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Reciprocating internal combustion engines — Measurement method for exhaust silencers — Sound power level of exhaust noise and insertion loss using sound pressure and power loss ratio

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National foreword

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Foreword

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 70, *Internal combustion engines.*

Introduction

This International Standard specifies methods for measuring the sound power level of exhaust noise and the insertion loss of exhaust silencers installed on reciprocating internal combustion engines and a method for measuring the power loss ratio of reciprocating internal combustion engines.

Sound power level of exhaust noise, insertion loss, and transmission loss are parameters to characterize the acoustic performance of exhaust silencers. Sound power levels of exhaust noise and insertion loss are important parameters to characterize the acoustic matching performance of exhaust silencers and reciprocating internal combustion engines. Transmission loss is the difference in sound power level of exhaust noise between the noise before and after transmitting through the exhaust silencer, which is the parameter to characterize the acoustic performance of the exhaust silencer itself and is irrelevant with the reciprocating internal combustion engine. Power loss ratio and pressure loss are parameters to characterize the aerodynamic performance of exhaust silencers. Power loss ratio is an important parameter to characterize the aerodynamic matching performance of exhaust silencers and reciprocating internal combustion engines, whereas resistance coefficient which is closely related to pressure loss is to characterize the aerodynamic performance of the exhaust silencer itself and is irrelevant with the reciprocating internal combustion engine on which the exhaust silencer is installed. The matching parameters of the sound power level of exhaust noise, the insertion loss, and the power loss ratio are used in this International Standard as the measurement parameters.

For sound power level of exhaust noise, the measurement results at 90° direction and 45° direction can be different. The measurement results at 45° direction is slightly greater than the actual value, the measurement results at 90° direction is much closer to the actual results. For insertion loss, the measurement results at 90° direction and 45° direction may be different, but the measurement uncertainty at 90° direction is smaller than that at 45° direction. Measurement at 90° direction is used for the laboratory measurement (engineering method). The measurement at 90° or 45° direction is used for laboratory measurement (survey method). The measurement at 45° direction is used for site measurement.

Reciprocating internal combustion engines — Measurement method for exhaust silencers — Sound power level of exhaust noise and insertion loss using sound pressure and power loss ratio

1 Scope

This International Standard specifies the measurement method and requirements for exhaust silencers which is installed on reciprocating internal combustion engines, including laboratory measurement and site measurement.

The following parameters are measured for laboratory measurement (engineering method):

— the sound power level (A-weighted or in frequency bands) of exhaust noise using sound pressure, accuracy grade 2;

— the insertion loss (A-weighted or in frequency bands) of exhaust silencers;

— the power loss ratio of reciprocating internal combustion engines.

The following parameters are measured for site measurement and laboratory measurement (survey method):

— the sound power level (A-weighted) of exhaust noise using sound pressure, accuracy grade 3;

— the insertion loss (A-weighted) of exhaust silencers.

NOTE 1 The aim of laboratory measurement in measuring the sound power level of exhaust noise is accuracy grade 2 (engineering method) result. When the correction for background noise and/or the environment conditions and/or the location of exhaust outlets cannot meet the requirements of the engineering method of this International Standard, then accuracy grade 3 (survey method) result is obtained. The aim of site measurement in measuring the sound power level of exhaust noise in this International Standard is accuracy grade 3 (survey method) result.

The laboratory measurement (engineering method) of this International Standard can be used to make acceptance tests and engineering measures. The site measurement and laboratory measurement (survey method) of this International Standard can be used to make comparative tests.

This International Standard applies to all exhaust silencers installed on reciprocating internal combustion engines falling within the field of application of ISO 3046-1 and other exhaust silencers, if no suitable International Standard exists.

NOTE 2 Throughout the text, exhaust silencer is referred to as silencer and reciprocating internal combustion engine as engine.

1.1 Measurement uncertainty

1.1.1 Engineering method

The standard deviation of reproducibility is equal to or less than 1,5 dB for A-weighted sound power levels. In one-third octave bands, it is equal to or less than 5 dB from 50 Hz to 80 Hz, 3 dB from 100 Hz to 160 Hz, 2 dB from 200 Hz to 315 Hz, 1,5 dB from 400 Hz to 5 000 Hz, and 2,5 dB from 6 300 Hz to 10 000 Hz. In octave bands, it is equal to or less than 5 dB for 63 Hz, 3 dB for 125 Hz, 2 dB for 250 Hz, 1,5 dB from 500 Hz to 4 000 Hz, and 2,5 dB for 8 000 Hz.

1.1.2 Survey method

The standard deviation of reproducibility is equal to or less than 4,0 dB for A-weighted sound power levels.

NOTE 1 The standard deviations listed in 1.1 are associated with the test conditions and procedures defined in this International Standard and not with the noise source itself, including variations of installation and/or operation conditions. They arise in part from variations between measurement laboratories, changes in atmospheric conditions if outdoors, the geometry of the test room or outdoor environment, the acoustical properties of the reflecting plane, absorption at the test room boundaries if indoors, background noise, and the type and calibration of instrumentation. They are also due to variations in experimental techniques, including the size and shape of the measurement surface, measurement distances, number and location of microphone positions, sound source location, determination of environmental corrections, if any, and integration time. The standard deviations are also affected by errors associated with measurements taken in the near field of the source. Such errors depend upon the nature of the sound source, but generally increase for smaller measurement distances and lower frequencies (below 250 Hz).

NOTE 2 If several laboratories use similar facilities and instrumentation, the results of sound power determinations on a given source in those laboratories may be in better agreement than would be implied by the standard deviations of 1.1.

NOTE 3 For a family of silencers, of similar size with similar sound power spectra and similar operating conditions, the standard deviations of reproducibility may be smaller than the values given in 1.1.

NOTE 4 The standard deviations of reproducibility, as listed in 1.1, include the uncertainty associated with repeated measurements on the same noise source under the same conditions (for standard deviations of reproducibility). This uncertainty is usually much smaller than the uncertainty associated with interlaboratory variability.

NOTE 5 The procedures of this International Standard and the standard deviations given in 1.1 are applicable to measurements on an individual silencer.

The measurement uncertainty depends on the standard deviation of reproducibility and on the degree of confidence that is desired. As examples, for a normal distribution of sound power levels, there is 90 % confidence that the true value of the sound power level of a source lies within the range ±1,645σ_R of the measured value and a 95 % confidence that it lies within the range ±1,960σ_R of the measured value.

NOTE 6 For a normal distribution of sound power levels, there is 90 % confidence that the probability of acceptance is 95 % and a 95 % confidence that the probability of acceptance is 97,5 %.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 3046-1:2002, *Reciprocating internal combustion engines — Performance — Part 1: Declarations of power, fuel and lubricating oil consumptions, and test methods — Additional requirements for engines for general use*

ISO 3046-3:2006, *Reciprocating internal combustion engines — Performance — Part 3: Test measurements*

ISO 6926:1999, *Acoustics — Requirements for the performance and calibration of reference sound sources used for the determination of sound power levels*

IEC 60942:2003, *Electroacoustics — Sound calibrators*

IEC 61260:1995, *Electroacoustics — Octave-band and fractional-octave-band filters*

IEC 61672-1:2002, *Electroacoustics — Sound level meters — Part 1: Specifications*

3 Terms and definitions

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

3.1
sound pressure
p
difference between instantaneous pressure and static pressure, expressed in pascals

3.2
sound pressure level
L_p
ten times the logarithm to the base 10 of the ratio of the square of the sound pressure, p, to the square of a reference value, p_0

$$L_p = 10 \lg \frac{p^2}{p_0^2}$$

where the reference value, p_0, is 20 μPa

Note 1 to entry: If specific frequency and time weightings, as specified in IEC 61672–1, and/or specific frequency bands are applied, this is indicated by appropriate subscripts, e.g. L_{pA} denotes the A-weighted sound pressure level.

Note 2 to entry: It is expressed in decibels.

3.3
time-averaged sound pressure level
$L_{p,T}$
ten times the logarithm to the base 10 of the ratio of the time average of the square of the sound pressure, p, during a stated time interval of duration, T (starting at t_1 and ending at t_2), to the square of a reference value, p_0

$$L_{p,T} = 10 \lg \left[\frac{\frac{1}{T}\int_{t_1}^{t_2} p^2(t)\,dt}{p_0^2} \right]$$

where the reference value, p_0, is 20 μPa

Note 1 to entry: In general, the subscript "T" is omitted since time-averaged sound pressure levels are necessarily determined over a certain measurement time interval.

Note 2 to entry: Time-averaged sound pressure levels are often A-weighted, in which case they are denoted by $L_{pA,T}$, which is usually abbreviated as L_{pA}.

Note 3 to entry: It is expressed in decibels.

3.4
surface time-averaged sound pressure level
$\overline{L_p}$
mean (energy average) of the time-averaged sound pressure levels over all the microphone positions, or traverses, on the measurement surface, with the background noise correction, K_1, and the environmental correction, K_2, applied

Note 1 to entry: It is expressed in decibels.

3.5
measurement time interval
T
portion or a multiple of an operational period or operational cycle of the noise source under test for which the time-averaged sound pressure level is determined

Note 1 to entry: It is expressed in seconds.

3.6
acoustic free field
sound field in a homogeneous, isotropic medium free of boundaries

Note 1 to entry: In practice, an acoustic free field is a field in which the influence of reflections at the boundaries or other disturbing objects are negligible over the frequency range of interest.

3.7
reflecting plane
sound-reflecting planar surface on which the noise source under test is located

3.8
acoustic free field over a reflecting plane
acoustic free field in the half-space above an infinite reflecting plane in the absence of any other obstacles

3.9
frequency range of interest
for general purposes, the frequency range of octave bands with nominal mid-band frequencies from 63 Hz to 8 000 Hz (including one-third octave bands with mid-band frequencies from 50 Hz to 10 000 Hz)

Note 1 to entry: For special purposes, the frequency range can be extended or reduced, provided that the test environment and instrument specifications are satisfactory for use over the modified frequency range. Changes to the frequency range of interest are included in the test report.

3.10
measurement radius
r
radius of a spherical measurement surface

Note 1 to entry: It is expressed in metres.

3.11
measurement surface
hypothetical spherical surface of area, S, on which the microphone positions are located at which the sound pressure levels are measured, enveloping the noise source under test

3.12
background noise
noise from all sources other than the noise source under test

Note 1 to entry: Background noise includes contributions from airborne sound, noise from structure-borne vibration, and electrical noise in the instrumentation.

3.13
background noise correction
K_1
correction applied to the mean (energy average) of the time-averaged sound pressure levels over all the microphone positions on the measurement surface, to account for the influence of background noise

Note 1 to entry: The background noise correction is frequency dependent; the correction in the case of a frequency band is denoted by K_{1f}, where f denotes the relevant mid-band frequency, and that in the case of A-weighting is denoted by K_{1A}.

Note 2 to entry: It is expressed in decibels.

3.14
environmental correction
K_2
correction applied to the mean (energy average) of the time-averaged sound pressure levels over all the microphone positions on the measurement surface, to account for the influence of reflected sound

Note 1 to entry: The environmental correction is frequency dependent; the correction in the case of a frequency band is denoted by K_{2f}, where f denotes the relevant mid-band frequency, and that in the case of A-weighting is denoted by K_{2A}.

Note 2 to entry: In general, the environmental correction depends on the area of the measurement surface and, usually, K_2 increases with S.

Note 3 to entry: It is expressed in decibels.

3.15
sound power
P
through a surface, the product of the sound pressure, p, and the component of the particle velocity, u_n, at a point on the surface in the direction normal to the surface, integrated over that surface

Note 1 to entry: The quantity relates to the rate per time at which airborne sound energy is radiated by a source.

Note 2 to entry: It is expressed in watts.

3.16
sound power level
L_W
ten times the logarithm to the base 10 of the ratio of the sound power of a source, W, to a reference value, W_0

$$L_W = 10 \lg \frac{W}{W_0}$$

where the reference value, W_0, is 1 pW

Note 1 to entry: If a specific frequency weighting, as specified in IEC 61672–1, and/or specific frequency bands are applied, this is indicated by appropriate subscripts, e.g. L_{WA} denotes the A-weighted sound power level.

Note 2 to entry: It is expressed in decibels.

3.17
exhaust silencer
chamber with acoustic lining and/or special structure designed to reduce exhaust noise

Note 1 to entry: The ICE exhaust silencer generally comprises the entire part from its inlet but does not include the exhaust manifold and pipe.

3.18
substitution pipe
rigid, non-absorbing pipe having the same length and the same cross section area of outlet as the tested silencer

3.19
straight transition pipe
straight pipe used to connect two pipes of different cross section areas

3.20
bent transition pipe
bent pipe used to change the airflow direction and to connect two pipes of the same cross section area

3.21
centre distance of several exhaust outlets
b
double average distance from one exhaust outlet to the geometric centre of all exhaust outlets

3.22
insertion loss
D_{I}
loss of sound power due to the insertion of a component or device at some point in a transmission system

Note 1 to entry: Specifically, it is the difference between the sound power level of exhaust noise when the substitution pipe is installed on the engine and when the exhaust silencer is installed on the engine. It is expressed in decibels.

$$D_{\mathrm{I}} = L_{W(\mathrm{SP})} - L_{W(\mathrm{ES})}$$

where

$L_{\mathrm{W(SP)}}$ is the sound power level of exhaust noise when the substitution pipe is installed on the engine, in decibels;

$L_{\mathrm{W(ES)}}$ is the sound power level of exhaust noise when the silencer is installed on the engine, in decibels.

3.23
power loss ratio
r_{p}
ratio of the difference between the engine power when the substitution pipe is installed on the engine and when the exhaust silencer is installed on the engine, to the engine power with the substitution pipe installed on the engine in the declared condition

Note 1 to entry: It is expressed in percentage.

$$r_P = \frac{P_{\mathrm{r(SP)}} - P_{\mathrm{r(ES)}}}{P_{\mathrm{r(SP)}}} \times 100\%$$

where

$P_{\mathrm{r(SP)}}$ is the engine power when the substitution pipe is installed on the engine under standard reference condition, in kilowatts;

$P_{\mathrm{r(ES)}}$ is the engine power when the exhaust silencer is installed on the engine under standard reference condition, in kilowatts.

4 Test environment

4.1 General

Environmental conditions having an adverse effect on the microphones used for the measurements (e.g. strong electric or magnetic fields, wind, impingement of air discharge from the noise source being tested, high temperatures) shall be avoided. The instructions of the manufacturer of the measuring instrumentation regarding adverse environmental conditions shall be followed.

In an outdoor area, care shall be taken to minimize the effects of adverse meteorological conditions (e.g. temperature, humidity, wind, precipitation) on sound propagation and sound generation over the frequency range of interest or on the background noise during the course of the measurements.

When a reflecting surface is not a ground plane or is not an integral part of a test room surface, particular care should be exercised to ensure that the plane does not radiate any appreciable sound due to vibrations.

4.1.1 Engineering method

The test environments that are applicable for measurements in accordance with this International Standard are the following:

a) a laboratory room or a flat outdoor area which is adequately isolated from background noise (see 4.2) and which provides an acoustic free field over a reflecting plane;

b) a room or a flat outdoor area which is adequately isolated from background noise (see 4.2) and in which an environmental correction can be applied to allow for a limited contribution from the reverberant field to the sound pressures on the measurement surface.

4.1.2 Survey method

The test environment that is applicable for measurements in accordance with this International Standard is a room or a flat outdoor area which is adequately isolated from background noise (see 4.2) and which meets the qualification requirements of 4.3.

4.2 Criteria for background noise

4.2.1 Engineering method relative criteria

4.2.1.1 General

The time-averaged sound pressure level of the background noise measured and averaged (see 8.2.1) over the microphone positions or traverses on the measurement surface shall be at least 6 dB, and preferably more than 15 dB, below the corresponding uncorrected time-averaged sound pressure level of the noise source under test when measured in the presence of this background noise. For measurements in frequency bands, this requirement shall be met in each frequency band within the frequency range of interest.

If this requirement is met, the background noise criteria of this International Standard are satisfied.

4.2.1.2 Frequency band measurements

The requirements of 4.2.1.1 may not be achievable in all frequency bands, even when the background noise levels in the test room are extremely low and well controlled. Therefore, any band within the frequency range of interest in which the A-weighted sound power level of the noise source under test is at least 15 dB below the highest A-weighted band sound power level may be excluded from the frequency range of interest for the purposes of determining compliance with the criteria for background noise.

4.2.1.3 A-weighted measurements

If the A-weighted sound power level is to be determined from frequency band levels and reported, the following steps shall be followed to determine whether this quantity meets the background noise criteria of this International Standard.

a) The A-weighted sound power level is computed in accordance with the procedures in this International Standard using the data from every frequency band within the frequency range of interest.

b) The computation is repeated, but excluding those bands for which $\Delta L_p < 6$ dB.

If the difference between these two levels is less than 0,5 dB, the A-weighted sound power level determined from the data for all bands may be considered as conforming to the background noise criteria of this International Standard.

4.2.2 Absolute criteria

If it can be demonstrated that the background noise levels in the test room at the time of the measurements are less than or equal to those given in Table 1 for all bands within the frequency range of interest, the measurements can be taken as having met the background noise requirements of this International Standard, even if the 6 dB requirement (see 4.2.1.1) is not met for all bands. It can be assumed that the source emits little or no measurable noise in these frequency bands and that the data reported represent an upper bound to the sound power level in these bands.

In the case where some of the measured time-averaged levels from the source under test are less than or equal to those given in Table 1, the frequency range of interest may be restricted to a contiguous range of frequencies that includes both the lowest and highest frequencies at which the sound pressure level from the noise source exceeds the corresponding value in Table 1. In such cases, the applicable frequency range of interest shall be reported.

4.2.3 Statement of non-conformity with criteria

If neither the relative criteria of 4.2.1 nor the absolute criteria in 4.2.2 are met, the report shall clearly state that the background noise requirements of this International Standard have not been met and, in the case of frequency band measurements, shall identify the particular frequency bands that do not meet the criteria. Furthermore, the report shall not state or imply that the measurements have been made “in full conformity” with this International Standard.

Table 1 — Maximum background noise levels in the test room for absolute criteria

One-third octave mid-band frequency Hz	**Maximum band sound pressure level** dB
50	44
63	38
80	32
100	27
125	22
160	16
200	13
250	11
315	9
400	8
500	7
630	7
800	7
1 000	7
1 250	7
1 600	7
2 000	7
2 500	8
3 150	8
4 000	8
5 000	8
6 300	8

Table 1 *(continued)*

One-third octave mid-band frequency Hz	**Maximum band sound pressure level** dB
8 000	12
10 000	14

4.2.4 Survey method

The A-weighted sound pressure levels due to background noise averaged over the microphone positions shall be at least 3 dB below the mean sound pressure level due to the noise source under test in operation when measured in the presence of this background noise (see 8.2.1).

4.3 Criterion for acoustic adequacy of test environment

4.3.1 Engineering method

4.3.1.1 General

A test room shall provide a measurement surface that lies inside a sound field that is essentially free of undesired sound reflections from the room boundaries or nearby objects (apart from the floor).

As long as it is practicable, the test environment shall be free from reflecting objects other than the reflecting plane(s).

NOTE 1 An object in the proximity of the noise source under test can be considered to be sound reflecting if its width (e.g. diameter of a pole or supporting member) exceeds one-tenth of its distance from the reference box.

The reflecting plane(s) shall extend at least 0,5 m beyond the projection of the measurement surface on the plane(s). The sound absorption coefficient of the reflecting plane(s) shall be less than 0,1 over the frequency range of interest.

NOTE 2 Smooth concrete or smooth sealed asphalt surface(s) are generally satisfactory.

Annex A specifies procedures for determining the magnitude of the environmental correction, K_2, to account for deviations of the test environment from the ideal condition. Measurements in accordance with this International Standard are only valid where $K_{2A} \leq 4$ dB.

The environmental correction, K_2, is assumed to be zero for measurements made in hemi-anechoic rooms which meet the requirements of ISO 3745.

For an outdoor space which consists of a hard, flat ground surface, such as asphalt or concrete, with no sound-reflecting objects within a distance from the noise source equal to 10 times the greatest distance from the geometric centre of the source to the lowest measurement points, it shall be assumed that the environmental correction K_2 is less than 0,5 dB and can be neglected.

4.3.1.2 Criterion for environmental correction

The environmental correction, K_{2A}, shall first be determined without reference to frequency band data, using one of the procedures of Annex A. Then

a) if $K_{2A} > 4$ dB, this International Standard is not applicable, and

b) if $K_{2A} \leq 4$ dB, measurements may be made in accordance with this International Standard, either in frequency bands or A-weighted.

Where it is decided to make measurements in frequency bands, the relevant environmental correction K2 shall be determined in each band over the frequency range of interest in accordance with A.2 or A.3.4

and all measurements to determine LW of a noise source shall be made in frequency bands. LWA shall be calculated using the frequency-band levels (see Annex C).

4.3.2 Survey method

Annex A specifies procedures for determining the magnitude of the environmental correction, K_{2A}, to account for deviations of the test environment from the ideal condition. Measurements in accordance with this International Standard are only valid where $K_{2A} \leq 7$ dB.

5 Instrumentation

5.1 General

The instrumentation system, including the microphones, cables, and windscreens, if used, shall meet the requirements of IEC 61672-1:2002, class 1 for results of accuracy grade 2 and class 2 for results of accuracy grade 3, and the filters shall meet the requirements of IEC 61260:1995, class 1.

5.2 Calibration

Before and after each series of measurements, a sound calibrator meeting the requirements of IEC 60942:2003, class 1 shall be applied to each microphone to verify the calibration of the entire measuring system at one or more frequencies within the frequency range of interest. Without any adjustment, the difference between the readings made before and after each series of measurements shall be less than or equal to 0,5 dB. If this value is exceeded, the results of the series of measurements shall be discarded.

The calibration of the sound calibrator, the compliance of the instrumentation system with the requirements of IEC 61672-1, the compliance of the filter set with the requirements of IEC 61260, and, if used, the compliance of the reference sound source with the requirements of ISO 6926 shall be verified at intervals in a laboratory making calibrations traceable to appropriate standards.

Unless national regulations dictate otherwise, it is recommended that the sound calibrator should be calibrated at intervals not exceeding 1 y, the reference sound source should be calibrated at intervals not exceeding 2 y, the compliance of the instrumentation system with the requirements of IEC 61672-1 should be verified at intervals not exceeding 2 y, and the compliance of the filter set with the requirements of IEC 61260 should be verified at intervals not exceeding 2 y.

6 Installation and operation of noise source under test for laboratory measurement

6.1 General

The manner in which the silencer under test is installed and operated may have a significant influence on the sound power emitted by a noise source, for example, the shape, inner diameter, and length of the exhaust outlet may have influence on the sound power and/or power loss ratio. The flow noise generated by high-flow speed can be greater due to the smaller inner diameter of the exhaust outlet. The silencer to be tested shall be installed with respect to, as if it were in normal use. This clause specifies conditions that are intended to minimize variations of the sound power level due to the installation and operating conditions of the noise source under test.

6.2 Source location

6.2.1 Engineering method

The exhaust outlet shall be installed outdoors or in a test room which meets the requirements of accuracy grade 2 (engineering method) and is not the same room where the engine is. For the requirements of exhaust outlet location, see Table 2; for the requirements of measurement radius *r*, see 7.2.1.1.

NOTE If the location of the exhaust outlet cannot meet the requirements of the engineering method, see 6.2.2.

6.2.2 Survey method

The exhaust outlet and the engine are installed in the same room, and the measurement result of the sound power level of accuracy grade 3 (survey method) is obtained. For the requirements of exhaust outlet location, see Table 2; for the requirements of measurement radius *r*, see 7.2.1.2

Table 2 — Requirements of exhaust outlet location

Dimensions in metres

Parameters	Engineering method	Survey method
distance between exhaust outlet and reflecting planes (ground), d_1	$d_1 \geq r$ and $d_1 \geq 0{,}5$	$d_1 \geq r$ and $d_1 \geq 0{,}25$
distance between exhaust outlet and wall/ceiling at flow direction, d_2	$d_2 \geq 2r$	$d_2 \geq 2r$
distance between exhaust outlet and wall/ceiling at non-flow direction, d_3	$d_3 \geq r$ and $d_3 \geq 0{,}5$	$d_3 \geq r$ and $d_3 \geq 0{,}25$

6.3 Installation requirements

6.3.1 General

If the exhaust outlet installed outdoors or in a test room which is not the same room where the engine is, sound insulation and vibration isolation shall be made between the exhaust pipe and walls.

If the exhaust outlet and the engine are installed in the same room, the excessive noise generated by the engine and the dynamometer as one part of background noise shall be shielded or wrapped to meet the requirements of criteria for background noise (see 4.2) to reduce extraneous noise influencing the noise radiated from the exhaust outlet.

6.3.2 Straight transition pipe

If the inner diameter of the exhaust pipe and/or substitution pipe and the inner diameter of the inlet of the silencer are different, use a straight transition pipe to connect them (see Figure 1). The use of a straight transition pipe shall meet the requirement of Formula (1).

$$\frac{l}{|a_{in} - a_{out}|} \geq 2,8 \qquad (1)$$

where

a_{in} is the inner diameter of the inlet of the exhaust silencer, in metres;

a_{out} is the inner diameter of the outlet of the exhaust silencer or equivalent inner diameter for several exhaust outlets (area calculated using the equivalent inner diameter are the sum of all cross-section areas of exhaust outlets), in metres;

l is the length of the straight transition pipe, in metres.

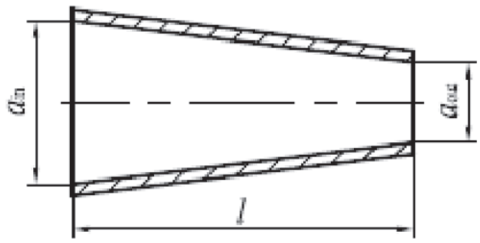


Figure 1 — Straight transition pipe (schematic)

6.3.3 Bent transition pipe

The bent transition pipe shall be used to change the direction of airflow (see Figure 2). If used, it shall meet the requirement of Formula (2).

$$\frac{R}{d_p} \geq 2 \qquad (2)$$

where

R is the radius, in metres;

d_p is the diameter of the steel pipe, in metres.

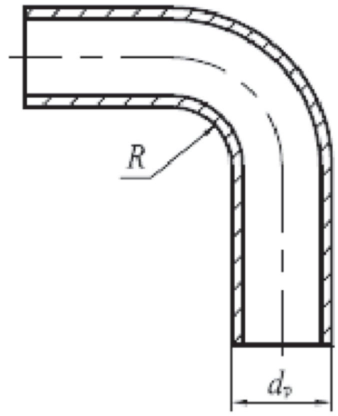


Figure 2 — Bent transition pipe (schematic)

NOTE Minimize the number of bent transition pipes which influence the measurement results of tested parameters.

6.4 Operation condition

For the laboratory measurement, the engine shall be operated at its ISO standard power and speed as defined in ISO 3046-1 under ISO standard reference conditions in a steady state when the substitution pipe is installed on the engine. The engine shall be operated under ISO standard reference conditions when the exhaust silencer is installed on the engine, keeping the throttle opening unchanged as the condition of the substitution pipe installed on the engine is in a steady state. The temperature of the oil, coolant, and tested silencer shall be stable when the engine is operated in a steady state, where the ambient and intake temperature shall not be higher than 45°C.

Measurements can be made in other operating conditions and, if necessary, can also be made in accelerated or decelerated conditions. All measurements made in such conditions shall be stated in the test report.

7 Measurement

7.1 General

This International Standard specifies two measurement methods: laboratory measurement and site measurement. Laboratory measurement is the measurement when the engine on which the silencer is installed in the test room. Site measurement is the measurement when the engine on which the silencer is installed is at the service site. Laboratory measurement aims to obtain accuracy grade 2 (engineering method) or accuracy grade 3 (survey method) measurement results of sound power level. Site measurement aims to obtain accuracy grade 3 (survey method) measurement results of sound power level. Laboratory measurement (engineering method) can provide a relatively complete evaluation about the silencers. The main evaluation parameters are sound power level of exhaust noise, insertion loss, and power loss ratio. Laboratory measurement (survey method) and site measurement can provide comparative evaluations about different silencers installed on the same engine. The main evaluation parameters are sound power level of exhaust noise and insertion loss.

The sound pressure level of exhaust noise and engine power shall be measured during the same period in the measurement.

To minimize the influence of observers on the measurements, the microphones shall preferably be mounted on a rigid frame or stand and be connected to the sound level meter by a cable. It is essential to ensure that the rigid frame or stand is not connected to the vibrating surface.

In addition to the specification given in Clause 5, the microphone shall always be oriented in such a way that the angle of incidence of the sound waves is that for which the microphone is calibrated and always be oriented to the centre of the exhaust outlet. The time-averaged sound pressure level shall be measured using an integrating sound level meter. If the sound level meter is used to measure time-weighting sound pressure level, the time-weighting characteristic “S” shall be used for the engine operated in steady condition and the time-weighting characteristic “F” shall be used for the engine operated in accelerated or decelerated condition which can be expressed as the time-averaged sound pressure level if measured.

Measurement results include sound pressure level $L'_{p(\mathrm{ES})}$ (when the tested silencer is installed on the engine) and $L'_{p(\mathrm{SP})}$ (when the substitution pipe is installed on the engine) (A-weighted or in frequency bands) under operation and sound pressure level of background noise $L_{p(\mathrm{B,ES})}$ and/or $L_{p(\mathrm{B,SP})}$ (A-weighted or in frequency bands).

The period of observation for the A-weighted sound pressure level shall be at least 4 s. For the frequency bands centred on or below 160 Hz, the period of observation shall be at least 30 s. For the frequency bands centred on or above 200 Hz, the period of observation shall be at least 10 s.

The test condition when the silencer is installed on the engine shall be similar as that condition when the substitution pipe is installed on the engine to reduce the measurement uncertainty. The location of the exhaust outlet and microphone positions shall remain unchanged.

7.2 Laboratory measurement

7.2.1 Microphone arrays

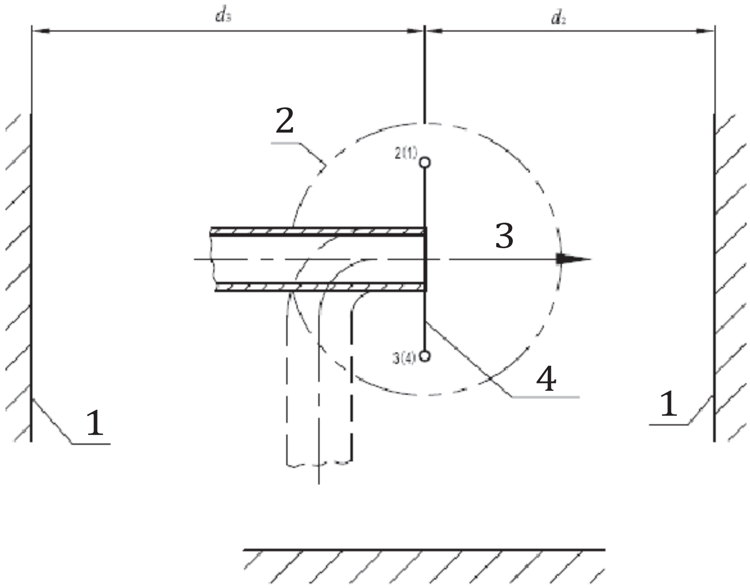
7.2.1.1 Engineering method

Four microphone positions shall be used for the engineering method. These measurement points shall be arranged on the spherical measurement surface, the centre of which is the outlet geometrical centre. The straight line connecting one measurement point and the spherical centre shall be 90° from the flow direction. Also, this straight line shall be 45° from the horizontal line, which is passing through the spherical centre and is vertical to the flow direction. The measurement points are shown in Figure 3 (horizontal airflow) and Figure 4 (vertical airflow).

The measurement radius, *r,* shall be equal to or more than two times the inner diameter of the outlet, a_{out}. For several outlets, measurement radius, *r,* shall be equal to or more than two times the centre distance of several outlets, *b*.

The recommend value of measurement radius *r* is 0,5 m and it shall be at least 0,25 m. The preferred value of measurement radius *r* shall be selected from the series: 0,25 m, 0,5 m, 1 m, 2 m, 4 m, 8 m. The value may also be selected from the following series: 0,25 m, 0,315 m, 0,4 m,..., 5 m, 6,3 m, 8 m. Also, the measurement radius, *r,* shall meet the requirements of the engineering method in Table 2.

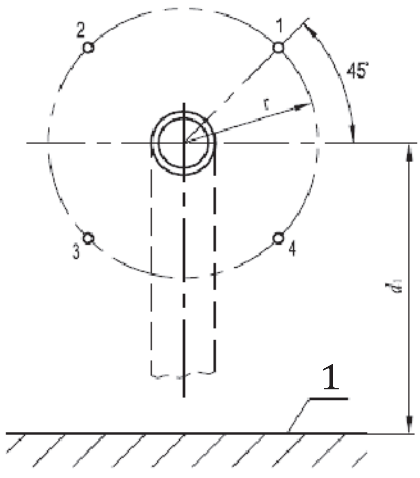
A smaller value of the measurement radius may be used in the test when the exhaust outlet is located indoors, while a bigger value may be used when the exhaust outlet is located outdoors.



a) front view

Key

1 wall
2 spherical measurement surface
3 flow direction
4 measurement plane
○ four measuring points

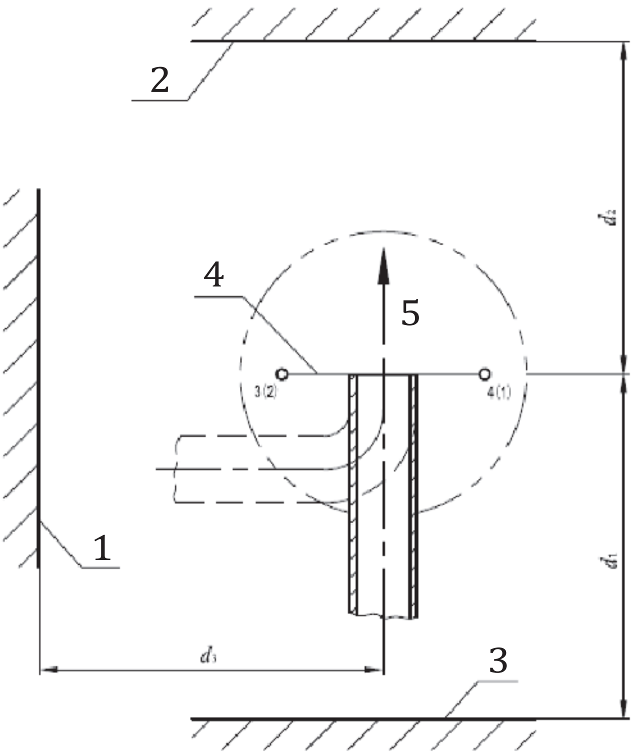


b) right view

Key

1 floor
○ four measuring points

Figure 3 — Arrangement of the key measurement points and measurement surface for the exhaust silencer (direction: 90°) (horizontal airflow) (schematic)



a) front view

Key

1 wall

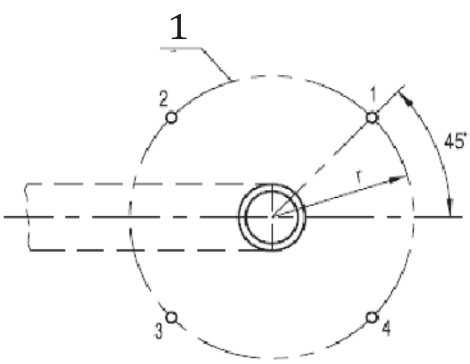
2 ceiling

3 floor

4 measurement plane

5 flow direction

○ four measuring points



b) top view

Key

1 spherical measurement surface

○ four measuring points

Figure 4 — Arrangement of the key measurement points and measurement surface for the exhaust silencer (direction: 90°) (vertical airflow) (schematic)

7.2.1.2 Survey method

One microphone position is adequate for the survey method. This measurement point shall be arranged on the spherical measurement surface, the centre of which is the outlet geometrical centre. The straight line connecting the measurement point and the spherical centre shall be 90° or 45° from the flow direction.

Select one point as far from the silencer body and/or reflecting plane as possible as the microphone position, e.g. point number 1 or 2 shown in Figure 3 and Figure 4 for the measurement of the 90° direction and point number 1 shown in Figure 5 and Figure 6 for the measurement of the 45° direction.

The measurement radius, *r*, shall be equal to or more than $\sqrt{2}$ times the inner diameter of outlet, a_{out}. For several outlets, measurement radius, *r*, shall be equal to or more than $\sqrt{2}$ times the centre distance of several outlets, *b*.

The recommend value of measurement radius, *r*, is 0,5 m and it shall be at least 0,125 m. The preferred value of measurement radius, *r*, shall be selected from the series: 0,125 m, 0,25 m, 0,5 m, 1 m, 2 m, 4 m, 8 m. The value may also be selected from the following series: 0,125 m, 0,16 m, 0,2 m,..., 5 m, 6,3 m, 8 m. Also, the measurement radius, *r*, shall meet the requirements of the survey method in Table 2.

A smaller value of the measurement radius may be used in the test when the exhaust outlet is located indoors, while a bigger value may be used when the exhaust outlet is located outdoors.

7.2.2 Determination of engine power

The measurements of engine power shall be determined in accordance with ISO 3046-3 and all measurement results shall be recorded.

The engine shall be operated at its ISO standard power and speed as defined in ISO 3046-1 under ISO standard reference conditions in a steady state. When the substitution pipe is installed on the engine, record the engine power at the declared speed. The engine shall be operated under ISO standard reference conditions when the exhaust silencer is installed on the engine, keeping the throttle opening unchanged as the condition of the substitution pipe installed on the engine is in a steady state. Record the engine power at the declared speed.

If the ambient test conditions are different from standard reference conditions, adjust the power from the ambient test conditions to the standard reference conditions according to ISO 3046-1, and record the adjusted power at the declared speed.

Also, the measurement results of the pressure loss of the engine measured according to the specification of Annex B is only for reference.

7.3 Site measurement

The same microphone array as that for the laboratory measurement (survey method) shall be used. One microphone position is adequate, this measurement point shall be arranged on the spherical measurement surface, the centre of which is the outlet geometrical centre. The straight line connecting the measurement point and spherical centre shall be 45° from the flow direction. Select one point as far from the silencer body and/or reflecting plane as possible as the microphone position, e.g. point number 1 shown in Figure 5 and Figure 6.

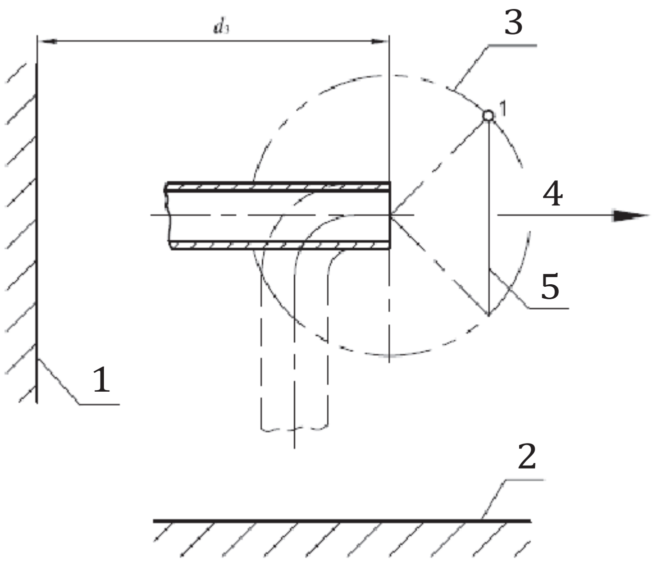
The measurement radius, *r*, shall be equal to or more than $\sqrt{2}$ times the inner diameter of outlet, a_{out}. For several outlets, measurement radius, *r*, shall be equal to or more than $\sqrt{2}$ times the centre distance of several outlets, *b*.

The recommend value of measurement radius, *r*, is 0,5 m and it shall be at least 0,125 m. The preferred value of measurement radius, *r*, shall be selected from the series: 0,125 m, 0,25 m, 0,5 m, 1 m, 2 m, 4 m, 8 m. The value may also be selected from the following series: 0,125 m, 0,16 m, 0,2 m,..., 5 m, 6,3 m, 8 m. Also, the measurement radius, *r*, shall meet the requirements of the survey method in Table 2.

A smaller value of the measurement radius may be used in the test when the exhaust outlet is located indoors, while a bigger value may be used when the exhaust outlet is located outdoors.

All site measurements shall be carried out with the similar ambient conditions and operating conditions of the engine for comparison. The site ambient conditions and the operating conditions of the engine shall be stated in the test report.

Determine the engine operating conditions as required for site measurement.



a) front view

Key

1 wall

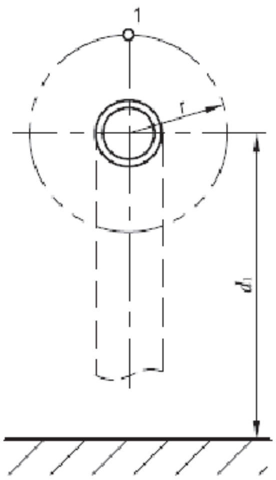
2 floor

3 spherical measurement surface

4 flow direction

5 measurement plane

○ one measuring point

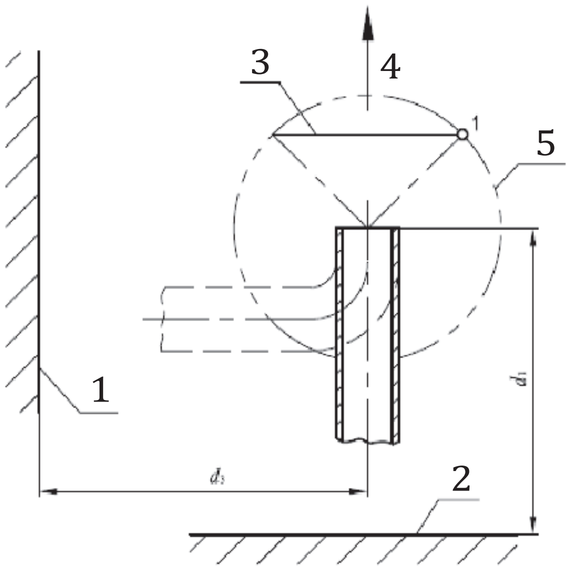


b) right view

Key

○ one measuring point

Figure 5 — Arrangement of the key measurement point and measurement surface for the exhaust silencer (direction: 45°) (horizontal airflow) (schematic)



a) front view

Key

1 wall

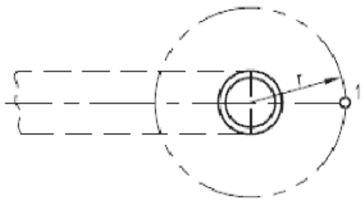
2 floor

3 measurement plane

4 flow direction

5 spherical measurement surface

○ one measuring point



b) top view

Key

○ one measuring point

Figure 6 — Arrangement of the key measurement point and measurement surface for the exhaust silencer (direction: 45°) (vertical airflow) (schematic)

8 Calculation

8.1 General

The sound power level (A-weighted or in frequency bands) of exhaust noise, the insertion loss (A-weighted or in frequency bands) of the exhaust silencer, and the power loss ratio of the engine shall be calculated for the laboratory measurement (engineering method). A-weighted sound pressure level can also be calculated from frequency band levels in accordance with Annex C which shall be stated in the report.

The sound power level (A-weighted) of the exhaust noise and the insertion loss (A-weighted) of the exhaust silencer shall be calculated for the site measurement and laboratory measurement (survey method).

8.2 Calculation of sound power level of exhaust noise

8.2.1 Calculation of mean time-averaged sound pressure levels

The mean time-averaged sound pressure level from the array of microphone positions over the measurement surface and the mean time-averaged sound pressure level of the background noise shall be calculated using Formula (3) and Formula (4), expressed in decibels

$$\overline{L'_{p(\mathrm{ST})}} = 10\lg\left[\frac{1}{N_\mathrm{M}}\sum_{i=1}^{N_\mathrm{M}} 10^{0,1L'_{pi(\mathrm{ST})}}\right] \mathrm{dB} \qquad (3)$$

$$\overline{L_{p(\mathrm{B,ST})}} = 10\lg\left[\frac{1}{N_\mathrm{M}}\sum_{i=1}^{N_\mathrm{M}} 10^{0,1L_{pi(\mathrm{B,ST})}}\right]\mathrm{dB} \tag{4}$$

where

$L'_{pi(\mathrm{ST})}$ is the time-averaged sound pressure level measured at the ith microphone position with the noise source under test in operation, in decibels;

$L_{pi(\mathrm{B,ST})}$ is the time-averaged sound pressure level of the background noise measured at the ith microphone position, in decibels;

N_M is the number of microphone positions.

NOTE Subscript of "ST" denotes tested sound source, including the situation of the exhaust silencer or substitution pipe installed on the engine.

8.2.2 Corrections for background noise

The background noise correction, $K_{1(\mathrm{ST})}$, shall be calculated using Formula (5), expressed in decibels

$$K_{1(\mathrm{ST})} = -10\lg\left(1-10^{-0,1\Delta L_{p(\mathrm{ST})}}\right) \tag{5}$$

where

$$\Delta L_{p(\mathrm{ST})} = \overline{L'_{p(\mathrm{ST})}} - \overline{L_{p(\mathrm{B,ST})}}$$

in which

$\overline{L'_{p(\mathrm{ST})}}$ is the mean time-averaged sound pressure level from the array of microphone positions over the measurement surface, with the noise source under test in operation, in decibels;

$\overline{L_{p(\mathrm{B,ST})}}$ is the mean time-averaged sound pressure level of the background noise from the array of microphone positions over the measurement surface, in decibels.

For laboratory measurement (engineering method), if $\Delta L_{p(\mathrm{ST})} > 15$ dB, $K_{1(\mathrm{ST})}$ is assumed to be zero and no correction for background noise shall be applied. If 6 dB ≤ $\Delta L_{p(\mathrm{ST})}$ ≤ 15 dB, corrections shall be calculated in accordance with Formula (5) and corrections shall be applied, that is 0,1 dB ≤ $K_{1(\mathrm{ST})}$ ≤ 1,3 dB. If $\Delta L_{p(\mathrm{ST})} < 6$ dB, that is $K_{1(\mathrm{ST})} > 1,3$ dB, the measurement is not valid.

NOTE 1 If $K_{1(\mathrm{ST})} > 1,3$ dB, the measurement results of the sound power level do not satisfy the accuracy grade 2, but the maximum correction to be applied to these measurements may be useful for determining an upper boundary to the sound power level of the noise source under test.

For site measurement and laboratory measurement (survey method), if $\Delta L_{p(\mathrm{ST})} > 10$ dB, $K_{1(\mathrm{ST})}$ is assumed to be zero and no correction for background noise shall be applied. If 3 dB ≤ $\Delta L_{p(\mathrm{ST})}$ ≤ 10 dB, corrections shall be calculated in accordance with Formula (5) and corrections shall be applied, that is 0,5 dB ≤ $K_{1(\mathrm{ST})}$ ≤ 3 dB. If $\Delta L_{p(\mathrm{ST})} < 3$ dB, that is $K_{1(\mathrm{ST})} > 3$ dB, the measurement is not valid.

NOTE 2 If $K_{1(\mathrm{ST})} > 3$ dB, the measurement results of the sound power level do not satisfy the accuracy grade 3, but the maximum correction to be applied to these measurements may be useful for determining an upper boundary to the sound power level of the noise source under test.

8.2.3 Corrections for environment

Determine the environmental correction, $K_{2(\mathrm{ST})}$, according to Annex A.

For laboratory measurement (engineering method), if $K_{2(\mathrm{ST})} \leq 4$ dB, the measurement is valid according to this International Standard. If $K_{2(\mathrm{ST})} > 4$ dB, the measurement is not valid.

NOTE 1 If K2(ST) > 4 dB, the measurement results of the sound power level do not satisfy the accuracy grade 2, but the maximum correction to be applied to these measurements may be useful for determining an upper boundary to the sound power level of the noise source under test.

For site measurement and laboratory measurement (survey method), if $K_{2(\mathrm{ST})} \leq 7$ dB, the measurement is valid according to this International Standard. If $K_{2(\mathrm{ST})} > 7$ dB, the measurement is not valid.

NOTE 2 If K2(ST) > 7 dB, the measurement results of the sound power level do not satisfy the accuracy grade 3, but the maximum correction to be applied to these measurements may be useful for determining an upper boundary to the sound power level of the noise source under test.

8.2.4 Calculation of surface time-averaged sound pressure levels

The surface time-averaged sound pressure level, $\overline{L_{p(\mathrm{ST})}}$, shall be calculated by correcting the mean time-averaged sound pressure level, $\overline{L'_{p(\mathrm{ST})}}$, for background noise ($K_1$, see 8.2.2) and for the influence of the test environment (K_2, see 8.2.3) using Formula (6), expressed in decibels

$$\overline{L_{p(\mathrm{ST})}} = \overline{L'_{p(\mathrm{ST})}} - K_{1(\mathrm{ST})} - K_{2(\mathrm{ST})} \quad (6)$$

8.2.5 Calculation of sound power levels

The sound power level, L_W, shall be calculated using Formula (7), expressed in decibels

$$L_{W(\mathrm{ST})} = \overline{L_{p(\mathrm{ST})}} + 10\lg\left(S_{(\mathrm{ST})}/S_0\right) \quad (7)$$

where

$S_{(\mathrm{ST})}$ is the area of the measurement surface, in square metres ($S_{(\mathrm{ST})} = 4\pi r^2$);

S_0 is equal to 1 m^2.

Reduced atmospheric pressure or a temperature below 10 °C creates a bias in the sound power level. At altitudes greater than 500 m above sea level or temperatures below 10 °C, the sound power levels, $L_{W\mathrm{ref,atm}}$, corresponding to the reference static pressure 101,325 kPa and reference atmospheric temperature 23,0 °C shall be calculated in accordance with Annex D.

8.3 Calculation of insertion loss

The calculation of insertion loss is given in 3.22. If the substitution pipe and the exhaust silencer have the same positions, dimensions, and sound field distributions, calculate the insertion loss, D_I, using Formula (8), expressed in decibels

$$D_\mathrm{I} = \overline{L_{p(\mathrm{SP})}} - \overline{L_{p(\mathrm{ES})}} \quad (8)$$

where

$\overline{L_{p(\mathrm{SP})}}$ is the surface time-averaged sound pressure level of exhaust noise when the substitution pipe is installed on the engine, in decibels;

$\overline{L_{p(\mathrm{ES})}}$ is the surface time-averaged sound pressure level of exhaust noise when the exhaust silencer is installed on the engine, in decibels.

8.4 Calculation of power loss ratio

The power loss ratio, r_p, shall be calculated using the formula given in 3.23.

9 Information to be recorded

9.1 General

The information listed in 9.2 to 9.6, when applicable, shall be compiled and recorded for all measurements made in accordance with this International Standard.

9.2 Description of the tested exhaust silencer and substitution pipe

a) a description of the tested exhaust silencer (including the type, serial number, dimensions, volume, mass, and manufacturer);

b) the inner diameter of the outlet of the substitution pipe.

9.3 Description of the engine on which the exhaust silencer is installed

a) a description of the engine on which the exhaust silencer is installed (including the type, serial number, declared power, declared speed, displacement, and manufacturer);

c) a description of the operating conditions (including the engine power, engine speed, specific fuel consumption, exhaust temperature, and exhaust gas flow).

9.4 Acoustic environment

a) a description of the test environment;

   1) if it is indoors, the description shall include the nature of the building, the construction and any lining of the walls, floor and ceiling, and a sketch showing the location of the noise source under test and any other contents of the room;

   2) if it is outdoors, the description shall include the nature of the reflecting floor surface and the surrounding terrain, with a sketch showing the location of the noise source under test;

   3) whether indoors or outdoors, the description shall also include any wall(s) against which the noise source under test stands;

b) a description of the acoustical qualification of the test environment in accordance with Annex A;

c) a description of the ambient conditions (including the barometric pressure, air temperature, relative humidity, and wind speed).

9.5 Description of instrumentation

a) the equipment used for the measurements, including the name, type, serial number, and manufacturer;

b) the date, place, and methods used to calibrate the sound calibrator and to verify the calibration of the instrumentation system and, if used, to calibrate the reference sound source, in accordance with 5.2;

c) the characteristics of the microphone windscreen, if any.

9.6 Acoustical data

a) the inner diameter of the exhaust outlet, and the measurement radius;

b) the measurement method and accuracy grade;

c) the time-averaged sound pressure levels, $L_{p(\mathrm{ST})}$, in the test environment from the noise source under test;

d) the correction(s), $K_{1(\mathrm{ST})}$, in decibels, to account for background noise;

e) the correction(s), $K_{2(\mathrm{ST})}$, in decibels, to account for the test environment, and the method from Annex A used to determine it (them);

f) the surface time-averaged sound pressure levels, $\overline{L_{p(\mathrm{ST})}}$, in decibels;

g) the sound power levels, L_W or $L_{W\mathrm{A}}$, in decibels, in frequency bands or A-weighted, as appropriate, rounded to the nearest 0,1 dB;

h) the date and time when the measurements were performed.

10 Test report

Only those recorded data (see Clause 9) which are required for the purpose of the measurements shall be reported. The report provides sound power level (A-weighted or in frequency bands) of exhaust noise and/or insertion loss (A-weighted or in frequency bands) of the exhaust silencer and/or engine power loss ratio. The report shall state that the time-averaged sound pressure level (A-weighted or in frequency bands) and the engine power have been obtained in full conformity with the requirements of this International Standard (i.e. ISO 15619). The report shall also contain any statements required to be reported by certain clauses in the main body of this International Standard.

Annex A
(normative)

Qualification procedures for the acoustic environment

A.1 General

Environmental influences shall be evaluated by selecting one of two alternative procedures used to determine the magnitude of the environmental correction, K_2. These procedures shall be used to determine if any undesired environmental influences are present and to qualify a given measurement surface for an actual noise source under test in accordance with this International Standard.

The first qualification test (absolute comparison test, see A.2) is carried out with a reference sound source (RSS) and can be used outdoors and indoors. This is the preferred procedure for qualifying a test environment, particularly if data in frequency bands are required, and if the noise source under test can be removed from the test site.

The second qualification test (method based on room absorption, see A.3) requires the determination of the equivalent absorption area, A, of the test room and is based on the assumption that the room has approximately a cubic shape, is substantially empty, and that sound is absorbed at the room boundaries. Four methods are described in which A can be calculated either from measurements of reverberation time (see A.3.2), from measurements of sound pressure levels from the noise source under test using a secondary measurement surface (see A.3.3), from measurements on a reference sound source (see A.3.4), or estimated from the mean absorption coefficient (see A.3.5). If the noise source under test cannot be moved and if its dimensions are large, one of these is the preferred method. The approximate method (A.3.5) is only for the survey method.

NOTE In some industrial buildings which are of low height and have reflecting surfaces, the sound propagation can be distorted. In these conditions, the second qualification method is not applicable; detailed guidelines and alternative methods may be given in noise test codes for specific types of machinery.

A.2 Absolute comparison test

A.2.1 General

For noise sources under test where a hemispherical measurement surface is used, a reference sound source meeting the requirements of ISO 6926 shall be mounted in the test environment, in essentially the same height of geometric centre as that of the noise source under test. The sound power level of the reference sound source shall be determined in accordance with the procedure of Clause 7 without the environmental correction, K_2 (i.e. K_2 is initially assumed equal to zero). The same measurement surface shall be used as that for the measurements of the noise source under test.

The environmental correction, K_2, expressed in decibels, is given by

$$K_2 = L^*_W - L_{W(\mathrm{RSS})} \tag{A.1}$$

where

L^*_W is the environmentally uncorrected sound power level of the reference sound source determined in accordance with Clause 7 when using the value 0 for K_2, in decibels;

$L_{W(\mathrm{RSS})}$ is the sound power level of the reference sound source measured in hemi-anechoic rooms under the meteorological conditions of the test, in decibels.

The height of the geometric centre, measurement surface, measurement positions, and number of reference sound source shall be the same as that of the noise source under test for sound power level measured in hemi-anechoic rooms.

This method is applicable to both directly measured A-weighted levels and frequency band levels. If the spectrum of the noise source under test is very different from that of the reference sound source, $K_{2\mathrm{A}}$ shall be determined from frequency band levels.

A.2.2 Locations of reference sound source in test environment

The height of the geometric centre of the reference sound source shall be the same as that of the noise source under test for laboratory measurement.

The microphone positions and number shall meet the requirements of 7.2 and 7.3.

A.3 Determination of the environmental correction based on room absorption

A.3.1 General

The environmental correction, K_2, shall be calculated from Formula (A.2), expressed in decibels

$$K_2 = 10\,\lg\left[1 + 4\frac{S}{A}\right] \tag{A.2}$$

where

A is the equivalent sound absorption area of the room, in square metres;

S is the area of the measurement surface, in square metres.

A.3.2 Reverberation method

This test method shall be used only in rooms of length and width each less than three times the ceiling height.

The equivalent sound absorption area, A, in square metres, of the test room shall be calculated by the Sabine reverberation time equation. At room temperatures between 15 °C and 30 °C,

$$A = 0{,}16 \frac{V}{T_n} \qquad \text{(A.3)}$$

where

V is the volume of the test room, in cubic metres;

T_n is the measured reverberation time, in seconds, for A-weighting or in frequency bands.

For the purpose of determining K_{2A} directly from A-weighted measured values, the use of the reverberation time measured in the frequency band with a mid-band frequency of 1 kHz is recommended.

This method is not suitable for use in a laboratory quality hemi-anechoic room or for outdoor measurements.

A.3.3 Two-surface method

This test method shall be used only in rooms where $K_2 \leq 2$ dB.

Two surfaces that surround the noise source shall be selected. The first surface shall be the measurement surface, in accordance with Clause 7, for the determination of the sound power level. The area of the first surface shall be designated S_1. The second surface with area S_2 shall be geometrically similar to the first surface and located further away and symmetrical with respect to the noise source under test. On both surfaces, the background noise criteria specified in 4.2 shall be fulfilled.

The microphone locations on the second surface shall correspond to those on the first surface. The ratio S_2/S_1 shall not be less than 2 and preferably should be greater than 4. The ratio S/A in Formula (A.2) is calculated from:

$$\frac{A}{S_1} = \frac{4(M-1)}{1 - M\left(S_1/S_2\right)} \qquad \text{(A.4)}$$

where

$$M = 10^{0{,}1\left(\overline{L_{p1}} - \overline{L_{p2}}\right)}$$

in which

$\overline{L_{p1}}$ is the mean time-averaged sound pressure level on S_1 [see Formula (3)], corrected for background noise but not for the influence of the environment (see 8.2.4), in decibels;

$\overline{L_{p2}}$ is the mean time-averaged sound pressure level on S_2 [see Formula (3)], corrected for background noise but not for the influence of the environment (see 8.2.4), in decibels;

S_1 is the area, in square metres, of the first measurement surface;

S_2 is the area, in square metres, of the second measurement surface.

The environmental correction K_2 for A-weighting or in frequency bands is obtained from Formula (A.2), with the S/A ratio calculated from Formula (A.4).

A.3.4 Determination of the equivalent absorption area *A* with a reference sound source (direct method)

A reference sound source meeting the requirements of ISO 6926 shall be mounted in the test environment near the noise source under test. The radius of the hemispherical measurement surface should preferably be 2 m, but in no case smaller than 1 m and not smaller than two times the largest diameter of the reference sound source. The distance from the source to other reflecting surfaces shall be greater than the diameter of the measurement hemisphere.

NOTE Normally, the reference sound source is calibrated for use in positions away from walls with the reference source either directly on the floor or on a stand at a specified elevation above the floor. If the reference sound source is used in other positions, unless it has been calibrated specifically in these positions, systematic errors can occur at low frequencies.

The mean background noise-corrected time-averaged sound pressure level from the reference sound source on the hemispherical measurement surface, $\overline{L_{p(\mathrm{insitu})}}$, shall then be determined in accordance with 8.2.1 and 8.2.4.

The equivalent absorption area, *A*, is then calculated using Formula (A.5):

$$A = \frac{4S}{(S/S_0)\times 10^{0,1\left[\overline{L_{p(\mathrm{insitu})}}-L_{W(\mathrm{RSS})}\right]}-1} \quad \text{(A.5)}$$

where

S is the area, in square metres, of the hemispherical measurement surface;

S_0 is equal to 1 m^2;

$\overline{L_{p(\mathrm{insitu})}}$ is the mean time-averaged sound pressure level of the reference sound source mounted near to the noise source under test, corrected for background noise but not for the influence of the environment (see 8.2.4), in decibels;

$L_{W(\mathrm{RSS})}$ is the sound power level of the reference sound source measured in hemi-anechoic rooms under the meteorological conditions of the test, in decibels.

If the static pressure or other atmospheric conditions differ significantly from the reference conditions for the determination of the sound power level of the reference sound source measured in hemi-anechoic rooms, $L_{W(\mathrm{RSS})}$, calculation of the sound power level of the reference sound source under *in situ* conditions, $L_{W(\mathrm{RSS,nsitu})}$, is recommended, in accordance with the manufacturer's instructions.

If $L_{W(\mathrm{RSS})}$ is not known, or if it is not possible to calculate $L_{W(\mathrm{RSS,insitu})}$ from $L_{W(\mathrm{RSS})}$, repetition of the measurements described above with the reference sound source in an acoustic free field over a reflecting plane outdoors to obtain a reference mean time-averaged sound pressure level, $\overline{L_{p(\mathrm{ref})}}$, is recommended.

From these measurements, the equivalent absorption area in the environment where the noise source under test is mounted is calculated using Formula (A.6):

$$A = \frac{4S}{10^{0,1\left[\overline{L_{p(\mathrm{insitu})}}-\overline{L_{p(\mathrm{ref})}}\right]}-1} \quad \text{(A.6)}$$

A.3.5 Approximate method for measurements made with A-weighting

This test method shall be used only in rooms of length and width each less than three times the ceiling height.

In order to ascertain the acoustic characteristics of the test environment, K_{2A} shall be determined from Formula (A.2) using a value of A given by Formula (A.7):

$$A = \alpha \cdot S_V \tag{A.7}$$

where

α is the mean sound absorption coefficient, given for A-weighted quantities in Table A.1;

S_V is the total area of the boundary surfaces of the test room (walls, ceiling, and floor), in square metres.

Table A.1 — Approximate values of the mean sound absorption coefficient, α

Mean sound absorption coefficient	Description of room
0,05	Nearly empty room with smooth hard walls made of concrete, brick, plaster, or tile
0,10	Partly empty room; room with smooth walls
0,15	Right cuboid room with furniture; right cuboid machinery room or industrial room
0,20	Irregularly shaped room with furniture, irregularly shaped machinery room, or industrial room
0,25	Room with upholstered furniture; machinery or industrial room with sound-absorbing material on part of ceiling or walls
0,30	Room with sound-absorbing ceiling, but no sound-absorbing materials on walls
0,35	Room with sound-absorbing material on both ceiling and walls
0,5	Room with large amounts of sound-absorbing materials on ceiling and walls

Annex B
(informative)

Measurement procedure for pressure loss

B.1 General

Determine the back pressure and uncertainty of the exhaust system according to ISO 3046-3.

B.2 Calculation of pressure loss

Calculate the pressure loss, ΔP_g, expressed in kilopascals, using Formula (B.1).

$$\Delta P_g = P_{g(ES)} - P_{g(SP)} \quad \text{(B.1)}$$

where

$P_{g(ES)}$ is the back pressure when the exhaust silencer is installed on the engine, in kilopascals;

$P_{g(SP)}$ is the back pressure when the substitution pipe is installed on the engine, in kilopascals.

Annex C
(normative)

Calculation of A-weighted sound power levels from frequency band levels

C.1 A-weighted sound power levels

The A-weighted sound power level, L_{WA}, may be calculated using Formula (C.1), expressed in decibels.

$$L_{WA} = 10\lg\left[\sum_{j=j_{\min}}^{j_{\max}} 10^{0,1\left(L_{Wj}+A_j\right)}\right] \quad \text{(C.1)}$$

where

L_{Wj} is the sound power level in the jth one-third octave band or in the jth octave band, in decibels;

j, A_j are given in Table C.1 for one-third octave bands and in Table C.2 for octave bands;

$j_{\min}$, $j_{\max}$ are the values of j corresponding, respectively, to the lowest and highest frequency bands of measurement.

C.2 Values of j and A_j for use in calculations

Values of j and A_j are given in Tables C.1 and C.2 for calculations with frequency band data covering the range of mid-band frequencies 50 Hz to 10 kHz for one-third octave bands and 63 Hz to 8 kHz for octave bands, respectively.

If the noise source emits audible discrete tones, the calculation should be performed using one-third octave band values.

Table C.1 — Values of j and A_j for mid-band frequencies of one-third octave bands

j	**Mid-band frequency** Hz	A_j dB
1	50	−30,2[a]
2	63	−26,2[a]
3	80	−22,5[a]
4	100	−19,1
5	125	−16,1
6	160	−13,4
7	200	−10,9
8	250	−8,6
9	315	−6,6
10	400	−4,8
11	500	−3,2
12	630	−1,9

[a] Values of A_j given for use only where the test environment and instrumentation are satisfactory for use at the frequencies concerned.

Table C.1 *(continued)*

j	**Mid-band frequency** Hz	A_j dB
13	800	−0,8
14	1 000	0
15	1 250	0,6
16	1 600	1,0
17	2 000	1,2
18	2 500	1,3
19	3 150	1,2
20	4 000	1,0
21	5 000	0,5
22	6 300	−0,1
23	8 000	−1,1
24	10 000	−2,5

[a] Values of A_j given for use only where the test environment and instrumentation are satisfactory for use at the frequencies concerned.

Table C.2 — Values of j and A_j for mid-band frequencies of octave bands

j	**Mid-band frequency** Hz	A_j dB
1	63	−26,2 [a]
2	125	−16,1
3	250	−8,6
4	500	−3,2
5	1 000	0
6	2 000	1,2
7	4 000	1,0
8	8 000	−1,1

[a] This value of A_j given for use only where the test environment and instrumentation are satisfactory for use at the frequencies concerned.

Annex D
(normative)

Sound power level under reference meteorological conditions

D.1 The sound power level under reference meteorological conditions of static pressure 101,325 kPa and atmospheric temperature 23,0 °C, $L_{W\text{ref,atm}}$, shall be calculated using Formula (D.1), expressed in decibels

$$L_{W\text{ref,atm}} = L_W + C_1 + C_2 \tag{D.1}$$

where

L_W is the sound power level under the meteorological conditions which occurred at the time and place of the test, from Formula (7), in decibels;

C_1 is the reference quantity correction, in decibels, to account for the different reference quantities used to calculate decibel sound pressure level and decibel sound power level and is a function of the characteristic impedance of the air under the meteorological conditions at the time and place of the measurements:

$$C_1 = -10\lg\frac{p_S}{p_{S,0}} + 5\lg\left[\frac{(273{,}15+\theta)}{\theta_0}\right]$$

NOTE 1 C_1 is omitted when K_2 is determined using the absolute comparison test of A.2.

C_2 is the radiation impedance correction, in decibels, to change the actual sound power relevant for the meteorological conditions at the time and place of the measurement into the sound power under reference meteorological conditions. The value shall be obtained from the appropriate noise test code, but in the absence of a noise test code, the following formula is valid for a monopole source and is a mean value for other sources:

$$C_2 = -10\lg\frac{p_S}{p_{S,0}} + 15\lg\left[\frac{(273{,}15+\theta)}{\theta_1}\right]$$

in which

p_S is the static pressure, in kilopascals, at the time and place of the test;

$p_{S,0}$ is the reference static pressure, 101,325 kPa;

θ is the air temperature, in degree Celsius, at the time and place of the test;

θ_0 is equal to 314 K;

θ_1 is equal to 296 K.

The air temperature, θ, may be estimated and the static pressure, p_S, can be calculated using Formula (D.2):

$$p_S = p_{S,0}\left(1 - aH_a\right)^b \tag{D.2}$$

where

H_a is the altitude, in metres, of the test site;

a is equal to $2{,}256\,0 \times 10^{-5}$ m^{-1};

b is equal to 5,255 3.

NOTE 2 The value given for θ_0 leads to a characteristic impedance of air of 400 N·s/m^3 at the reference static pressure 101,325 kPa.

If the sound power level is calculated under reference meteorological conditions, this fact shall be stated in the test report.

Bibliography

[1] ISO 3744:2010, *Acoustics — Determination of sound power levels and sound energy levels of noise sources using sound pressure — Engineering methods for an essentially free field over a reflecting plane*

[2] ISO 3746:2010, *Acoustics — Determination of sound power levels and sound energy levels of noise sources using sound pressure — Survey method using an enveloping measurement surface over a reflecting plane*

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