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Acoustics — Measurement procedures for ducted silencers — Insertion loss, flow noise and total pressure loss

Acoustique — Méthodes de mesurage pour silencieux en conduit — Perte d'insertion, bruit d'écoulement et perte de pression totale

Reference number
ISO 7235:1991(E)

Foreword

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

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

International Standard ISO 7235 was prepared by Technical Committee ISO/TC 43, *Acoustics*.

Annexes A, B and C form an integral part of this International Standard. Annexes D, E and F are for information only.

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Introduction

This International Standard specifies the substitution method for determining the insertion loss of ducted silencers. Another measurement method, the direct method, was also considered when preparing this International Standard, but this method is not specified here. It may form the subject of a future International Standard.

The test arrangement is designed to allow the application of either the substitution method or the direct method (method not covered by this International Standard). It is such that the measured data arise only from the silencer under test and not from elements to which the silencer is connected.

In the substitution method the sound pressure level of the transmitted wave is first determined with the silencer installed between the test ducts and then when the silencer is replaced by the substitution duct (a hard-duct element). The sound pressure level of the transmitted wave can be measured either in the test duct after the silencer or in a reverberation room connected to this test duct via a transmission element. A reverberation room is used when the flow noise of the microphone in the test duct cannot be sufficiently suppressed. In the substitution method, the determination of the sound power level of the incident wave is not necessary. The method does, however, create the problem of maintaining an unchanged sound power and pressure distribution in the incident wave when replacing the silencer by the substitution duct.

The insertion loss of a silencer is generally affected by the air flow. The insertion loss is therefore measured with superimposed air flow if the silencer is to be used in flow ducts. This measurement requires the provision of an additional air-moving device with its own silencer. The same arrangement is necessary for measuring the flow noise and pressure loss of the silencer under test.

An air flow through a silencer produces noise. This flow noise establishes the lowest sound pressure level which can be achieved after the silencer. It is, therefore, necessary to know the sound power level of the flow noise behind the silencer. This is preferably determined in a reverberation room connected to the test duct 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.

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Acoustics — Measurement procedures for ducted silencers — Insertion loss, flow noise and total pressure loss

1 Scope

This International Standard specifies the substitution method for determining the insertion loss of ducted silencers. It sets out requirements for determining

- the insertion loss, in frequency bands, of silencers with and without air flow;
- the sound power level, in frequency bands, of the flow noise generated by silencers;
- the total pressure loss of silencers with air flow.

The measurement procedures are intended for laboratory measurements on silencers but may also be used for *in situ* measurements on silencers if the requirements of this International Standard can be met.

This International Standard applies to silencers for ventilating and air-conditioning systems which are usually connected to ducts or splitter absorbers mounted in ducts. Other duct elements, such as bends or T-connectors, may also be tested using this International Standard.

This International Standard does not apply to reactive silencers used for motor vehicles.

NOTE 1 Exact information on the precision of the method cannot be given at this time. Interlaboratory tests are necessary for the determination of the reproducibility standard deviation σ_R of the method (relevant terms and methods are given in ISO 5725). The following estimates of the reproducibility standard deviation, σ_R, were determined from tests made on splitter-type silencers.

Centre frequencies of the one-third octave hand Hz	Reproducibility standard deviation, σ_R dB
50 to 1 250	3
1 600 to 10 000	2

2 Normative references

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

ISO 266:1975, *Acoustics — Preferred frequencies for measurements.*

ISO 3741:1988, *Acoustics — Determination of sound power levels of noise sources — Precision methods for broad-band sources in reverberation rooms.*

ISO 5136:1990, *Acoustics — Determination of sound power radiated into a duct by fans — In-duct method.*

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

IEC 225:1966, *Octave, half-octave and third-octave band filters intended for the analysis of sounds and vibrations.*

IEC 651:1979, *Sound level meters.*

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

3 Definitions

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

3.1 sound pressure level, L_p**, in decibels:** Ten times the logarithm to the base 10 of the ratio of the mean-square sound pressure p of a sound wave to the square of the references sound pressure, p_o:

$$L_p = 10 \lg \frac{p^2}{p_o^2}$$

The width of a restricted frequency band shall be indicated, for example, octave band pressure level, one-third octave band pressure level, etc. The reference sound pressure is $p_o = 20$ µPa.

3.2 sound power level, L_W**, in decibels:** Ten times the logarithm to the base 10 of the ratio of a given sound power, P, to the reference sound power, P_o:

$$L_W = 10 \lg \frac{P}{P_o}$$

The width of a restricted frequency band shall be indicated, for example, octave band power level, one-third octave band power level, etc. The reference sound power is $P_o = 1$ pW.

3.3 insertion loss, D**, in decibels (of a silencer):** The reduction in sound power level at a given location behind the silencer due to the insertion of the silencer into the duct in place of a hard-walled duct section

$$D = L_{W\text{II}} - L_{W\text{I}}$$

where

$L_{W\text{I}}$ is the sound power level in the frequency band considered in the test duct or in the connected reverberation room when the test silencer is installed;

$L_{W\text{II}}$ is the sound power level in the frequency band considered in the test duct or in the connected reverberation room when the test silencer is replaced by the substitution duct.

3.4 test duct: Straight, hard-walled duct of constant cross-section in front of or after the test silencer in which the sound pressure and the static pressure mesurements are performed.

3.5 in front of (behind): Indication of a position relative to the direction of the sound propagation of the sound signal to be measured corresponding to the "source side" ("receiving side") of the silencer.

3.6 total pressure loss, Δp_t **(of a silencer):** The difference between the total pressure upstream and downstream of the test silencer. The total pressure loss coefficient ζ is the total pressure loss divided by the velocity pressure upstream of the test silencer.

3.7 transition: A duct element which connects two different duct cross-sections to each other.

3.8 anechoic termination: A device intended to reduce sound reflections at the end of the test duct.

3.9 transmission element: The connection from the test duct on the receiving side of a silencer to a reverberation room. It transmits the sound energy from the duct into the room, avoiding acoustical reflections.

3.10 substitution duct: A rigid, non-absorbing duct element with no sound leakage into the test room; this duct element has the same length and the same connecting cross-section as the silencer.

3.11 reverberation room: A room specially designed to facilitate the production of approximately diffuse sound fields.

3.12 background noise: The sound pressure level at the indicating instrument when the signal to be measured is not present.

NOTE 2 The signal may be either the airborne sound pressure from the loudspeaker equipment propagating through the test duct or the flow noise generated by the silencer being tested.

The main elements in background noise are

- flow noise generated at the microphone;
- flow noise from the fan or from the duct system;
- structure-borne sound from the fan or from the loudspeaker equipment 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;
- electrical noise in the measurement equipment.

3.13 reflection coefficient, r_a**:** The ratio of the reflected sound pressure amplitude to the pressure amplitude of the sound wave incident on the reflecting object.

3.14 transmission coefficient, τ **(of the transmission element):** The ratio of the sound power transmitted into the reverberation room to the incident sound power. For transmission elements which comply with the requirements of this International Standard the transmission coefficient is determined from the reflection coefficient using the following equation:

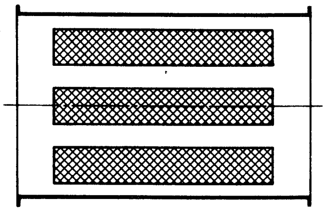
$$\tau = 1 - r_a^2$$

3.15 frequency range of interest: The one-third octave bands with centre frequencies from 50 Hz to 10 000 Hz. For certain applications, it may be sufficient to measure in the frequency range between 100 Hz and 8 000 Hz.

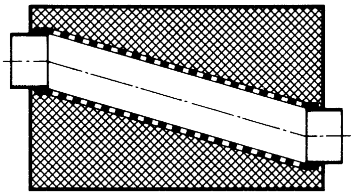
3.16 limiting insertion loss: The maximum insertion loss which can be determined in a given test installation without flow. It is generally determined by the flanking transmission along the duct walls.

3.17 test silencer: Silencer ready for installation, including its housing and its inlet and outlet openings to be connected to ducts.

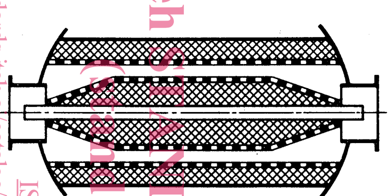
Examples are given in figure 1.



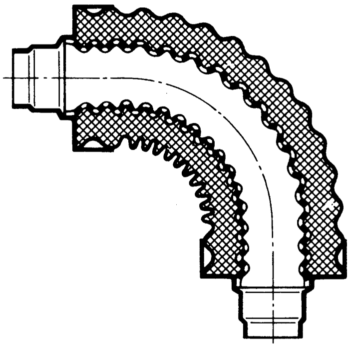
a) Splitter-type silencer



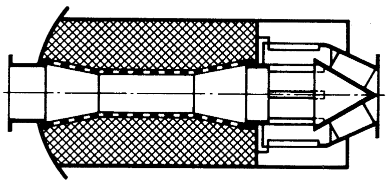
b) Off-set silencer



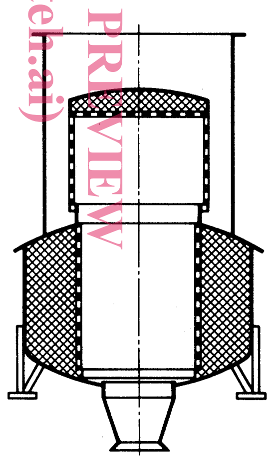
c) Silencer with centre body



d) Flexible duct silencer



e) Silencer with spark arrestor



Steam-escape silencer

Figure 1 — Examples of test silencers

4 Symbols and indices

See table 1 and table 2.

Table 1 — Symbols

Symbol	Definition	Unit	Reference
A	Total surface area of the reverberation room	m^2	6.5
b	Largest side length of the cross-section of the rectangular duct	m	
c	Velocity of sound	m/s	
d	Diameter	m	
d_e	Equivalent diameter	m	6.6.2
D	Insertion loss	dB	3.3; 6.2
f	Frequency	s^{-1}	
f_o	Cut-off frequency	s^{-1}	C.2.2; D.2.2
l	Length of the transition element or length of the measuring path	m	5.1.5
L_p	Sound pressure level	dB	3.1
L_{pi}	Sound pressure level at measuring position i	dB	6.2
$\overline{L_p}$	Average sound pressure level	dB	
$\overline{L_{pI}}$	Average sound pressure level behind the test silencer	dB	6.2
$\overline{L_{pII}}$	Average sound pressure level behind the substitution duct	dB	6.2
L_W	Sound power level	dB	3.2
L_{WI}	Level of the sound power transmitted with the test silencer between the test ducts	dB	6.2
L_{WII}	Level of the sound power transmitted with the substitution duct between the test ducts	dB	6.2
p	RMS value of the sound pressure	µPa	3.1
p_o	Reference sound pressure	µPa	3.1
P	Sound power	pW	3.2
P_o	Reference sound power	pW	3.2
p_a	Atmospheric pressure	bar	6.5
p_{ao}	Reference pressure (= 1 bar)	bar	6.5
p_d	Velocity pressure	Pa	6.6.2
p_s	Static pressure	Pa	6.6.2
p_t	Total pressure	Pa	6.6.2
p_{dn}	Velocity pressure for the middle of flow range investigated	Pa	6.6.2
Δp_{sn}	Static pressure loss of the test silencer for the middle of the flow range investigated	Pa	6.6.2
Δp_t	Total pressure loss	Pa	3.6
Δp_{tn}	Total pressure loss of the test silencer in the middle of the flow range investigated	Pa	6.6.2
q_m	Mass flow rate	kg/s	6.6.1
q_V	Volume flow rate	m^3/s	6.6.1
r_a	Reflection coefficient	—	3.14
R	Gas constant	N·m/(kg·K)	6.6.2
S	Cross-sectional area of the duct	m^2	6.6.2
t	Reverberation time of the room	s	6.5
t_o	Reference time (= 1 s)	s	6.5
V	Volume of the reverberation room	m^3	6.5

Symbol	Definition	Unit	Reference
V_o	Reference volume (= 1 m³)	m³	6.5
ϱ_n	Air density	kg/m³	6.6.2
θ_1	Air temperature at the inlet to the test silencer	°C	6.6.2
τ	Transmission coefficient	—	3.14
ζ	Total pressure loss coefficient	—	3.6; 6.6

Table 2 — Indices

Index	Meaning
o	Reference values
a	Atmospheric pressure
d	Velocity pressure
s	Static pressure
t	Total pressure
n	Values referring to the middle of the flow rate investigated
p	Sound pressure
W	Sound power
1	Upstream of the silencer
I	With the test silencer installed
II	With the substitution duct installed

5 Test facilities and instrumentation

5.1 Test facility for measuring the insertion loss without air flow

5.1.1 General

The test facility shall consist of the following items (see figure E.1):

a) sound source equipment (see 5.1.2);

b) sound measurement equipment (see 5.1.3);

c) test ducts on the source side and on the receiving side of the silencer (see 5.1.4);

d) transitions to connect test ducts and silencer of different cross-sectional areas to each other (see 5.1.5);

e) a substitution duct (see 5.1.9);

f) an anechoic termination of the test duct on the receiving side, if the sound measurements behind the test silencer are to be made in the test duct (see 5.1.6);

g) a transmission element and reverberation room on the receiving side, if the sound measurements behind the silencer are to be made in the reverberation room (see 5.1.7 and 5.1.10).

5.1.2 Sound source equipment

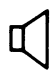
The sound source equipment shall excite a sound field with dominating plane wave mode in the test duct in front of the test silencer. The sound source equipment shall consist of a random noise generator, an amplifier and a loudspeaker unit.

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

NOTE 3 The signal-to-noise ratio may 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.

The graphical symbol for the loudspeaker unit used in the figures describing the test arrangements (see figure E.1 and figure E.2) is shown in figure 2.



NOTE — The opening of the loudspeaker is directed towards the desired direction of the sound propagation.

Figure 2 — Graphical symbol for the loudspeaker unit

5.1.3 Sound measurement equipment

The sound measurement equipment shall consist at least of the following elements:

a) a microphone;

b) a one-third octave filter;

c) a sound level meter.

The obstruction caused by the microphone in any test ducts shall not exceed 5 % of its free area. The acoustical measurement equipment shall meet at least the requirements for a type 1 instrument as specified in IEC 651 or IEC 804. The filter set shall meet the requirements of IEC 225. The band centre frequencies shall be those tabulated in ISO 266.

The measurement equipment in a connected reverberation room shall also meet the requirements of ISO 3741.

5.1.4 Test ducts

5.1.4.1 Cross-section

Test ducts shall be straight and of either rectangular or circular cross-section. It is preferable that the cross-dimensions of the ducts be the same as those of the inlet or outlet area of the silencer. However, if they differ from one another, transitions shall be used. The test duct cross-sectional area shall be between 0,7 and 2 times the inlet or outlet area of the silencer.

5.1.4.2 Duct length

Each test duct shall be at least as long as half the wavelength of the lowest centre frequency in the frequency range of interest and not less than four times the maximum duct cross-dimension. For measurements with flow, see also 6.6.2.

5.1.5 Transitions

All transitions connected to the test silencer, including transitions from rectangular to circular cross-sections, shall be straight and coaxial and shall meet the following criteria:

a) the maximum enclosed angle of the sides shall be 15°;

b) the minimum length, l_{min}, shall be given by

$$\frac{l_{min}}{l_o} = \frac{\text{larger area}}{\text{smaller area}} - 1$$

where $l_o = 1$ m.

The design of the transitions shall be reported.

5.1.6 Anechoic termination

The test duct on the receiving side for the sound measurements in the duct shall have an anechoic termination to avoid standing waves. The reflection coefficient, r_a, shall not exceed the values specified in table 3.

Table 3 — Maximum reflection coefficients for an anechoic termination

Centre frequency of the frequency band, Hz	Reflection coefficient, r_a max.
50	0,4
63	0,35
80	0,3
100	0,25
> 125	0,15

NOTE — The maximum values of the reflection coefficients of the anechoic terminations and of the transmission element are subject to specified limitations which are a compromise between the possibilities of realization and the accuracy of the final results.

Suggestions for the design of the anechoic termination are given in annex D. The reflection coefficient of the termination shall be determined by the method described in clause D.2.

5.1.7 Transmission element

If the acoustic measurements are carried out in a connected reverberation room, the transmission element transfers the sound energy from the duct into the room. Its reflection coefficient, r_a, should not exceed the maximum values specified in table 4.

Table 4 — Maximum reflection coefficients for a transmission element

Centre frequency of the frequency band, Hz	Reflection coefficient, r_a max.
50	0,8
63	0,7
80	0,6
100	0,5
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).

The transmission coefficient of the transmission element shall be determined by the method described in annex B. An example of the design of the transmission element is given in clause B.1. The transmission element may extend into the room.

5.1.8 Duct walls

The walls of the test ducts, of the transitions, of the transmission element and of the substitution duct shall be rigid and designed in such a way that the limiting insertion loss is at least 10 dB higher than the transmission loss of the silencer being tested. The limiting insertion loss shall be determined using the arrangements described either in C.2.1 or C.2.2, and the measurement procedure specified in 6.2.

5.1.9 Substitution duct

The substitution duct shall be conical if the cross-sectional areas of the entrance and exit of the silencer are different from each other. If the planes of the connections of the silencer are not parallel to each other, the connections shall be made with smooth curved ducts with a bend radius of the walls as large as possible and fulfilling the above requirements.

The geometry of the substitution duct shall be given in the test report.

NOTE 4 The substitution duct may be the housing of the test silencer, if it fulfils the above requirements.

5.1.10 Reverberation room

The reverberation room shall be qualified in accordance with ISO 3741 down to at least the 125 Hz one-third octave band. The qualification procedure shall be carried out with the outlet airway of the transmission element closed by an acoustically hard panel but with other openings of the reverberation room retained as they are used during silencer testing. Reverberation room volumes larger than 300 m^3 are permitted.

For the purposes of this International Standard, the measurements in accordance with ISO 3741 shall be extended down to the 50 Hz one-third octave band.

NOTE 5 Allowances given above are made because only level differences are determined. For the flow noise measurements, higher uncertainties are accepted in the extended low-frequency range.

5.2 Test facility for measuring the insertion loss with air flow

5.2.1 General

In addition to complying with the requirements laid down in 5.1, the test facility shall consist of the following items (see, for example, the arrangement illustrated in figure E.2):

a) a fan, to produce the air flow (see 5.2.2);

b) silencer(s), for reducing the fan noise (see 5.2.3);

c) a device for varying the flow rate (see 5.2.4);

d) a device for measuring the flow rate (see 5.2.5).

If sound measurements are to be made in the reverberation room, the test facility shall also incorporate the following items:

e) a transmission element;

f) a reverberation room.

If sound measurements are to be made in the test duct, the test facility shall also incorporate an:

g) anechoic termination [as an alternative to e) and f)].

The test facility shall be designed so that the air flow entering the test silencer has no substantial swirl.

5.2.2 Fan

The fan shall be vibration-isolated from the duct.

5.2.3 Fan silencers

Silencers shall be mounted between the test ducts and the fan or the device for varying the flow rate. They shall reduce the fan and throttle noise at every measurement position to at least 10 dB below the level of the sound pressure level generated by the sound source at each microphone position.

Silencers downstream of the fan and any throttle arrangement shall be designed to prevent any substantial swirl. A flow straightener and/or screens may be needed upstream of the sound source.

5.2.4 Device for varying the flow rate

In order to obtain low fan noise at low flow rates, the variation in the flow rate should preferably be achieved by changing the rotational speed of the fan.

5.2.5 Device for measuring the flow rate

An airtight duct as described in ISO 5221 shall be provided in such a way that no substantial swirl prevails in the flow upstream of the flow measuring device.

NOTE 6 From measurements made with this device complying with ISO 5221, the assessment of mass flow rate will be obtained so that if the air density upstream of the silencer is known either the air volume or the mean flow velocity through the inlet of the test silencer may be calculated. The device for measuring the flow rate should not interfere with the sound measurement.

5.2.6 Anechoic termination

The flow noise of the anechoic termination shall not influence the acoustic measurement. Suitable designs are described in annex D.

5.2.7 Transmission element

In addition to complying with the requirements laid down in 5.1.7, transmission elements shall not produce flow noise sufficient to disturb the sound measurement in the reverberation room.

5.2.8 Sound measurement equipment

If sound measurements are to be made in the duct, it may be necessary to suppress the air-flow-induced microphone signal (i.e. generated by turbulent pressure fluctuations) by using appropriate windscreens (for example, nose cone, foam ball or sampling tube) in order to obtain the required signal-to-noise ratio of 10 dB between the sound pressure generated by the sound source and attenuated by the test silencer and the background noise generated by turbulent flow over the microphone. The signal-to-noise ratio can be checked by switching the sound source on and off.

NOTE 7 If a sampling tube complying with ISO 5136 is used, problems may arise as a result of the directivity of the sampling tube.

The sound power level of the flow noise generated by the test silencer should preferably be determined in a test facility with a connected reverberation room. In this case the sound pressure level of the background noise within the room shall be more than 4 dB below the sound pressure level of the flow noise generated in the test silencer.

5.3 Additional equipment for determining the total pressure loss

In addition to complying with the requirements laid down in 5.2.1, the test facility shall also include a device for measuring the mean static pressure in the flow upstream and downstream of the test silencer.

An example of a test arrangement is given in figure E.3.

6 Test procedure

6.1 General

The signal of the sound source equipment is random noise of the one-third octave bandwidth. The sound pressure level measurements are made in one-third octave bands.

The insertion loss, flow noise and total pressure loss of the test silencer shall be determined for the range of flow velocities for which the test silencer is designed. If the test silencer can be used for different flow directions, the insertion loss, flow noise and total pressure loss shall be determined for forward and reverse flow relative to the direction of the sound propagation.

6.2 Insertion loss

The insertion loss, D, shall be determined from spatially averaged sound pressure levels $\overline{L_{p\mathrm{I}}}$ and $\overline{L_{p\mathrm{II}}}$ determined from measurements of local sound pressure levels taken at identical points or paths either in the reverberation room or in the test duct behind the test silencer during the two test series.

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

In the second series, $\overline{L_{p\mathrm{II}}}$ shall be determined with the test silencer 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 (see 5.1.10).

If the local sound pressure levels are measured in the test duct behind the test silencer, the spatial average shall be determined from the sound pressure levels measured at least at three key positions equally spaced as shown in figure 3. The longitudinal span of this line shall be at least as long as a quarter wavelength at the centre frequency of the respective one-third octave band. It should be positioned at about half the length of the test duct. If the difference, in decibels, between the highest and the lowest level of the three measurements exceeds the values given in table 5, then five positions shall be used. Spatial averaging is also permitted by continuous measurement along the diagonal line across the test duct.

Table 5 — Maximum level differences for three microphone positions in the test duct

Centre frequency of the frequency band dB	Maximum level difference dB
50	10
63	10
80	8
100	8
125	7
> 160	6

The spatial average sound pressure level, $\overline{L_p}$, in decibels, shall be calculated from the local sound pressure levels, L_{pi}, using the following equation: