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Reciprocating internal combustion engines — Measurement method for air cleaners — Sound power level of combustion air inlet noise and insertion loss using sound pressure

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National foreword

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Reciprocating internal combustion engines — Measurement method for air cleaners — Sound power level of combustion air inlet noise and insertion loss using sound pressure

Moteurs alternatifs à combustion interne — Méthode de mesure du bruit des purificateurs d'air — Niveau de puissance sonore du bruit d'entrée d'air de combustion et de perte d'insertion utilisant une pression sonore

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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 Technical Specification specifies methods for measuring the sound power level of combustion air inlet noise and the insertion loss of air cleaners installed on reciprocating internal combustion engines.

Sound power level of combustion air inlet noise, insertion loss, and transmission loss are parameters to characterize the acoustic performance of air cleaners. Sound power levels of combustion air inlet noise and insertion loss are important parameters to characterize the acoustic matching performance of air cleaners and reciprocating internal combustion engines. Transmission loss is the difference in sound power level of combustion air inlet noise between the noise before and after transmitting through the air cleaner, which is the parameter to characterize the acoustic performance of the air cleaner itself and is irrelevant with the reciprocating internal combustion engine. The matching parameters of the sound power level of combustion air inlet noise and the insertion loss are used in this Technical Specification as the measurement parameters.

The enveloping surface method of this Technical Specification is applicable for engineering method (accuracy grade 2) and survey method (accuracy grade 3). Engineering method allows the determination of the A-weighted and frequency-band sound power level, survey method allows the determination of the A-weighted sound power level. The measurement result of sound power level is rounded to the nearest 0,1 dB.

In the combustion air inlet noise control of air cleaner, the relevant members (including manufacturer, installation, and the user) should make effective communication of acoustic information which is obtained by measurement. The measurement result is valid only in the specified measurement conditions by using the instrumentation as specified in this Technical Specification to obtain a clear acoustic value. Engineering method or survey method may be selected according to the purpose of noise measurement and measurement conditions.

The measurement surface defined based on the characteristics of noise source under test in this Technical Specification is spherical. To meet the requirements of the measurement uncertainty, this Technical Specification gives specification of the distance from the installation location of the noise source to the reflecting plane (ground).

Reciprocating internal combustion engines — Measurement method for air cleaners — Sound power level of combustion air inlet noise and insertion loss using sound pressure

1 Scope

This Technical Specification specifies the measurement method and requirements for combustion air inlet noise of air cleaners which are installed on reciprocating internal combustion engines, including laboratory measurement (engineering method and survey method) and site measurement (survey method).

This Technical Specification applies to all air cleaners installed on reciprocating internal combustion engines (reciprocating internal combustion engine is referred to as engine except particular explanation in the following text) falling within the field of application of ISO 3046-1 and/or other air induction installation.

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, *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, *Reciprocating internal combustion engines — Performance — Part 3: Test measurements*

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

IEC 60942, *Electroacoustics — Sound calibrators*

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

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

3 Terms and definitions

For the purposes of this document, the terms and definitions defined in ISO 3046-1, ISO 3046-3, ISO 6926, IEC 60942, IEC 61260 and IEC 61672-1 and the following apply.

3.1
sound pressure
p
difference between instantaneous pressure and static pressure

Note 1 to entry: It is 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* (3.1), 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* (3.1), 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* (3.5).

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 to 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* (3.3) over all the microphone positions, or traverses, on the *measurement surface* (3.11), with the *background noise correction* (3.13), K_1, and the *environmental correction* (3.14), 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* (3.3) 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 (3.6) in the half-space above an infinite *reflecting plane* (3.7) in the absence of any other obstacles

3.9
frequency range of interest
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)

3.10
measurement radius
r
radius of a spherical *measurement surface* (3.11)

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* (3.2) 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* (3.3) over all the microphone positions on the *measurement surface* (3.11), to account for the influence of *background noise* (3.12)

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* (3.3) over all the microphone positions on the *measurement surface* (3.11), 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: It is expressed in decibels.

3.15
sound power
W
through a surface, product of the *sound pressure* (3.1), *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* (3.15) of a source, *W*, to a reference value, W_0, expressed in decibels

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

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
air cleaner
air filter
device which removes particles suspended in the fresh charge as it is drawn into the engine

Note 1 to entry: The air cleaner generally comprises the entire part from its air inlet but does not include the air induction manifold and pipe.

3.18
substitution pipe
rigid, non-absorbing circular pipe having the same length and the same cross section area of outlet as the tested *air cleaner* (3.17)

3.19
bent transition pipe
bent pipe used to change the airflow direction and to connect two pipes of the same cross section area

3.20
characteristic source dimension
d_0
characteristic dimension of source to determine the *measurement radius* (3.10)

3.21
insertion loss
D_I
the difference between the *sound power level* (3.16) of combustion air inlet noise when the substitution pipe (3.18)is installed on the engine and when the *air cleaner* (3.17) is installed on the engine

$$D_I = L_{W(SP)} - L_{W(AC)}$$

where

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

$L_{W(AC)}$ is the sound power level of combustion air inlet noise when the air cleaner is installed on the engine, in decibels

Note 1 to entry: It is expressed in decibels.

4 Test environment

4.1 General

For engineering method, the test environments that are applicable for measurements in accordance with this Technical Specification are the following:

a) a room or a flat outdoor area which is adequately isolated from background noise 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 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.

For survey method, the test environment that is applicable for measurements in accordance with this Technical Specification is a room or a flat outdoor area which is adequately isolated from background noise and which meets the qualification requirements given in 4.3.

Environmental conditions having an adverse effect on the microphones used for the measurements (e.g. wind, impingement of air discharge, high or low temperatures) shall be avoided. The instructions of the manufacturer of the measuring instrumentation regarding adverse environmental conditions shall be followed. Particular care should be exercised to ensure that the plane does not radiate any appreciable sound due to vibrations.

4.2 Criterion for background noise

For engineering method, the time-averaged sound pressure level of the background noise measured and averaged over the microphone positions 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 frequency band measurements, the criteria for background noise may not be achievable in all frequency bands, even when the background noise levels in the test room are extremely low and well controlled.

For measurements in frequency bands, the following steps shall be followed to determine whether meeting the requirements of the background noise criteria.

a) The A-weighted sound power level is computed using the data from every frequency band within the frequency range of interest.

b) The computation of A-weighted sound power level is repeated but excluding those bands 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 and for which $\Delta L_p < 6$ dB (see 8.2.2).

c) 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 Technical Specification, or the measurement is not valid.

For survey method, the time-averaged sound pressure level of the background noise measured and averaged over the microphone positions, shall be at least 3 dB, and preferably more than 10 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.

4.3 Criterion for acoustic adequacy of test environment

Annex A specifies procedures for determining the magnitude of the environmental correction, K_2.

For engineering method, as long as it is practicable, the test environment shall be free from reflecting objects other than the reflecting plane(s). 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 1 Smooth concrete or smooth sealed asphalt surface(s) are generally satisfactory.

Measurements in accordance with engineering method of this Technical Specification are only valid where $K_{2A} \leq 4$ dB.

NOTE 2 The environmental correction, K_2, is assumed to be zero for measurements made in hemi-anechoic rooms which meet the requirements of ISO 3745.

The environmental correction, K_{2A}, shall first be determined without reference to frequency band data, using one of the procedures of Annex A. Where it is decided to make measurements in frequency bands, the relevant environmental correction K_2 shall be determined in each band over the frequency range of interest in accordance with A.4. L_{WA} of a noise source shall be calculated in accordance with Annex B.

Measurements in accordance with survey method of this Technical Specification are only valid where $K_{2A} \leq 7$ dB.

5 Instrumentation

5.1 General

The instrumentation system, including the microphones, cables and windscreen, if used, shall meet the requirements of IEC 61672-1, 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.

5.2 Calibration

Before and after each series of measurements, a sound calibrator meeting the requirements of IEC 60942, 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 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, 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.

5.3 Application

To minimize the influence of observers on the noise measurements, the microphones shall preferably be mounted on a rigid frame or stand which is not connected to the vibrating surface; 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 air inlet.

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 noise source under test operated in steady condition, and the time-weighting characteristic "F" shall be used for the noise source under test operated in non-steady condition (e.g. engine operated in the accelerated or decelerated condition). The measured average value can be expressed as the time-averaged sound pressure level.

The period of measurement for the time-averaged sound pressure level shall be at least 10 s, 20 s, or longer is better.

6 Installation and operation conditions

6.1 General

The manner in which the air cleaner is installed and operated may have a significant influence on the sound power emitted by a noise source under test; for example, the shape, inner diameter, and length of the air inlet may have influence on the sound power. The flow noise generated by high-flow speed can be greater due to the smaller inner diameter of the air inlet. The air cleaner to be tested shall be installed as if it were in normal use when the measurement is made in the laboratory. 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 Installation condition

For engineering method, the air inlet shall be installed outdoors or in a test room which meets the requirements given in 4.2 and 4.3 (engineering method). The distance between the centre of air inlet and reflecting plane (ground/wall/ceiling) shall be equal to or more than (r + 0,25) m (the requirements of r, see 7.4).

For survey method, the air inlet shall be installed outdoors or in a test room which meets the requirements given in 4.2 and 4.3 (survey method). The distance between the centre of air inlet and reflecting plane (ground/wall/ceiling) shall be equal to or more than (r + 0,125) m (the requirements of r, see 7.4).

If the air inlet 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 inlet pipe and walls.

If the air inlet and the engine are installed in the same room, the excessive noise generated by the engine and dynamometer as one part of background noise shall be shielded or wrapped to meet the requirements given in 4.2 to reduce extraneous noise influencing the noise radiated from the inlet.

The bent transition pipe shall be used to change the direction of airflow, see Figure 1. Minimize the number of bent transition pipe which influence the measurement results of tested parameters.

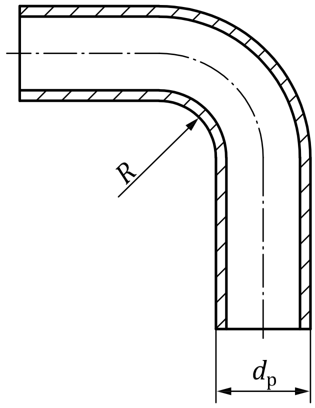


Figure 1 — Bent transition pipe (schematic)

If the bent transition pipe is used, it shall meet for the requirement of Formula (1):

$$\frac{R}{d_p} \geq 2 \quad (1)$$

where

R is the radius, in metres;

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

6.3 Operation condition

For the laboratory measurement, the engine on which the air cleaner or substitution pipe is installed shall be operated at its ISO standard power and corresponding rate as defined in ISO 3046-1 under ISO standard reference conditions in a steady state. At that time, the temperature of the oil and coolant shall be stable; the ambient and intake air temperature shall not be higher than 45 °C.

Measurements can be made in accelerated/decelerated conditions and other operating conditions if necessary; all measurements made in such conditions shall be stated in the test report.

The engine power and corresponding rate shall be measured according to the requirements of ISO 3046-3.

For the site comparison measurement, the engine on which the air cleaner or substitution pipe is installed shall be operated at the similar operation and ambient conditions as for the laboratory measurement which shall be stated in the test report.

7 Measurement

7.1 General

This Technical Specification specifies two measurement methods: laboratory measurement and site measurement.

Laboratory measurement is the measurement when the engine on which the air cleaner is installed is in the test room. Site measurement is the measurement when the engine on which the air cleaner 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 of combustion air inlet noise. Site measurement aims to obtain accuracy grade 3 (survey method) measurement results of sound power level of combustion air inlet noise. Engineering method can provide a relatively complete evaluation about the air cleaners, the measured parameters are sound power level (A-weighted or in frequency bands) and insertion loss (A-weighted or in frequency bands). The engineering method can be used to make acceptance tests and engineering measures. Survey method can provide comparative evaluations about different air cleaners installed on the same engine; the measured parameters are sound power level (A-weighted) and insertion loss (A-weighted). The survey method can be used to make comparative tests.

NOTE The aim of laboratory measurement in measuring the sound power level of combustion air inlet noise is accuracy grade 2 (engineering method) result. When the correction for background noise and/or the environment conditions and/or the location of air inlets cannot meet the requirements of the engineering method of this Technical Specification, then accuracy grade 3 (survey method) result of sound power level is obtained.

In order to facilitate the selection of the measurement surface and the arrangement of the microphones, the characteristic source dimension and measurement radius shall first be delineated for noise measurement.

Measurement results include the sound pressure level of noise source under operation and the sound pressure level of background noise when the noise source is not working.

7.2 Measurement uncertainty

The measurement uncertainty of sound power level determined in accordance with this Technical Specification shall meet the requirements given in Table 1.

Table 1 — Measurement uncertainty of sound power level (upper bound values of the standard deviation of reproducibility)

Dimensions in decibels

Mid-band frequency Hz		Engineering method accuracy grade 2	Survey method accuracy grade 3
Octave bands	One-third-octave bands		
63	50~80	5,0	—
125	100~160	3,0	
250	200~315	2,0	
500~4 000	400~5 000	1,5	
8 000	6 300~10 000	2,5	
A-weighted		1,5	3,0

NOTE 1 The standard deviations listed in Table 1 are associated with the test conditions and procedures defined in this Technical Specification, including the methods of arrangement of microphones and the measurement procedure of environmental correction and not with the noise source itself, including variations of installation and operation conditions.

NOTE 2 For a family of sound sources, of similar size with similar sound power spectra or several laboratories, use same/similar facilities and instrumentation; the uncertainty associated with interlaboratory variability may be smaller than the values given in Table 1.

NOTE 3 The standard deviations of reproducibility, as listed in Table 1, include the standard deviation of repeatability. This uncertainty is usually much smaller than the uncertainty associated with interlaboratory variability.

NOTE 4 The standard deviations given in Table 1 are applicable to measurements on an individual sound source.

NOTE 5 "—" means there is no requirement.

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 ±1,64 σ_R of the measured value and a 95 % confidence that it lies within the range ±1,96 σ_R of the measured value.

NOTE 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 %.

7.3 Characteristic source dimension

The specifications of the characteristic source dimension, d_0, see Figure 2 according to the shape of inlet of air cleaner installed on the engine.

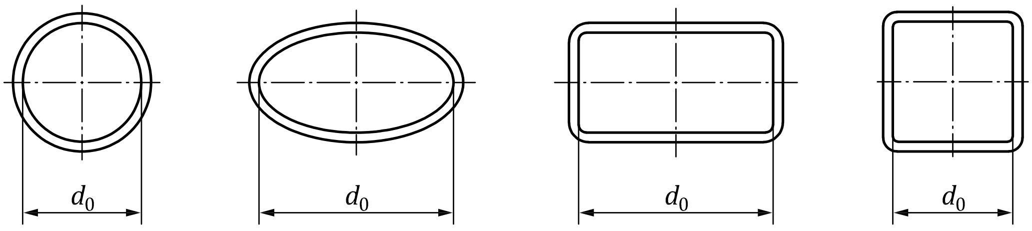


Figure 2 — Characteristic source dimension d_0 of typical air inlet (schematic)

7.4 Measurement radius

The measurement radius, *r*, shall be equal to or more than the characteristic source dimension, d_0, and meet the requirements of 6.2.

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

The recommend value of measurement radius, *r*, is 0,5 m and it shall be at least 0,25 m for engineering method. 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.

The recommend value of measurement radius, *r*, is 0,5 m, and it shall be at least 0,125 m for survey method. 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.

7.5 Measurement surface and area

The area, *S*, of spherical measurement surface shall be calculated using Formula (2), in square metres:

$$S = 4\pi r^2 \quad (2)$$

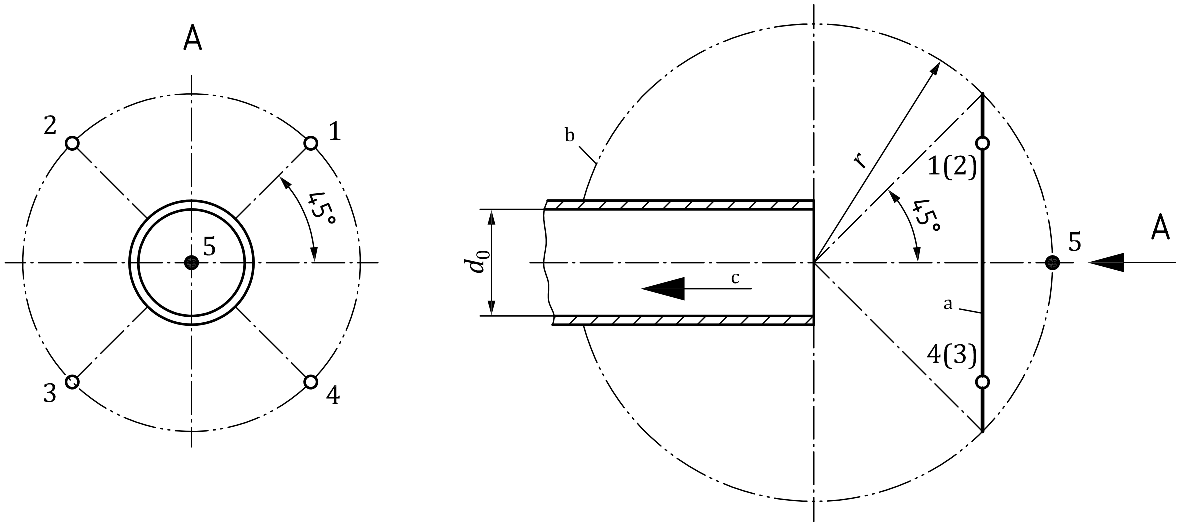
where

r is the measurement radius, in metres.

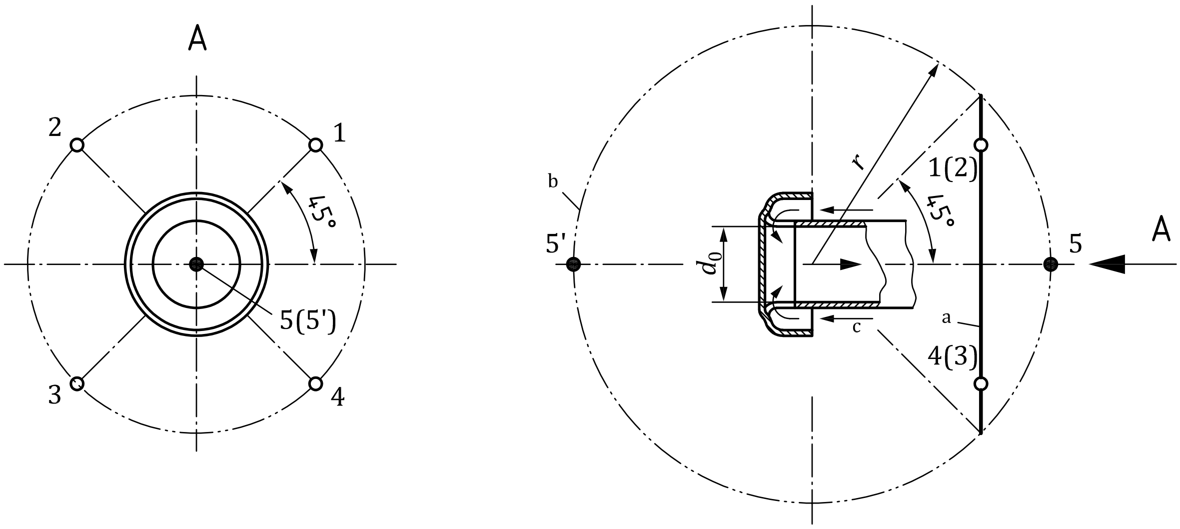
7.6 Microphone arrays

Four microphone positions shall be used for engineering method. These measurement points shall be arranged on the spherical measurement surface, the centre of which is the inlet geometrical centre. The straight line connecting one measurement point and the spherical centre shall be 45° 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 numbered 1 to 4 shall meet the requirements shown in Figure 3.

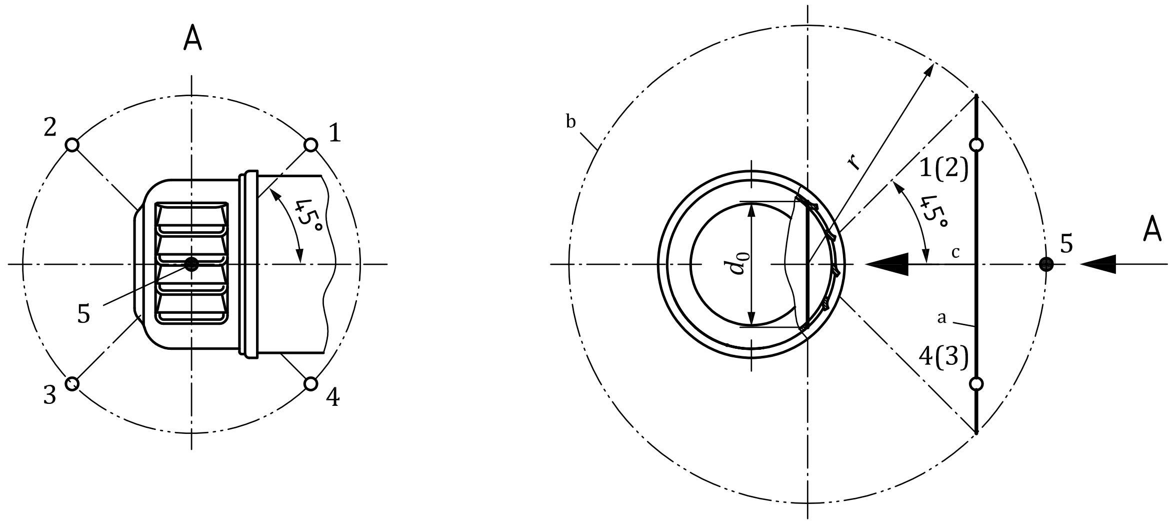
One microphone position is adequate for survey method. The measurement point shall be arranged on the axis of flow direction as number 5, shown in Figure 3. If this measurement point cannot be arranged for obstacle as shown in Figure 3 b), the preferred measurement point shall be arranged as numbered 5′. Also one point from 1 to 4 as far from the air cleaner body and/or reflecting plane as possible can be selected as the microphone position.



a) Tubular air inlet



b) Peripheral air inlet



c) Partial air inlet

Key

a Measurement plane.

b Spherical measurement surface.

c Flow direction.

Figure 3 — Microphone arrays (schematic)

8 Calculation

8.1 General

This Technical Specification specifies calculation methods of sound power level and insertion loss.

The sound power level (A-weighted or frequency-band) of combustion air inlet noise and the insertion loss (A-weighted or frequency-band) of the air cleaner shall be calculated for the engineering method. A-weighted sound power level also can be calculated from frequency band levels in accordance with Annex B, which shall be stated in the report.

The sound power level (A-weighted) of combustion air inlet noise and the insertion loss (A-weighted) of the air cleaner shall be calculated for the survey method.

8.2 Calculation of sound power level

8.2.1 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:

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

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

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 i^{th} 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 air cleaner 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 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 sound power level do not satisfy the accuracy grade 2, but the maximum correction to be applied to these measurement may be useful for determining an upper boundary to the sound power level of the noise source under test.

NOTE 2 The particular specifications for the band measurement, see 4.2.

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

8.2.3 Corrections for environmental

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

For engineering method, if $K_{2(ST)}$ ≤ 4 dB, the measurement is valid according to this Technical Specification. If $K_{2(ST)}$ > 4 dB, the measurement is not valid.

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

For survey method, if $K_{2(ST)}$ ≤ 7 dB, the measurement is valid according to this Technical Specification. If $K_{2(ST)}$ > 7 dB, the measurement is not valid.

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

8.2.4 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:

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

8.2.5 Sound power levels

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

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

where

$S_{(ST)}$ 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.

Atmospheric pressure and/or a temperature create a bias in the radiation of sound power. At altitudes greater than 500 m above sea level and/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 C and stated in the report.

8.3 Calculation of insertion loss

The calculation of insertion loss is given in 3.21.

If the pipe centre of the substitution pipe and the inlet of air cleaner have the same positions and measurement radius that are the same microphone locations and number, calculate the insertion loss, D_I, using Formula (8), expressed in decibels:

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

where

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

$\overline{L_{p(\text{AC})}}$ is the surface time-averaged sound pressure level of combustion air inlet noise when the air cleaner is installed on the engine, in decibels.

9 Information to be recorded

The information listed in a) to e), when applicable, shall be compiled and recorded for all measurements made in accordance with this Technical Specification.

a) The tested air cleaner and substitution pipe:

1) a description of the tested air cleaner (including the type, serial number, manufacturer, characteristic section dimension, and length of the inlet/outlet pipe and body);

2) the inner diameter of the inlet of the substitution pipe.

b) The engine on which the air cleaner is installed:

1) a description of the engine on which the air cleaner is installed (including the type, serial number, ISO standard power and corresponding speed, displacement, and manufacturer);

2) a description of the operating conditions (including the engine power, engine speed, specific fuel consumption).

c) Acoustic environment:

1) a description of the test environment (including the nature of the floor, walls and ceiling, and a sketch showing the location of the noise source under test and any other contents of the room;

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

3) a description of the ambient conditions near the noise source under test (including the barometric pressure, air temperature, relative humidity, and wind speed).

d) Description of instrumentation:

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

2) the date, place, results, and methods used to calibrate the sound calibrator and to verify the calibration of the instrumentation system;

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

e) Acoustical data:

1) the measurement method and accuracy grade;

2) the characteristic source dimension, d_0, and measurement radius, r;

3) the time-averaged sound pressure level measured at the i^{th} microphone position with the noise source under test in operation, $L'_{pi(\text{ST})}$;

4) the correction(s), $K_{1(\text{ST})}$, to account for background noise;

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

6) the surface time-averaged sound pressure levels, $\overline{L_{p(\text{ST})}}$;

7) the sound power levels, L_W;

8) the date and place where the measurements were performed and the person conducting the measurements.

10 Test report

Only those required data according to Clause 9 shall be recorded in the report which provides the measurement results of sound power level (A-weighted or frequency-band) and/or insertion loss (A-weighted or frequency-band). The report shall state that the measurement has been made in full conformity with the requirements of this Technical Specification. The report shall also contain any statements required to be reported by certain clauses in the main body of this Technical Specification.

The measurement results of sound power level (A-weighted or frequency-band) in the report shall be rounded to the nearest 0,1 dB.

Annex A
(normative)

Qualification procedures for the acoustic environment

A.1 General

This Annex specifies procedures to determine the magnitude of the environmental correction, K_2. These procedures can be used to qualify a given measurement surface for an actual noise source under test in accordance with this Technical Specification.

The qualification test based on room absorption 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, from measurements of sound pressure levels from the noise source under test using a secondary measurement surface, from measurements on a reference sound source, or estimated from the mean absorption coefficient (The approximate method is only for survey method).

The environmental correction, K_2, shall be calculated from Formula (A.1), expressed in decibels:

$$K_2 = 10\lg\left[1 + 4\frac{S}{A}\right] \quad \text{(A.1)}$$

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.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:

$$A = 0{,}16\frac{V}{T_n} \quad \text{(A.2)}$$

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 $K_{2\mathrm{A}}$ 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 hemi-anechoic room or for outdoor measurements.

A.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 under test 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. The second surface with area S' 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'/S shall not be less than 2 and preferably should be greater than 4. The ratio S/A is calculated from Formula (A.3):

$$\frac{A}{S} = \frac{4(M-1)}{1 - M\left(S/S'\right)} \tag{A.3}$$

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

S' 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.1), with the S/A ratio calculated from Formula (A.3).

A.4 Determination of the equivalent absorption area A with a reference sound source

A reference sound source meeting the requirements of ISO 6926 shall be mounted in the test environment and hemi-anechoic room respectively, in essentially the same height of geometric centre, the same measurement surface, the same microphone positions and number 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 given in Clause 7 without the environmental correction (i.e. K_2 is initially assumed equal to zero).

The environmental correction of the measurement surface, K_2, expressed in decibels, is given by:

$$K_2 = L^*_W - L_{W(\mathrm{SA})} \tag{A.4}$$

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;

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

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

$$A = \frac{4S}{10^{0,1K_2} - 1} \quad \text{(A.5)}$$

where

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

Then the environmental correction K_2 of other measurement surface is obtained from Formula (A.1).

A.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.1) using a value of A given by Formula (A.6):

$$A = \alpha \cdot S_V \quad \text{(A.6)}$$

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
(normative)

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

B.1 A-weighted sound power levels

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

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

where

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

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

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

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

Values of j and A_j are given in Tables B.1 and B.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.

NOTE It is recommended that calculation be performed using one-third octave band values.

Table B.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
2	63	-26,2
3	80	-22,5
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
13	800	-0,8
14	1 000	0
15	1 250	0,6

Table B.1 *(continued)*

j	**Mid-band frequency** Hz	A_j dB
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

Table B.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
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

Annex C
(normative)

Sound power level under reference meteorological conditions

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 (C.1), expressed in decibels:

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

where

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

C_1 is the reference quantity correction, in decibels;

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

C_2 is the radiation impedance correction, in decibels;

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

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 degrees Celsius, at the time and place of the test;

θ_0 = 40,36 °C;

θ_1 = 23 °C.

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

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

where

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

A is equal to 2,256 0 × 10^{-5} m^{-1};

b is equal to 5,255 3.

NOTE 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, *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 3745, *Acoustics — Determination of sound power levels and sound energy levels of noise sources using sound pressure — Precision methods for anechoic rooms and hemi-anechoic rooms*

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