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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

Moteurs alternatifs à combustion interne — Méthode de mesure pour silencieux d'échappement — Niveau de puissance acoustique du bruit à l'échappement et perte par insertion à partir de la pression acoustique et du rapport de perte de puissance

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Foreword

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

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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.