longitudinal attenuation of the modal filter;

d) reflection coefficient of the sound source equipment.

7.4 Test, substitution and transmission ducts

The following information, when applicable, shall be compiled and recorded:

a) wall thickness, length, cross-sectional dimensions, material and structure of the ducts;

b) limiting insertion loss when the substitution duct is blocked as described in C.2.2;

c) position of the duct outlet in the reverberation room.

7.5 Transitions

The following information, when applicable, shall be compiled and recorded:

a) wall thickness, length, material;

b) maximum enclosed angle;

c) open area of both ends.

7.6 Anechoic termination

The reflection coefficient of this, including the transition and test duct, shall be recorded.

7.7 Reverberation room

The volume of the reverberation room shall be recorded.

7.8 Acoustical test results

The test results given in 7.8 a) to e) shall be presented in tabular form, rounded to the nearest integer, as well as in graphical form as functions of frequency with 5 mm on the abscissa representing one-third-octave band width and 20 mm on the ordinate representing 10 dB. A scaling of both axes by the same factor is permissible.

a) Record the insertion loss, in one-third-octave bands, with centre frequencies from 50 Hz to 10 000 Hz (or 100 Hz to 5 000 Hz, see 3.17) for all volume rates used. Extrapolation of the measurement results to temperatures beyond the range of 250 K to 330 K, and/or to pressures beyond the range of $0,8 \times 10^5$ Pa to $1,2 \times 10^5$ Pa is not allowed[1]. If transitions are used, the following statement shall be given:

   “This insertion loss is valid for the test object together with the transitions since the effects of the transitions cannot always be neglected.”

1) Information on extrapolation is given in ISO 14163.

b) Record the limiting insertion loss of the test facility as a function of frequency.

c) Record the sound power level of the flow noise without the test object for all inlet volume flow rates for which measurements were provided.

d) Record the sound power level of the flow noise of the test object in all frequency bands and for all inlet volume flow rates for which measurements were provided.

e) Record the transmission loss, in one-third-octave bands, for air-terminal unit or air-terminal device, if applicable.

In addition, the average total pressure loss coefficient, ζ, shall be recorded (see 5.4.1.1 and 6.5.2).

7.9 Measurement uncertainty

Exact information on the quality of the systems and procedures needed and on the precision achievable cannot be given at this time. Important parameters are the ratio of geometrical dimensions and wavelengths of sound, the transmission loss of duct walls, the absorptive properties of the test object, and the flow velocity. The estimates of the reproducibility standard deviation, $\sigma_{R\mathrm{i}}$ of the insertion loss given in Table 7 were determined from tests made on 1 m long parallel-baffle silencers. The standard deviations of reproducibility for transmission loss and sound-intensity measurements are estimates based on experience.

Table 7 — Estimated standard deviation of reproducibility for different frequency bands

Centre frequencies of the one-third-octave band Hz	Standard deviation of reproducibility, $\sigma_{R\mathrm{i}}$, of the insertion loss dB	Standard deviation of reproducibility, $\sigma_{R\mathrm{t}}$, of the transmission loss dB	Standard deviation of reproducibility of the intensity level measured as per ISO 9614-3 dB
50 to 100	1,5	3	3
125 to 500	1	3	1,5
630 to 1 250	2	3	1
1 600 to 10 000	3	3	1[a]

[a] Upper frequency limit 5 000 Hz.

For tests on circular-cross-section silencers, see reference [18].

Unless more specific knowledge is available, the expanded measurement uncertainty for a coverage probability of 95 % shall be recorded to be two times the standard deviation of reproducibility as given in Table 7.

8 Information to be reported

The test report shall include the following information:

a) date and time when the measurements were carried out;

b) information recorded in 7.1 to 7.8.

The test report shall contain the statement that the results have been obtained in compliance with the requirements of this International Standard.

It is recommended to include a statement on the measurement uncertainty in accordance with 7.9.

Annex A
(normative)

Design of the sound field excitation equipment and qualification tests

A.1 General

There are several designs for equipment that will excite a sound field in front of the test object with predominantly acoustical plane waves.

A.2 Modal filter for measurement without flow

A straight duct lined with absorbent material is usually sufficient if the absorption coefficient of the lining multiplied by the length of the duct exceeds the cross-sectional diameter. If there is not enough space available for the length of the duct, the effective cross-sectional diameter may be reduced by absorbent baffles in the duct (see Figure A.1). The low-frequency absorption coefficient of the lining increases with the thickness of the lining.

A.3 Sound field excitation equipment for measurement with flow

The sound field in front of the test object may be excited using various designs. However, a qualification test in accordance with A.4 is prescribed to ensure that the sound field in front of the test object is dominated by an acoustical plane-wave mode.

Figure A.2 shows possible designs in which the sound field is excited by a loudspeaker unit within a source chamber connected to the test duct in front of the test object.

The ratio of the cross-sectional areas of the source chamber and the test duct should be not less than 5:1 to provide uniform flow conditions at the entrance of the test object.

The loudspeakers should be so positioned in the chamber that they face toward the inlet of the test duct. Static pressure equalization on the front and rear sides of the loudspeaker membranes should be provided. If more than one loudspeaker is used, the loudspeakers shall be driven in-phase.

The sound field excitation used for measurements with flow may also be used for measurements without flow, subject to the qualification test.

A.4 Qualification test

To verify the qualification of the modal filter (see 5.2.2.3 and A.2), a measurement of the longitudinal attenuation as specified in Annex F is required. For further verifications of sound source equipment for acoustic testing, see 5.2.2.5.

For sound field excitation for measurements with flow, the following qualification test is specified.

The qualification test is based on the comparison of measured insertion losses.

The following steps shall be performed for each frequency band of interest:

a) determination of the insertion loss of the test object in accordance with 6.2 (i.e. without flow) using the sound field excitation illustrated in Figure A.1 (loudspeaker baffle);

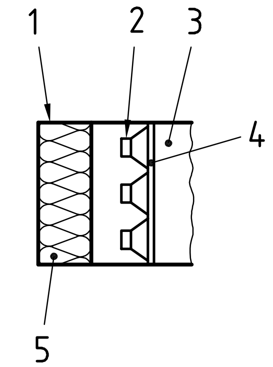
b) determination of the insertion loss of the test object in accordance with 6.2 (i.e. without flow) using the chosen sound field excitation equipment specified in A.3.

The test arrangements used for step a) and step b) shall differ only in the manner of the sound field excitation.

If the insertion loss determined in accordance with step a) is $D_i \leqslant 20$ dB, the insertion losses measured in accordance with step a) and b) shall not deviate by more than 2 dB.

If the insertion loss determined in accordance with step a) is $D_i > 20$ dB, the insertion losses measured in accordance with steps a) and b) shall not deviate by more than 3 dB.

The sound source excitation equipment designed in accordance with A.3 is qualified for the relevant frequency band if the above requirements are met.



Key

1 enclosure

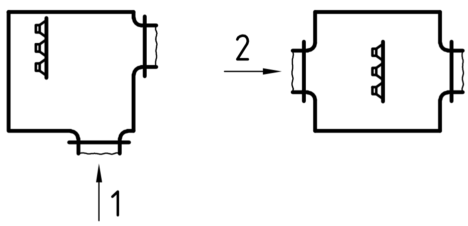
2 loudspeaker

3 test duct

4 baffle

5 sound-absorbent material

Figure A.1 — Schematic presentation of a loudspeaker baffle — Actual test arrangement



Key

1 airflow, actual test

2 airflow

Figure A.2 — Schematic presentation of the sound field excitation from a source chamber

Annex B
(normative)

Transmission element

B.1 Design of a transmission element

B.1.1 For measurements without flow, any horn shape or absorption in the transmission element is permissible, which limits the reflection coefficient in a way that it does not exceed the maximum permissible values given in Table 5.

B.1.2 For the measurement of flow noise (or regenerated sound), it is essential that the transmission element transmit a large part of the sound power into the connected reverberation room. It shall therefore have nearly zero dissipative losses and the reflection coefficient at the open end shall be small or shall be computable according to B.3 (see 5.4.2.6).

B.1.3 The transmission element shall not produce flow noise (or regenerated sound) which influences the measurements in the reverberation room (see 5.5.3).

B.1.4 The wall of the transmission element shall have a high transmission loss to prevent sound energy losses through this wall.

B.1.5 A transmission element suitable for the measurement of flow noise (or regenerated sound) is a horn in which the enclosed angle of the walls does not exceed 15° and the walls are acoustically hard and rigid (see Figure B.1).

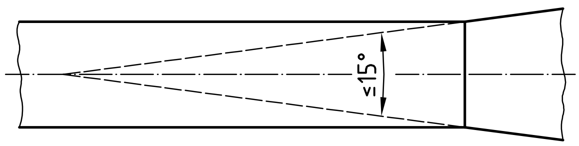


Figure B.1 — Schematic of a suitable transmission element

B.2 Measurement of the reflection coefficient of a transmission element

B.2.1 The reflection coefficient, r, of the transmission element is given by the following formula:

$$r = \frac{10^{\Delta L/20} - 1}{10^{\Delta L/20} + 1} \quad \text{(B.1)}$$

The difference, ΔL, between the maximum and minimum sound pressure levels of the standing wave is measured in a straight duct with rigid walls.

B.2.2 It is recommended that the reflection coefficient be measured using pure tones at the centre frequencies of one-third-octave bands from 50 Hz up to the cut-on frequency, f_C, of higher-order modes in the duct.

B.2.3 Alternatively, a two-microphone technique may be used to determine the complex transfer function H_{12} between the signals of two microphones spaced along the axis of a measurement duct at a distance $s < c/(4f)$, where c = 340 m/s and f is the measuring frequency. The magnitude of the pressure reflection coefficient is then calculated from

$$r = \frac{H_{12}\,\mathrm{e}^{\mathrm{j}2\pi f s/c} - 1}{\mathrm{e}^{\mathrm{j}2\pi f s/c} - H_{12}} \tag{B.2}$$

where j is the imaginary unit (see also ISO 5136).

B.3 Calculation of the transmission loss and reflection coefficient at the open end of a duct

For the purposes of this International Standard, the transmission loss, D_{td}, at the open end of a straight and rigid duct is calculated from

$$D_{td} = 10\,\lg\left[1 + \frac{\Omega}{\left(\frac{4\pi f\sqrt{S}}{c}\right)^2}\right]\,\mathrm{dB} \tag{B.3}$$

where

S is the cross-sectional area of the duct;

Ω is the solid angle of radiation at the duct end (see Table B.1);

f is the frequency;

c is the speed of sound in air.

Therefore, the reflection coefficient, r, is calculated from Equation (B.4):

$$r = \left[\frac{1}{\Omega}\left(\frac{4\pi f\sqrt{S}}{c}\right)^2 + 1\right]^{-1/2} \tag{B.4}$$

Table B.1 — Values of Ω for configurations shown in Figure B.2

Configuration	Ω
A	2π
B	π
C	4π
D	2π
E	4π

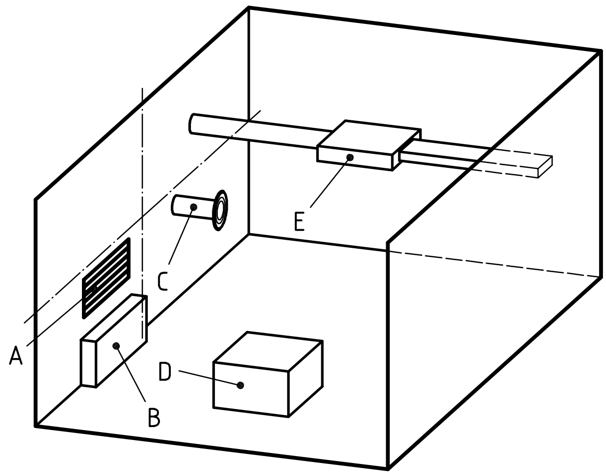


Figure B.2 — Positioning of air-terminal units in the test room (see Table B.1)

Annex C
(normative)

Duct walls and limiting insertion loss

C.1 Flanking transmission

C.1.1 General

The limiting insertion loss of a test facility is fixed by the flanking sound transmission arising from the following phenomena (see Figure C.1):

a) structure-borne sound bypass (see C.1.2);

b) airborne sound bypass (I) through the duct walls and the test room (see C.1.3);

c) airborne sound bypass (II) through the duct openings (see C.1.4).

C.1.2 Structure-borne sound bypass

In general, the structure-borne sound bypass is the most severe. Flanking transmission along the duct walls may be reduced

— by using duct wall materials with high internal losses, such as sandwich structures, or

— by subdividing the test ducts into sections with elastic layers at the joints between the sections.

C.1.3 Airborne sound bypass (I)

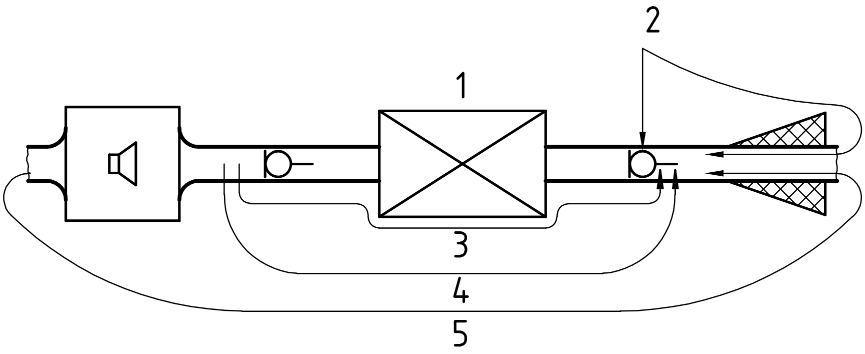
The airborne sound bypass (I) through the duct walls and the test room can be avoided by heavy duct walls and/or double-layer wall constructions with a sound insertion loss of at least 30 dB. Acoustic leaks should be avoided by effective sealing of even the smallest opening(s).

C.1.4 Airborne sound bypass (II)

The airborne sound bypass (II) through the duct openings can be reduced

— by placing the opposite duct openings in different rooms, and/or

— by terminating the ducts with silencers or with highly absorptive anechoic terminations.



Key

1 test object

2 environmental sound

3 structure-borne sound bypass

4 airborne sound bypass (I)

5 airborne sound bypass (II)

Figure C.1 — Bypass transmission in test arrangements for test object in-duct measurements

C.2 Arrangements for determining the limiting insertion loss

C.2.1 Two alternative methods for determining the limiting insertion loss are given under C.2.2 and C.2.3 (see Figure C.2).

C.2.2 The test ducts shall be blocked by a highly insulating wall, for example, a double-layer concrete wall tightly sealed to the duct walls at the positions where the test object is to be placed. A good acoustical absorption layer should be placed on this insulating wall facing the sound source.

NOTE Without this absorption layer, standing waves will be set up and the limiting insertion loss measured will be erroneous.

The measurement procedure for the limiting insertion loss shall be the same as the corresponding procedure for the determination of an insertion loss of a test object (see 6.1).

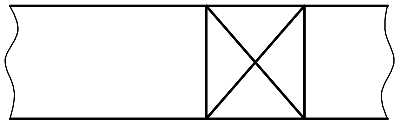
C.2.3 The test object shall be mounted in place and the test ducts shall be closed using chipboard or plasterboard panels to give an airtight seal.

Measure the insertion loss of the arrangement using the same procedure according to 6.2 as for the test object alone.

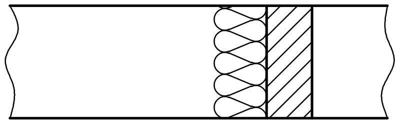
If the addition of the panel increases the measured insertion loss by at least 10 dB, then the insertion loss measured for the test object alone is not affected by flanking sound transmission.

NOTE In this case the limiting insertion loss of the test arrangement could be higher than the measured insertion loss with the panels added. The limiting insertion loss is found by adding more and more panels until no further increase in the measured insertion loss can be achieved.

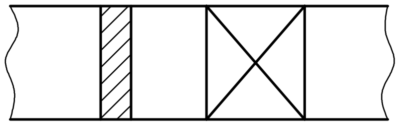
If the increase in measured insertion loss due to the addition of the panels is less than 10 dB, add more panels until no further increase in the measured insertion loss can be achieved, i.e. until the limiting insertion loss of the test rig has been reached.



a) Test object



b) According to C.2.2



c) According to C.2.3

Figure C.2 — Arrangements for determining the limiting insertion loss

Annex D
(normative)

Conversion of one-third-octave-band attenuation values to octave-band attenuation values

According to this International Standard, the attenuation is measured in one-third-octave bands. The conversion to octave-band values shall be carried out using the following formula:

$$D_{1/1} = -10 \lg \left(\frac{1}{3} \sum_{k=1}^{3} 10^{-0,1 D_{1/3,k}} \right) \text{dB} \tag{D.1}$$

where

$D_{1/1}$ is the attenuation value, in decibels, for the full octave band in question;

$D_{1/3,1}$ to $D_{1/3,3}$ are the attenuation values, in decibels, for the three one-third-octave bands constituting the octave band in question.

Declaring attenuation values in octave bands will suffice for broadband noise and for silencers with broadband effect. For tonal noise and for resonator silencers with narrow-band effect, it is recommended that attenuation values be given in one-third-octave bands.

NOTE Octave-band attenuation data may strongly depend upon the spectrum of the sound (see ISO 14163:1998, Annex B).

Annex E
(normative)

Measurements on large parallel-baffle silencers

Baffle-type silencers may have dimensions that are too large or that vary too much from one silencer to the next to be tested as complete units in any test facility in accordance with this International Standard. In this case, a model of the silencer, having a reduced width and height, shall be tested. The baffles of this model shall be inserted into a substitution duct. This substitution duct may have any appropriate height larger than the thickness of the baffles under test.

NOTE 1 Common standard heights of test baffles are 500 mm and 600 mm.

The model silencer shall have the same specifications (baffle type, length and widths, airway widths; see also Note 2) as the type of silencer to be tested, i.e. it shall be a cutout of the type of silencer to be tested. Examples of permissible cutouts are given in Figure E.1.

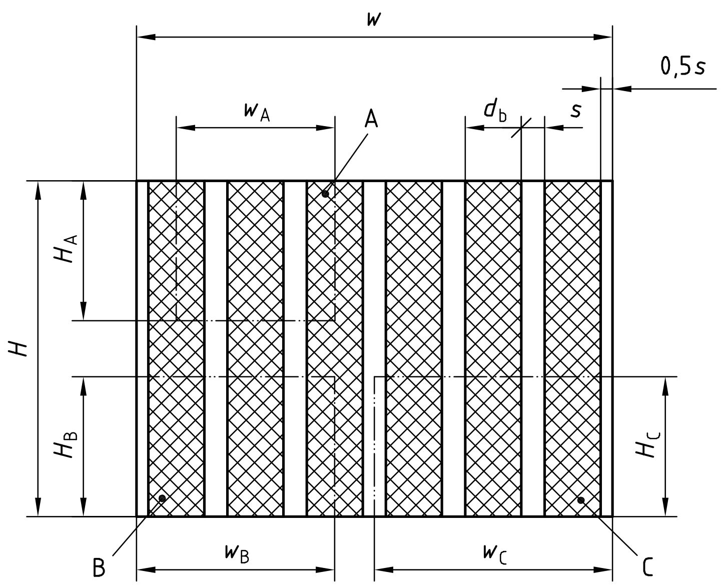


Figure E.1 — Schematic representation of the actual silencer used as an example showing three possible cutouts

The following minimum requirements shall be fulfilled:

— the type of baffle (symmetrical or not),

— the baffle length, and

— the airway width(s) (full and half, see Note 2)

shall be the same as in the actual silencer.

The baffles shall be tightly fitted between the top and bottom walls of the test duct section.

NOTE 2 Generally, the outermost airways (or baffles, respectively) of a silencer are half as wide as the inner airways (or baffles), as the duct walls reflect sound geometrically.

NOTE 3 It is common practice to use elastic fillers between the top of the baffle and the (usually removable) top wall of the test duct section.

The model silencer may contain the following elements.

a) For a silencer containing symmetrical baffles:

— full-width baffles between two full-width airways (as in cutouts A, B and C of the example below);

— full-width baffles with a half-width airway on the side facing the duct wall and a full width airway on the other side (as in cutouts B and C of the example below);

— half-width baffles mounted tightly against the test duct wall (as in cutout B of the example below).

For aerodynamic reasons, full-width baffles are preferable.

NOTE 4 Of the examples given, only C would be permissible for a silencer with unsymmetrical baffles.

b) For a silencer containing unsymmetrical baffles, half-width baffles shall not be used.

The insertion loss of the model measured in accordance with this procedure represents that of actual silencers having different heights and widths, but with otherwise identical specifications.

The sound power level of the flow noise (or regenerated sound) of the actual silencer can be calculated from that measured using the model:

$$L_{W,\text{flow,sil}} = L_{W,\text{flow,test}} + 10 \lg \left(S_{\text{sil}} / S_{\text{test}} \right) \text{ dB} \quad \text{(E.1)}$$

where

$L_{W,\text{flow,sil}}$ is the sound power level of the flow noise to be expected for the actual silencer, in decibels (dB);

$L_{W,\text{flow,test}}$ is the sound power level of the flow noise measured with the model, in decibels (dB);

S_{sil} is cross section of the actual silencer, in square metres (m^2);

S_{test} is cross section of the model, in square metres (m^2).

No correction shall be applied to the pressure loss coefficient of the model.

EXAMPLE

Cutouts from a silencer with identical baffles.

Width w: 1 700 mm

Height H: 1 200 mm

Baffle thickness t_b: 200 mm

Airway width s: 83 mm

In the example, shown in Figure E.1, the dimensions of the cutouts are:

A: 567 mm × 500 mm

B: 708 mm × 500 mm

C: 850 mm × 500 mm

$H_A = H_B = H_C$ = 500 mm

w_A = 567 mm

w_B = 708 mm

w_C = 850 mm

Annex F
(normative)

Test of longitudinal attenuation

The longitudinal attenuation of a duct of constant cross section and uniform longitudinal design is determined by means of a microphone moved along the duct axis. The decrease in sound pressure level per unit length that occurs in the mid-section of the duct is the propagation loss, D_a. The longitudinal attenuation of the fundamental mode in the frequency bands of interest is determined from the product $D_a l_m$, where l_m is the length of the absorbent lining.

Annex G
(informative)

Anechoic terminations

G.1 Guidelines for the design and construction of an anechoic termination

G.1.1 The primary feature of an anechoic termination is a sufficiently gradual change in duct area to suppress the reflection of the sound waves back into the duct where they would interfere with the sound level measurements. The criterion for this is specified in 5.2.4.3 in terms of a maximum permissible pressure reflection coefficient. A procedure for determining whether a given termination meets the requirements of 5.2.4.3 is described in G.2.

G.1.2 A number of different designs meeting the requirements of 5.2.4.3 have been described in ISO 5136 and references [14], [23], [18], and [21].

G.1.3 A variety of designs that have been successfully used are shown in detail in ISO 5136. In these designs the gradual change in the cross-sectional area of the duct approximates an exponential or a catenoidal horn. The latter gives a slightly better performance than an exponential horn. As in most successful anechoic terminations, part of the horn is filled with absorptive material to provide attenuation for the noise of devices mounted downstream of the horn. Details of the performance of these horns and the effect of various design alternatives are given in references [23] and [18].

It is not necessary to adhere exactly to the exponential or catenoidal profile. Approximation to these profiles by exponential or conical sections, and stepped anechoic terminations as shown in Figure G.1, are adequate.

G.1.4 Since the inlet of the anechoic terminations and the outlet of the duct form a smooth transition, the internal diameters are equal at the point of connection, as shown in Figure G.1. Some of the anechoic termination dimensions are given in terms of the internal diameter, d, of the test duct.

However, scaling to diameters other than those tested should only be done to a limited degree, because the ratio of wavelength to dimensions will be changed.

The outer skin of the termination may be made of any material having sufficient strength to retain its dimensional characteristics.

In the anechoic termination shown in Figure G.1, the aerodynamic passage through the centre of the horn is defined by perforated metal having about 35 % open area. The volume between the perforated metal and the cylindrical sections of the horn is filled with porous sound-absorbing material (e.g. expanded polyurethane foam with a density of approximately 32 kg/m^3).

G.2 Evaluation of performance

G.2.1 This clause gives an example of the determination of the pressure reflection coefficient. The pressure reflection coefficient, r, is calculated from a measurement of the difference ΔL between the maximum and the minimum sound pressure levels occurring in the duct as a result of the standing wave formed by the incident and the reflected plane waves at each centre frequencies of the frequency bands using Equation (B.1).

G.2.2 It is recommended that the pressure reflection coefficient be measured from 50 Hz to the cut-on frequency, f_C, of the first cross-mode, which is given by Equations (4) and (5).

NOTE Only at frequencies lower than f_C can one be sure that only plane waves exist in the duct.

G.2.3 A procedure for evaluating the anechoic termination performance is given in G.2.3.1 to G.2.3.7.

G.2.3.1 After connecting the test duct to the anechoic termination, mount a high-quality loudspeaker in a baffle, which covers the inlet of the test duct.

G.2.3.2 Make provision for moving a microphone along the full length of the centreline of the measurement duct.

G.2.3.3 Apply a pure-tone signal from an audio oscillator to the loudspeaker, via an amplifier if necessary, for the centre frequency of the one-third-octave band.

G.2.3.4 Filter the microphone signal through a narrow-band or a one-third-octave-band analyser and record the filtered signal using a graphic level recorder.

If a graphic level recorder is not available, manual recording of the maximum and the minimum sound pressure levels is permitted.

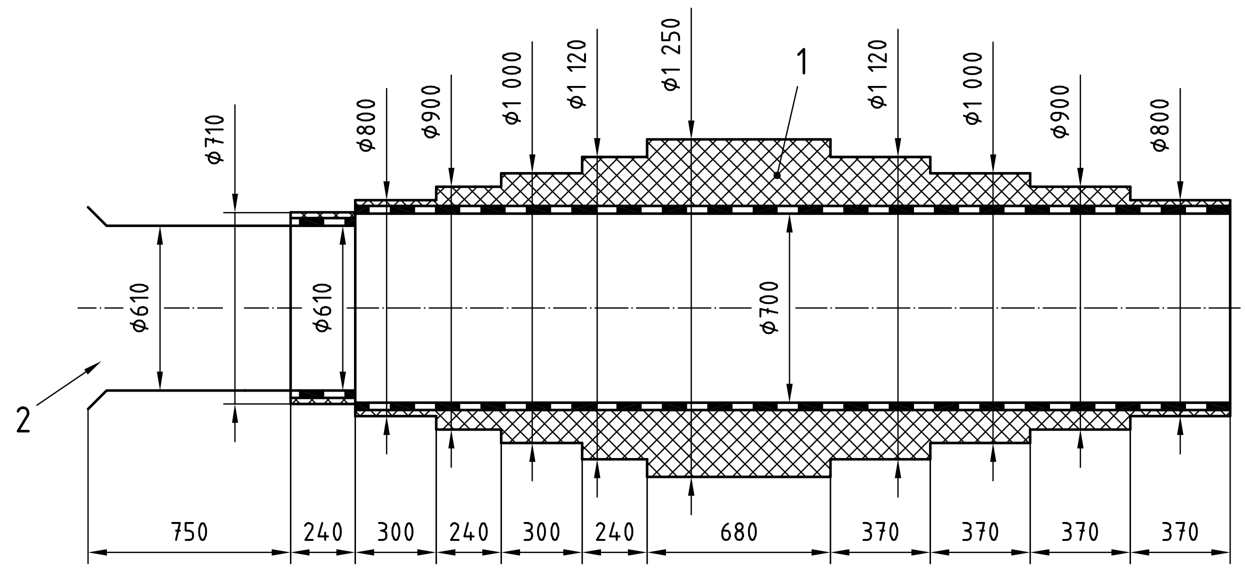
G.2.3.5 Move the microphone along the axis of the measurement duct and determine the difference between the maximum and the minimum sound pressure levels from the output of the graphic level recorder.

G.2.3.6 Take the difference between the maximum and the minimum sound pressure levels (ΔL) and insert it into Equation (B.1). Compare the reflection coefficient r obtained with the values given in 5.2.4.3.

G.2.3.7 Repeat steps G.2.3.3 to G.2.3.5 for the centre frequencies of the one-third-octave bands between 50 Hz and f_C.

G.2.3.8 If the anechoic termination is fitted with a means of flow rate control, repeat step G.2.3.7 with the throttle set to give the maximum flow rate and then to give the minimum flow rate.

Dimensions in millimetres



Key

1 porous sound-absorbing material

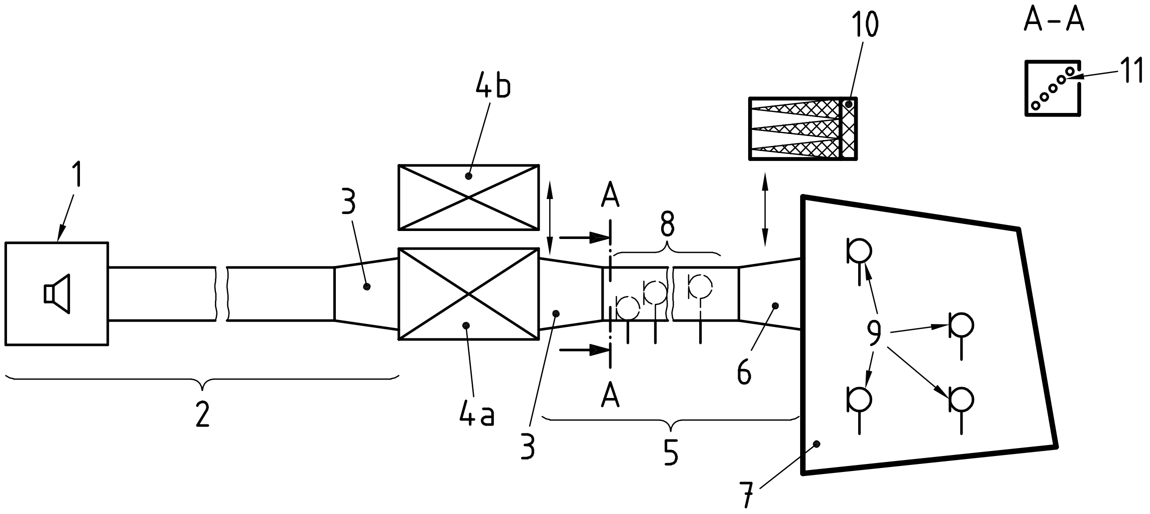
2 flow measurement device

Figure G.1 — Example of an anechoic termination

Annex H
(informative)

Examples of measurement arrangements

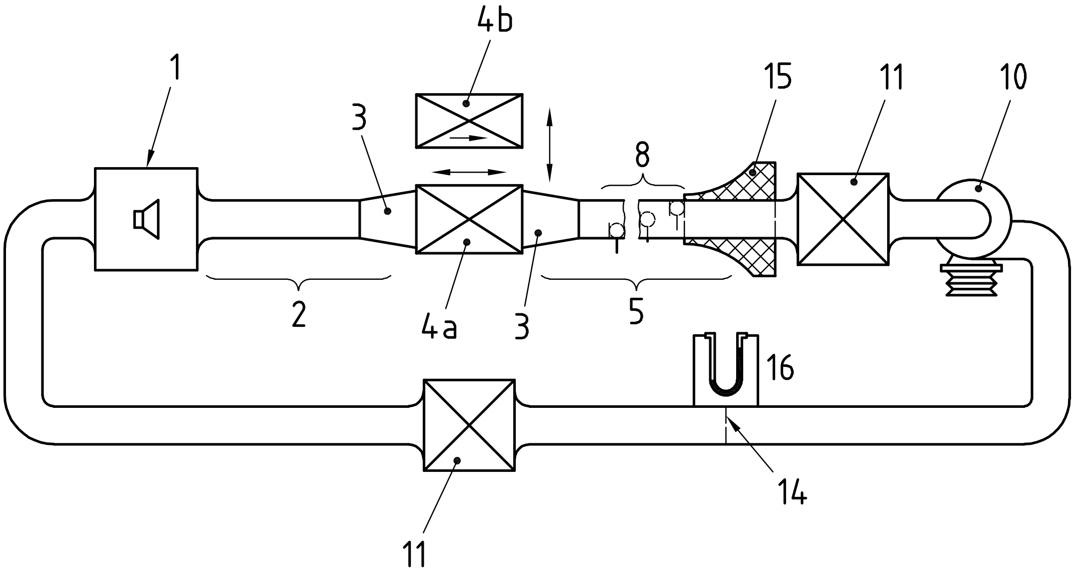
Examples are given in Figures H.1 and H.2.



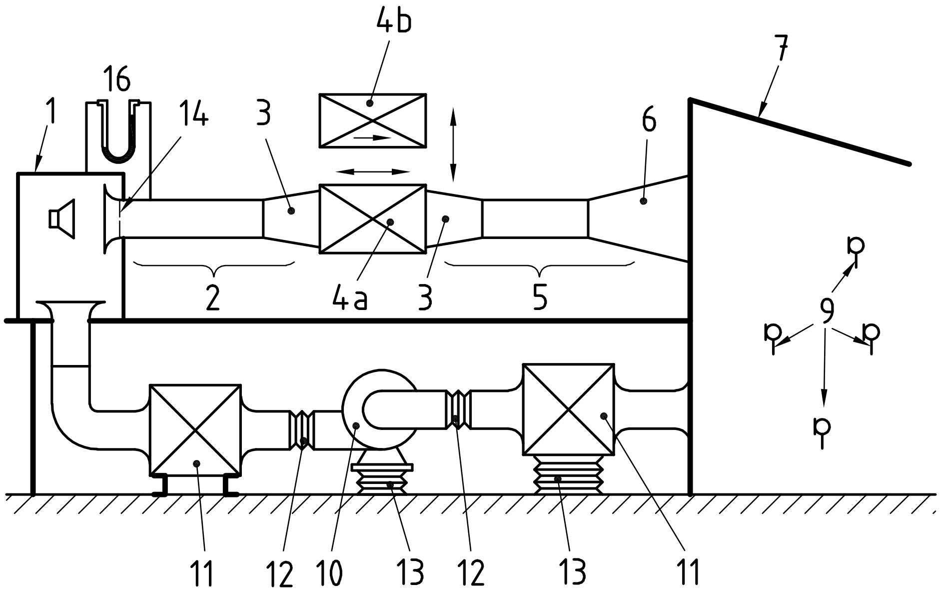
Key

1 loudspeaker unit
2 test duct in front of the test object
3 transitions
4a test object
4b substitution duct
5 test duct behind the test object
6 transmission element (together with 7 as an alternative to 10)
7 reverberation room (together with 6 as an alternative to 10)
8 microphone positions behind the test object (as alternatives to 9)
9 microphone positions in the reverberation room (as alternatives to 8)
10 anechoic termination (as an alternative to 6 and 7)
11 microphone positions

Figure H.1 — Examples of arrangements of the test facility for measurements of insertion loss without airflow



a) Arrangement for in-duct measurements



b) Arrangement when using a reverberation room

Key

1 loudspeaker unit in the source chamber
2 test duct in front of the test object
3 transitions
4a test object
4b substitution duct
5 test duct behind the test object
6 transmission element, also used as flow diffuser
7 reverberation room
8 wind-shielded microphones (as alternative to 9)
9 microphone positions in the reverberation room (as alternative to 8)
10 fan (installed to generate either forward or reverse flow relative to the direction of sound propagation,
11 fan silencers
12 flexible duct sections
13 vibration isolation
14 nozzle for measurement of flow rate (alternatives: orifice or Venturi nozzle)
15 anechoic termination
16 static pressure measurement

Figure H.2 — Examples of arrangements of the test facility for measurements of insertion loss with airflow and/or flow noise

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