INTERNATIONAL STANDARD

ISO 14163

First edition
1998-10-15

Acoustics — Guidelines for noise control by silencers

Acoustique — Lignes directrices pour la réduction du bruit au moyen de silencieux

ISO 14163:1998(E)

Contents

International Organization for Standardization
Case postale 56 • CH-1211 Genève 20 • Switzerland
Internet iso@iso.ch

Printed in Switzerland

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 3.

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

International Standard ISO 14163 was prepared by Technical Committee ISO/TC 43, *Acoustics*, Subcommittee SC 1, *Noise*.

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

Introduction

Whenever airborne sound cannot be controlled at the source, silencers provide a powerful means of sound reduction in the propagation path. Silencers have numerous applications and different designs based on various combinations of absorption and reflection of sound, as well as on reaction on the sound source. This International Standard offers a systematic description of principles, performance data and applications of silencers.

Acoustics — Guidelines for noise control by silencers

1 Scope

This International Standard deals with the practical selection of silencers for noise control in gaseous media. It specifies the acoustical and operational requirements which are to be agreed upon between the supplier or manufacturer and the user of a silencer. The basic principles of operation are described in this International Standard, but it is not a silencer design guide.

The silencers described are suitable, among others,

— for attenuating system noise and preventing crosstalk in heating, ventilation and air-conditioning (HVAC) equipment;

— for preventing or reducing sound transmission through ventilation openings from rooms with high inside sound levels;

— for attenuating blow-off noise generated by high-pressure lines;

— for attenuating intake and exhaust noise generated by internal combustion engines; and

— for attenuating intake and outlet noise from fans, compressors and turbines.

They are classified according to their types, performance characteristics and applications. Active and adaptive passive noise-control systems are not covered in detail in this International Standard.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 3741, *Acoustics — Determination of sound power levels of noise sources using sound pressures — Precision methods for reverberation rooms.*

ISO 3744, *Acoustics — Determination of sound power levels of noise sources — Engineering methods for free-field conditions over a reflecting plane.*

ISO 7235, *Acoustics — Measurement procedures for ducted silencers — Insertion loss, flow noise and total pressure loss*.

ISO 11691, *Acoustics — Measurement of insertion loss of ducted silencers without flow — Laboratory survey method.*

ISO 11820, *Acoustics — Testing of silencers in situ.*

3 Terms and definitions

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

3.1
silencer
device reducing sound transmission through a duct, a pipe or an opening without preventing the transport of the medium

3.2
dissipative silencer
absorptive silencer
silencer providing for broad-band sound attenuation with relatively little pressure loss by partially converting sound energy to heat through friction in porous or fibrous duct linings

3.3
reactive silencer
general term for reflective and resonator silencers where the majority of the attenuation does not involve sound energy dissipation

3.4
reflective silencer
silencer providing for single or multiple reflections of sound by changes in the cross-section of the duct, duct linings with resonators, or branchings to duct sections with different lengths

3.5
resonator silencer
silencer providing for sound attenuation at weakly damped resonances of elements

NOTE The elements may or may not contain absorbent material.

3.6
blow-off silencer
silencer used in steam blow-off and pressure release lines throttling the gas flow by a considerable pressure loss in porous material and providing sound attenuation by lowering the flow velocity at the exit and reacting on the source of the sound (such as a valve)

3.7
active silencer
silencer providing for the reduction of sound through interference effects by means of sound generated by controlled auxiliary sound sources

NOTE Mostly low-order modes of sound in ducts are affected.

3.8
adaptive passive silencer
silencer with passive sound-attenuating elements dynamically tuned to the sound field

3.9
insertion loss,
D_i
difference between the levels of the sound powers propagating through a duct or an opening with and without the silencer

NOTE 1 The insertion loss is expressed in decibels, dB.

NOTE 2 Adapted from ISO 7235.

3.10
insertion sound pressure level difference

D_{ip}

difference between the sound pressure levels occurring at an immission point, without a significant level of extraneous sound, without and with the silencer installed

NOTE 1 The insertion sound pressure level difference is expressed in decibels, dB.

NOTE 2 Adapted from ISO 11820.

3.11
transmission loss

D_t

difference between the levels of the sound powers incident on and transmitted through the silencer

NOTE 1 The transmission loss is expressed in decibels, dB.

NOTE 2 For standard test laboratories D equals D_i, whereas results for D_t and D_i obtained from *in situ* measurements may often differ due to limited measurement possibilities.

NOTE 3 Adapted from ISO 11820.

3.12
discontinuity attenuation

D_s

that portion of the insertion loss of a silencer or silencer section due to discontinuities

NOTE The discontinuity attenuation is expressed in decibels, dB.

3.13
propagation loss

D_a

decrease in sound pressure level per unit length which occurs in the midsection of a silencer with constant cross-section and uniform longitudinal design, characterizing the longitudinal attenuation of the fundamental mode

NOTE The propagation loss is expressed in decibels per metre, dB/m.

3.14
outlet reflection loss

D_m

difference between the levels of the sound power incident on and transmitted through the open end of a duct

NOTE The outlet reflection loss is expressed in decibels, dB.

3.15
modes

spatial distributions (or transverse standing wave patterns) of the sound field in a duct that occur independently from one another and suffer a different attenuation

NOTE The fundamental mode is least attenuated. In narrow and in lined ducts, higher-order modes suffer substantially higher attenuation.

3.16
cut-on frequency

lower frequency limit for propagation of a higher-order mode in a hard-walled duct

NOTE 1 The cut-on frequency is expressed in hertz, Hz.

NOTE 2 In a duct of circular cross-section, the cut-on frequency for the first higher-order mode is $f_{cC} = 0{,}57c/C$ where c is the speed of sound and C is the duct diameter. In a rectangular duct with larger dimension H, $f_{cH} = 0{,}5c/H$.

3.17
pressure loss
Δp_t
difference between the mean total pressures upstream and downstream of the silencer

NOTE 1 The pressure loss is expressed in pascals, Pa.

NOTE 2 Adapted from ISO 7235.

3.18
regenerated sound
flow noise
flow noise caused by the flow conditions in the silencer.

NOTE Sound power levels of regenerated sound and pressure losses measured in laboratory tests are related to a laterally uniform flow distribution at the inlet of the silencer. If this uniform flow distribution is not attainable under *in situ* conditions, for example because of the upstream duct design, higher levels of regenerated sound and higher pressure losses will occur.

4 Specification, selection and design considerations

4.1 Requirements to be specified

4.1.1 In general, the sound pressure level (A-weighted, one-third-octave or full-octave) shall not exceed a specified value at a specified position (e.g. at a work station, in the neighbourhood, or in a recreation room). The permissible contribution from a sound source can then be determined in terms of the sound power level and the directivity index of that source using sound propagation laws and requirements concerning the allocation of contributions to several partial sound sources. The required insertion loss of the silencer is given by the difference between the permissible and the actual sound power level of the source.

In simple cases where the sound immission is determined solely by the sound source to be attenuated, the necessary insertion sound pressure level difference of the silencer can be calculated directly from the difference between the permissible and the actual sound pressure level at the immission point. When the difference in directivity indices with and without the silencer is negligible, the insertion sound pressure level difference equals the insertion loss of the silencer.

4.1.2 The permissible pressure loss shall not be exceeded.

NOTE This requirement should be specified as clearly as possible. Instead of the imprecise specification "as small as possible", a sensible limit value has to be found. Even if the pressure loss is considered as "not critical", a limit value should be determined from the maximum permissible flow velocity that may not be exceeded for reasons of mechanical stability, regenerated sound or energy consumption costs.

4.1.3 The permissible size of the silencer shall be kept as small as possible (for reasons of cost and weight).

NOTE There is a minimum size which (given the state of the art) cannot be reduced. This size depends on the required reduction in sound level, the permissible pressure loss and on other restrictions concerning materials to be used (or avoided), resistance to different kinds of stress, etc.

4.1.4 Additional requirements (concerning materials, durability, leakages, etc.) result from the application of the silencer in hot, dusty, humid or aggressive gases, in pressure lines or for high sound pressure levels and vibration levels, and from the combination of silencers with devices for the control of exhaust gas, sparks and particles.

4.2 Selection and layout of silencers

Specific information on silencers can be drawn from

— laboratory measurements made in accordance with ISO 7235;

— silencer manufacturers' test data;

— theoretical models to calculate propagation loss and insertion loss for silencers with circular or rectangular cross-section;

— pressure loss and regenerated sound prediction methods.

The selection of a dissipative, a reactive or a blow-off silencer will be determined by its application or by reference to the experience presented in this International Standard.

Results obtained from computer programs for the insertion loss of dissipative silencers depend on the assumptions made concerning the magnitude and distribution of airflow resistance in the silencer and the acoustical effect of the cover [18]. Certain geometrical features like off-setting of splitters or subdividing of absorbers are not easily accessible for calculation. Calculations are most accurate for parameter variations concerning design as well as operating conditions. Effects of flow on the performance of reactive silencers are taken into account by special highly sophisticated computer software.

4.3 Design of special silencers

5 Types of silencers, general principles and operational considerations

5.1 Overview

Silencers are used to

— prevent pulsations and oscillations of the gas at the source,

— reduce conversion of the pulsations and oscillations into sound energy, and

— provide conversion of sound energy into heat.

Table 1 — Typical advantages and shortcomings of different types of silencers

Type of silencer	Advantages	Shortcomings
Dissipative silencer	Broad-band attenuation, little pressure loss	Sensitive to contamination and mechanical destruction
Reactive silencers:		
Resonator type	Tuned attenuation, insensitive to contamination	Narrow-band attenuation, sensitive to flow
Reflective type	Robust element, application for large pressure pulsations, high sound levels, contaminated flow, strong mechanical vibrations	Greater pressure loss, acoustic pass bands (frequency bands with little or no attenuation), flow sensitivity of acoustical performance

The design of a special silencer is usually an iterative process featuring the following stages:

a) rough specification of the dimensions of free ducts for the flow and of connected spaces for the distribution of sound, for example using the manufacturers' declarations for similar silencers and taking into account the essential requirements and restrictions;

The resulting insertion loss for a silencer mounted in a duct will in general depend on all three of these mechanisms. According to the dominant attenuation mechanisms involved, silencers may be classified as (see table 1):

- dissipative silencers,
- reactive silencers, including resonator and reflective silencers,
- blow-off silencers, and
- active silencers.

5.1.1 Dissipative silencers

These provide broad-band sound attenuation by conversion of sound energy into heat with relatively little pressure loss. Precautions shall be taken to prevent coating or clogging of the surface of the absorbent material when dissipative silencers are used in ducts carrying gases contaminated with dust or encrusting material. Porous absorbers made of fine fibrous material or thin-walled structures may be mechanically destroyed by high amplitudes of alternating pressure.

5.1.2 Resonator silencers (reactive)

These reduce the conversion of gas pulsations and oscillations into sound energy and absorb sound. Single resonators are mounted as side branches in duct walls. Groups of resonators are used as duct linings or splitter elements (baffles) in ducts, thus causing a limited pressure drop. Resonances are mostly tuned to low and intermediate frequencies, where attenuation is needed. The performance is limited to a narrow frequency band, is sensitive to grazing flow and may (under certain unfavourable conditions) be negative so that a tone is generated.

5.1.3 Reflective silencers (reactive)

These reduce the conversion of gas pulsations and oscillations into sound energy. They are usually chosen for their robustness in applications where purely dissipative silencers are less suitable, and where greater pressure loss is permissible. This is the case, for example, with gas flows carrying dust, or with higher flow velocities and pressure pulsations, and for applications with strong mechanical vibrations. The maximum attenuation and the frequency where it occurs will be affected by the flow. It is possible that in some frequency bands only little or even negative attenuation is encountered.

5.1.4 Blow-off silencers

These are mounted on steam and pressurized air release lines and are effective by reaction on the source of sound, such as a valve, and by lowering the exit flow velocity through an expanded surface area while conversion of sound into heat is usually of little significance. Large pressure losses require the silencer to have a good mechanical stability. Its performance can be affected by material carried by the gas. There is also a danger of icing.

5.1.5 Active silencers

These mainly consist of speaker sets driven by amplifiers with input from suitable microphones. Control is effected by a high-performance computer, the controller. These are specialist devices not dealt with in this International Standard. Active silencers are most effective at low frequencies where passive dissipative silencers offer little attenuation [32].

NOTE Active systems are presently offered exclusively as individual solutions tailored for particular applications and are thus not discussed in this International Standard.

5.2 Acoustic and aerodynamic performance of silencers

The attenuation required from a silencer is described in terms of the insertion loss, D_i, if no particular immission point is defined, or in terms of the insertion sound pressure level difference, D_{i_p}, at a particular position. It is specified in one-third-octave bands or full-octave bands. According to the laboratory standard ISO 7235, the attenuation shall be measured in one-third-octave bands. Full-octave-band values may be calculated using equation (1):

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

where $D_{1/3,1}$ to $D_{1/3,3}$ are the attenuation values in the three one-third octaves of a full-octave band, in decibels, and $D_{1/1}$ is the resulting full-octave-band value. Declaring attenuation values in full octaves will suffice for broad-band noise and for silencers with broad-band effect. For tonal noise and for resonator silencers with narrow band effect, the attenuation data should be given in one-third-octave bands.

NOTE 1 Octave-band attenuation data may strongly depend upon the spectrum of the sound (see annex B).

A necessary parameter for the selection of a silencer is the permissible pressure loss in the flow. It shall not exceed the total pressure loss Δp_t which depends on the mean flow velocity and density of the gas and on the flow condition as described by equation (2):

$$\Delta p_t = (\zeta + \Delta\zeta)\frac{\rho}{2} v_1^2 \tag{2}$$

where

ζ is the total pressure loss coefficient as defined in ISO 7235 for uniform flow conditions at both ends of the silencer;

$\Delta\zeta$ is the additional pressure loss coefficient due to flow conditions *in situ* deviating from the laboratory conditions (values are to be estimated empirically);

ρ is the density of the gas, in kilograms per cubic metre, kg/m^3;

v_1 is the mean flow velocity in the inlet cross-section, in metres per second, m/s.

NOTE 2 It is common for definitions of the total pressure loss coefficient to differ from the one given in ISO 7235. It is therefore necessary to check the definitions before using any values. For example, a different definition is the one considering the flow velocity in the narrowest cross-section of the silencer instead of v_1. This will result in much lower values for ζ.

Other parameters to be considered which affect the acoustic and aerodynamic performance are

— the regenerated sound,

— the maximum dimensions available for the silencer, and

— the necessary durability of the silencer under exposure to flow, pressure pulsations and mechanical vibration.

5.3 Sound propagation paths

It is possible for sound propagating from a source to an immission point to follow several paths beside the direct one through the silencer (Figure 1, path 1). The additional paths are:

a) radiation from the housing of the source (path 2);

b) radiation from duct walls before the silencer (path 3);

c) radiation from the shell of the silencer (path 4); and

d) propagation of structure-borne sound along and past the silencer (path 5).

Sound propagation along these flanking paths shall be prevented by providing housings and duct walls with sufficient sound insulation and by inserting vibration isolation devices for interrupting the propagation path for structure-borne sound.

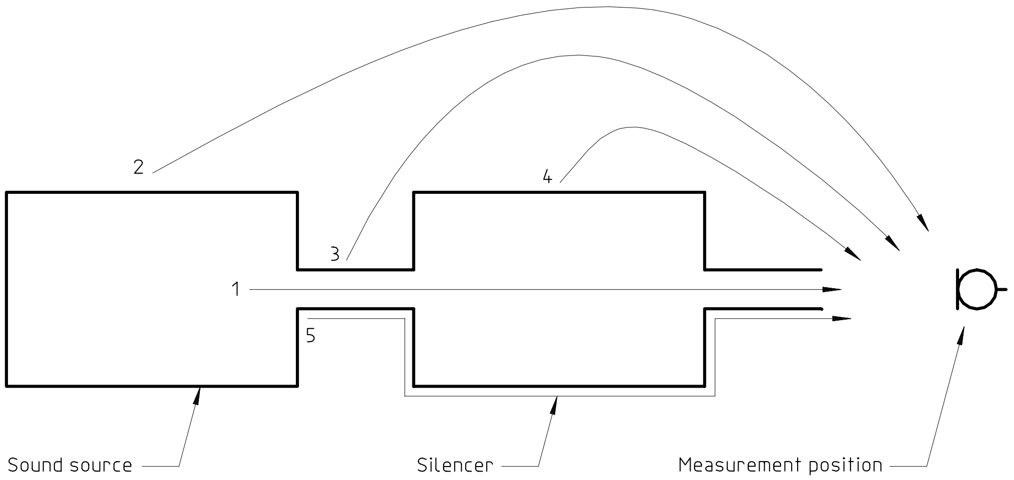

Figure 1 — Sound propagation paths (schematic)

5.4 Acoustic installation effect

For certain applications and silencer types, the sound attenuation provided by a silencer depends on the characteristics of the source connected to the inlet side and the characteristics of the termination connected to the outlet side. Such an installation effect occurs especially on reactive silencers or on all types of silencers for low frequencies.

It is also important that either the source or the termination is reactive, i.e. non-absorbing. When these conditions are fulfilled, unfavourable resonance effects can be expected in the system that will lead to strong coupling between different parts of the system. Formally, this type of installation effect can be described via equation (3):

$$L_W(\text{rad}) = L_W(\text{source}) - D - D + E \quad (3)$$

where

L_W(rad) is the level of sound power radiated from duct end, in decibels, dB,

L_W(source) is the level of sound power radiated from source into duct with anechoic termination, in decibels, dB;

D_t is the transmission loss (see 3.11), in decibels, dB;

D_m is the reflection loss at the duct outlet (see 3.14 and 6.2.2.), in decibels, dB;

E is the acoustic installation effect, in decibels, dB; in dissipative systems; the magnitude of E generally does not exceed 10 dB.

The reaction of reflected sound on the source described by E can result in an increase or a decrease of sound emission.

NOTE For strongly reactive systems, E can be a large positive quantity in narrow frequency bands, which implies that the silencer system actually amplifies the sound power radiated from the source.

5.5 Abrasion resistance and protection of absorbent surfaces

Abrasion of the materials used in dissipative silencers may lead to particles of the infill being carried in the gas flow.

NOTE Little is known about the particle number concentration in the gas stream for longer operation of silencers.

If the surface of a sound-absorbent material is mechanically damaged, low flow velocities will suffice to carry away large numbers of particles through erosion. This process may even result in the depletion of a whole absorbent element (such as a splitter).

To protect the sound-absorbing infill of silencers against moisture, water or pollutants carried in the gas (in particular in hospitals and in the food processing industry), foils are used for airtight sealing. Such foils not only reduce the attenuation performance at high frequencies (typically above 1 kHz) but may also rupture during plant operation. A difference in total (i.e. static and dynamic) pressures inside and outside the sealed element causes stress in the foil. High temperatures and impacting sharp (and hot) particles increase the risk of damage. Thus, the protection of sound-absorbing infill by means of foil needs careful consideration of foil thickness, temperatures, flow velocities and contamination of the gas.

5.6 Fire hazards and protection against explosion

There is a particular danger of fire being started or transmitted by ventilation silencers for technical equipment if oil aerosols are carried. This applies particularly to chemical laboratories, large kitchens and engine-testing installations. Organic substances like flour or milk powder may form explosive mixtures with air, and this shall be taken into account where dust-carrying gases flow through the silencer.

In all these applications, and in accordance with many building codes, "non-combustible" materials shall be used for the silencer. Collections of grease, oil or dust in the absorbent material shall be prevented by using appropriate shapes and arrangements of silencers. Resonator silencers without absorbent material and with precautions against dust deposit are also suitable to meet fire- and explosion-protection requirements.

5.7 Starting-up and closing-down of plants

Silencers in technical plants may cause problems when the plant is started up or closed down. Sufficient space shall be provided for the expansion of components of the silencer to allow for considerable changes in pressure and/or temperature. Particularly in the case of pressure variations and for foil covers, pressure relief shall be possible in the absorbent lining.

In the starting-up and closing-down phases of plants, there are frequently temperatures below the dew point, especially inside the absorbent linings and on the inside of the silencer housing. Collection of moisture should be prevented (for instance by "dry-running" the plant); particular corrosion problems may arise. Condensed liquid should be allowed to drain.

5.8 Corrosion

Sheet metal shells, covers and partitions of silencers as well as mounting flanges shall be protected from the effects of weather, acids in exhaust gases, and differences in voltage potentials of different materials. Corrosion can be prevented by selection of particular material (e.g. aluminium) or by application of protecting covers (e.g. rubber).

5.9 Hygienic requirements and risk of contamination

Special requirements shall be met, for example,

— in cleanrooms,

— in food-processing plants,

— in hospitals,