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Acoustics — Determination of sound power levels and sound energy levels of noise sources using sound pressure — Engineering/survey methods for use *in situ* in a reverberant environment

Acoustique — Détermination des niveaux de puissance acoustique et des niveaux d'énergie acoustique émis par les sources de bruit à partir de la pression acoustique — Méthode d'expertise et de contrôle pour une utilisation in situ *en environnement réverbérant*

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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

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

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 3747 was prepared by Technical Committee ISO/TC 43, *Acoustics*, Subcommittee SC 1, *Noise*.

This third edition cancels and replaces the second edition (ISO 3747:2000), which has been technically revised.

Introduction

This International Standard is one of the series ISO 3741[2] to ISO 3747, which specify various methods for determining the sound power levels and sound energy levels of noise sources including machinery, equipment and their sub-assemblies. The selection of one of the methods from the series for use in a particular application depends on the purpose of the test to determine the sound power level or sound energy level and on the facilities available. General guidelines to assist in the selection are provided in ISO 3740[1]. ISO 3740[1] to ISO 3747 give only general principles regarding the operating and mounting conditions of the machinery or equipment for the purposes of the test. It is important that test codes be established for individual kinds of noise source, in order to give detailed requirements for mounting, loading, and operating conditions under which the sound power levels or sound energy levels are to be obtained.

The method given in this International Standard is based on a comparison of the sound pressure levels in octave frequency bands of a noise source under test with those of a calibrated reference sound source; A-weighted sound power levels or sound energy levels may be calculated from the octave-band levels. The method is applied where the noise source is found *in situ* and as such is suitable for larger pieces of stationary equipment which, due to their manner of operation or installation, cannot readily be moved.

The method specified in this International Standard permits the determination of the sound power level and the sound energy level in octave bands from which the A-weighted value is calculated.

This International Standard describes a method giving results of either ISO 12001:1996, accuracy grade 2 (engineering grade) or ISO 12001:1996, accuracy grade 3 (survey grade), depending on the extent to which the requirements concerning the test environment are met. For applications where greater accuracy is required, reference can be made to ISO 3741[2], ISO 3744[5] or an appropriate part of ISO 9614[17]-[19]. If the relevant criteria for the measurement environment specified in this International Standard are not met, it might be possible to refer to another standard from this series, or to an appropriate part of ISO 9614[17]-[19].

Acoustics — Determination of sound power levels and sound energy levels of noise sources using sound pressure — Engineering/survey methods for use *in situ* in a reverberant environment

1 Scope

1.1 General

This International Standard specifies a method for determining the sound power level or sound energy level of a noise source by comparing measured sound pressure levels emitted by a noise source (machinery or equipment) mounted *in situ* in a reverberant environment, with those from a calibrated reference sound source. The sound power level (or, in the case of noise bursts or transient noise emission, the sound energy level) produced by the noise source, in frequency bands of width one octave, is calculated using those measurements. The sound power level or sound energy level with frequency A-weighting applied is calculated using the octave-band levels.

1.2 Types of noise and noise sources

The method specified in this International Standard is suitable for all types of noise (steady, non-steady, fluctuating, isolated bursts of sound energy, etc.) defined in ISO 12001. The method is primarily applicable to sources which emit broad-band noise. It can, however, also be used for sources which emit narrow-band noise or discrete tones, although there is a possibility that the measurement reproducibility is then degraded.

The noise source under test can be a device, machine, component or sub-assembly, especially one which is non-movable.

1.3 Test environment

The test environment that is applicable for measurements made in accordance with this International Standard is a room where the sound pressure level at the microphone positions depends mainly on reflections from the room surfaces (see 4.1). In measurements of ISO 12001:1996, accuracy grade 2 (engineering grade), background noise in the test environment is low compared to that of the noise source or reference sound source (see 4.2).

1.4 Measurement uncertainty

Information is given on the uncertainty of the sound power levels and sound energy levels determined in accordance with this International Standard, for measurements made in octave bands and for A-weighted frequency calculations performed on them. The uncertainty conforms with that of either ISO 12001:1996, accuracy grade 2 (engineering grade) or ISO 12001:1996, accuracy grade 3 (survey grade), depending on the extent to which the requirements concerning the test environment are met.

2 Normative references

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

ISO 5725 (all parts), *Accuracy (trueness and precision) of measurement methods and results*

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

ISO 12001:1996, *Acoustics — Noise emitted by machinery and equipment — Rules for the drafting and presentation of a noise test code*

ISO/IEC Guide 98-3, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement* (*GUM:1995*)

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 definitions apply.

3.1
sound pressure

p

difference between instantaneous pressure and static pressure

NOTE 1 Adapted from ISO 80000-8:2007[22], 8-9.2.

NOTE 2 Sound pressure 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, p, to the square of a reference value, p_0, expressed in decibels:

$$L_p = 10 \lg \frac{p^2}{p_0^2} \text{ dB} \tag{1}$$

where the reference value, p_0, is 20 μPa

[ISO/TR 25417:2007[21], 2.2]

NOTE 1 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. $L_{p\text{A}}$ denotes the A-weighted sound pressure level.

NOTE 2 This definition is technically in accordance with ISO 80000-8:2007[22], 8-22.

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, expressed in decibels

$$L_{p,T} = 10\ \lg\left[\frac{\dfrac{1}{T}\displaystyle\int_{t_1}^{t_2} p^2(t)\,\mathrm{d}t}{p_0^2}\right]\ \mathrm{dB} \tag{2}$$

where the reference value, p_0, is 20 µPa

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

NOTE 2 Time-averaged sound pressure levels are often A-weighted, in which case they are denoted by $L_{p\mathrm{A},T}$, which is usually abbreviated to $L_{p\mathrm{A}}$.

NOTE 3 Adapted from ISO/TR 25417:2007[21], 2.3.

3.4

single event time-integrated sound pressure level

L_E

ten times the logarithm to the base 10 of the ratio of the integral of the square of the sound pressure, p, of an isolated single sound event (burst of sound or transient sound) over a stated time interval T (starting at t_1 and ending at t_2) to a reference value, E_0, expressed in decibels

$$L_E = 10\ \lg\left[\frac{\displaystyle\int_{t_1}^{t_2} p^2(t)\,\mathrm{d}t}{E_0}\right]\ \mathrm{dB} \tag{3}$$

where the reference value, E_0, is $(20\ \mu\mathrm{Pa})^2\ \mathrm{s} = 4 \times 10^{-10}\ \mathrm{Pa}^2\ \mathrm{s}$

NOTE 1 This quantity can be obtained by $L_{p,T} + 10\ \lg(T/T_0)$ dB, where $T_0 = 1$ s.

NOTE 2 When used to measure sound immission, this quantity is usually called "sound exposure level" (see ISO/TR 25417:2007[21]).

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 Measurement time interval is expressed in seconds.

3.6

comparison method

method by which the sound power level or sound energy level of a noise source under test is determined from a comparison of the sound pressure levels produced by the source under test with those of a reference sound source of known sound power output, when both sources are operated in the same environment

3.7
reverberant sound field

that portion of the sound field in the test room over which the influence of sound received directly from the source is negligible

3.8
reference sound source

sound source meeting specified requirements

NOTE For the purposes of this International Standard, the requirements are those specified in ISO 6926:1999, Clause 5.

3.9
calibration position

position, well-defined relative to reflecting surfaces, in which the reference sound source has been calibrated

3.10
excess of sound pressure level at a given distance

ΔL_f

difference, at a given distance, between the sound pressure level of a sound source in a given room and the sound pressure level that would be expected in a free sound field, expressed in decibels

NOTE This term and its definition differ from that given in ISO 14257:2001[20], 3.6, which relates to an average difference over a given distance range.

3.11
frequency range of interest

for general purposes, the frequency range of octave bands with nominal mid-band frequencies from 125 Hz to 8 000 Hz

NOTE For special purposes, the frequency range can be extended or reduced, provided that the test environment, reference sound source, and instrument specifications are satisfactory for use over the modified frequency range. Any change to the frequency range of interest is clearly indicated in the test report. Measurements are not valid if the A-weighted levels are predominantly determined by high or low frequencies outside the frequency range of interest.

3.12
reference box

hypothetical right parallelepiped terminating on the floor of the test environment on which the noise source under test is located, that just encloses the source including all the significant sound-radiating components and any test table on which the source is mounted

3.13
measurement distance

d_m

distance from the nearest point of the reference box to a microphone position

NOTE Measurement distance is expressed in metres.

3.14
background noise

noise from all sources other than the noise source under test

NOTE Background noise includes contributions from airborne sound, noise from structure-borne vibration, and electrical noise in the instrumentation.

3.15
background noise correction

K_1

correction applied to the measured octave-band sound pressure levels at each microphone position to account for the influence of background noise

NOTE 1 Background noise correction is expressed in decibels.

NOTE 2 The background noise correction is frequency dependent; the correction in the case of a frequency band is denoted K_{1f}, where f denotes the relevant mid-band frequency.

3.16
sound power

P

through a surface, 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

[ISO 80000-8:2007[22], 8-16]

NOTE 1 Sound power is expressed in watts.

NOTE 2 The quantity relates to the rate per time at which airborne sound energy is radiated by a source.

3.17
sound power level

L_W

ten times the logarithm to the base 10 of the ratio of the sound power of a source, P, to a reference value, P_0, expressed in decibels

$$L_W = 10 \lg \frac{P}{P_0} \text{ dB} \tag{4}$$

where the reference value, P_0, is 1 pW

NOTE 1 If a specific frequency weighting as specified in IEC 61672-1 and/or specific frequency bands are applied, this should be indicated by appropriate subscripts; e.g. L_{WA} denotes the A-weighted sound power level.

NOTE 2 This definition is technically in accordance with ISO 80000-8:2007[22], 8-23.

[ISO/TR 25417:2007[21], 2.9]

3.18
sound energy

J

integral of the sound power, P, over a stated time interval of duration T (starting at t_1 and ending at t_2)

$$J = \int_{t_1}^{t_2} P(t)\, \mathrm{d}t \tag{5}$$

NOTE 1 Sound energy is expressed in joules.

NOTE 2 The quantity is particularly relevant for non-stationary, intermittent sound events.

[ISO/TR 25417:2007[21], 2.10]

3.19
sound energy level
L_J
ten times the logarithm to the base 10 of the ratio of the sound energy, J, to a reference value, J_0, expressed in decibels

$$L_J = 10 \lg \frac{J}{J_0} \text{ dB} \tag{6}$$

where the reference value, J_0, is 1 pJ

NOTE If a specific frequency weighting as specified in IEC 61672-1 and/or specific frequency bands are applied, this should be indicated by appropriate subscripts; e.g. $L_{J\mathrm{A}}$ denotes the A-weighted sound energy level.

[ISO/TR 25417:2007[21], 2.11]

4 Test environment

4.1 Criterion for acoustic adequacy of test environment

The test environment is where the noise source under test is found *in situ*, i.e. either where the source is built or where it normally operates. The method of test specified in this International Standard is for application in a reverberant sound field. The test environment shall therefore be sufficiently reverberant to cause the directivity of the source under test to have an insignificant influence on the sound pressure levels measured according to 7.5 and 7.6. The indicator, excess of sound pressure level at a given distance, ΔL_f, shall be determined in accordance with Annex A, and shall have a magnitude of at least 7 dB in regions where the requirement for a reverberant sound field is fulfilled. This indicator serves as the parameter by which to assess the measurement uncertainty, see Clause 9.

4.2 Criterion for background noise

At each microphone position, the octave-band sound pressure levels due to background noise shall be at least 6 dB and preferably more than 15 dB below the octave-band sound pressure levels from the noise source under test and from the reference sound source.

NOTE If it is necessary to make measurements where the difference between the sound pressure levels of the background noise and the sources is less than 6 dB, ISO 3746[7], ISO 9614-1[17] or ISO 9614-2[18] can be used.

5 Instrumentation and measurement equipment

5.1 General

The instrumentation system, including the microphones and cables, shall meet the requirements of IEC 61672-1:2002, class 1, and the filters shall meet the requirements of IEC 61260:1995, class 1. The reference sound source shall meet the requirements given in ISO 6926.

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 measurement system at one or more frequencies within the frequency range of interest. Without any adjustment, the difference between the readings 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, 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, it is recommended that the sound calibrator should be calibrated at intervals not exceeding 1 year, the reference sound source should be calibrated at intervals not exceeding 2 years, and the compliance of the instrumentation system with the requirements of IEC 61672-1 should be verified at intervals not exceeding 2 years.

6 Location, installation and operation of noise source under test

6.1 Source location and installation

Since the test procedure is designed for use *in situ*, the installation and location of the noise source under test have to be those where the source is found. However, the sound power or sound energy emitted by a source can be affected by the manner of installation and its location, for instance, relative to nearby walls or other reflecting surfaces.

Many small sound sources, although themselves poor radiators of low-frequency sound, can, as a result of the method of mounting, radiate more low-frequency sound when their vibrational energy is transmitted to surfaces large enough to be efficient radiators. In such cases, resilient mountings should if practicable be interposed between the noise source under test and the supporting structure, so that the transmission of vibration to the support and the reaction on the source are both minimized. In this case, the mounting base should be rigid (i.e. have a sufficiently high mechanical impedance) to prevent it from vibrating excessively and radiating sound. Such resilient mounts should not be used if the noise source under test is not resiliently mounted in typical usage.

Coupling conditions, e.g. between prime movers and driven machines, can exert considerable influence on the sound radiation of the noise source under test. It may be appropriate to use a flexible coupling, but similar considerations apply to these as to resilient mounts.

6.2 Auxiliary equipment

If practicable, all auxiliary equipment necessary for the operation of the noise source under test, but which is not an integral part of the source itself, including any electrical conduits, piping, air ducts, etc., connected to the source under test, shall be located outside the test environment. If this is impractical, care shall be taken to minimize any sound radiated into the test environment from such equipment. The noise source under test shall be taken to include all significant sources of sound emission, including auxiliary equipment which cannot either be removed or adequately quietened, and the reference box (see 7.2) shall be extended appropriately.

6.3 Operation of source during test

The sound power or sound energy emitted by a source can be affected by the load applied, the running speed, and the conditions under which it is operating. The source shall be tested, wherever possible, under conditions that are reproducible and representative of the noisiest operation in typical usage. The specifications given in a noise test code, if any exists, shall be followed, but in the absence of a noise test code one or more of the following modes of operation shall be selected for the test(s):

a) source under specified load and conditions;

b) source under full load [if different from a)];

c) source under no load (idling);

d) source at maximum operating speed under defined conditions;

e) source operating under conditions corresponding to maximum sound generation representative of normal use;

f) source with simulated loading, under defined conditions;

g) source undergoing a characteristic work cycle under defined conditions.

The source shall be stabilized in the desired operating condition, with any power source or transmission system running at a stable temperature, prior to the start of measurements for sound power level or sound energy level determination. The load, speed, and operating conditions shall either be held constant during the test, or varied through a defined cycle in a controlled manner.

If the sound power or sound energy emission depends on secondary operating parameters, e.g. the type of material being processed, the design of cutting tool, or the humidity, those parameters shall be selected, as far as is practicable, that give the smallest variations and that are typical of normal use. If simulated loading conditions are used, they shall be chosen such that the sound power levels or sound energy levels of the source under test are representative of normal use.

7 Measurement procedure

7.1 General

For determination of either the sound power level of a noise source emitting stationary noise or the sound energy level of a source which emits bursts of noise, two sets of measurements of sound pressure levels shall be made in the test environment, first with the noise source under test operating and then with the reference sound source operating; in some circumstances (see 7.3.1) the measurements with the reference sound source have to be repeated for different locations of the source. The specifications given in a noise test code, if any exists, shall be followed, but in the absence of a noise test code the procedures described hereafter shall be followed for the test(s).

7.2 Characterization of noise source under test

A preliminary aural examination of the noise emitted by the source under test shall be made to determine whether sound emitted from one component predominates. If so, the geometric centre of that component shall be assumed to be the acoustic centre of the source for the purpose of the test (see 7.3.2), and a reference box shall be delineated which just encloses that component and terminates on the floor on which the source under test is mounted. If no component appears to emit sound more than any other, any component which clearly emits no sound shall be excluded from consideration, the acoustic centre of the source shall be taken to be the geometric centre of the remainder, and the reference box shall be delineated accordingly.

Preliminary measurements shall be used to determine whether the sound emitted by the source is too directional for the method of this International Standard to be applied. The source directivity shall be evaluated by measuring sound pressure levels of the source (at intervals of 2 m or less along a given side for a large source) at a distance of 1 m from the reference box and a height normally of 1,5 m. If the source emits sound predominantly in an upward direction, the height at which the sound pressure levels are measured shall be sufficient to ensure that the microphone positions are in a direct line of sight to the acoustic centre of the source. If the A-weighted range of sound pressure levels so measured varies by no more than ±2 dB, the source shall be considered to be omnidirectional; if the variations exceed this amount, the source shall be considered to be directional. If the range of these directivity measurements exceeds ±7 dB, the engineering grade limits on source directivity are exceeded and the reported grade of accuracy shall not exceed that of ISO 12001:1996, accuracy grade 3 (survey grade) (see Clause 9).

7.3 Locations of the reference sound source

7.3.1 General

Normally, one location for the reference sound source is sufficient. For noise sources under test which are large or which have two or more clearly distinguishable sound sources far apart from one another, two or more locations may need to be used (see 7.3.3).

7.3.2 One location

If one location is sufficient, the reference sound source shall be positioned as close as possible to the acoustic centre of the noise source under test. For a directional source, the reference sound source should be located to simulate the emission pattern of the noise source under test or, if this is impractical, a position for the reference sound source on top of the source under test shall be chosen. If this is not possible, a location shall be selected alongside the source under test, at a height and position which best simulate the emission pattern of the source under test. In the latter case, positions closer than 0,5 m to the surface of the reference box should be avoided. For an omnidirectional source under test, care shall be taken to ensure that the reference sound source can emit sound equally in all directions.

NOTE 1 The more reverberant the test environment is, in other words, the larger ΔL_f is, the less critical is the selection of the location for the reference sound source. However, if a position is selected for the reference sound source for which it is not calibrated, the reproducibility of the sound power level or sound energy level determined is degraded, see Clause 9.

NOTE 2 Each reflecting surface within $\lambda/2$ (half a wavelength) of the reference sound source can increase its sound power, resulting in a possible underestimate of the noise source sound power level of up to 3 dB. Conversely, placing the reference sound source less than 0,5 m from the edge or edges of the reflecting floor plane can reduce its sound power output below 400 Hz, resulting in a possible overestimate of the noise source sound power level of up to 3 dB.

NOTE 3 Further guidance on selection of the location for the reference sound source is given in Annex B.

7.3.3 More than one location

The number of locations required for the reference sound source depends on the ratio a/d_m, where a is the largest dimension of the reference box and d_m is the measurement distance, see 7.4.1. The number of locations to be used is specified in a) to c).

a) If $a/d_\mathrm{m} > 1$ and if the source under test is omnidirectional, several locations shall be used for the reference sound source along the sides of the source under test, separated by a distance equal to d_m.

b) If $a/d_\mathrm{m} > 1$ and if the source under test has clearly definable sound emission areas, one location of the reference sound source shall be used for each emission area.

c) If $a/d_\mathrm{m} \leqslant 1$ and if the source under test is omnidirectional, but it is impossible to use a location on top of the source under test, four locations for the reference sound source shall be used, one adjacent to each vertical side of the reference box.

7.4 Microphone positions

7.4.1 General

The aim is to position the microphones around the sides of the noise source under test so that each position is situated similarly in relation to the sound-emitting areas of the source, i.e. for a particular microphone position, either there is a line of sight to each sound-emitting area or each area is screened. Positions to be avoided are those to which only a few parts of the source are emitting sound.

In total, three or four microphone positions are to be used (see 7.4.3), distributed as evenly as possible around the noise source under test. The same positions and microphone orientations are to be used for measurements made on the noise source under test, the reference sound source, and the background noise. The measurement distance, d_m, from the respective microphone positions to the nearest point of the reference box is to be selected so that, if possible, the microphone positions are in a part of the test environment where the sound field is reverberant, i.e. a region in which $\Delta L_f \geqslant 7$ dB (see Table 2).

No microphone position shall be closer than 0,5 m to any boundary surface of the test environment. If the environment is sufficiently spacious, and if the noise source under test is located away from all boundary surfaces, the microphones shall be positioned round all four vertical sides of the reference box. The microphone positions shall be spaced at least 2 m from each other. If the ceiling is high and sound absorbing, and frequencies greater than 2 000 Hz are important, if possible, at least two of the microphone positions shall be above the source.

7.4.2 Zoning

The test environment shall be divided into zones in which differences can be denoted in the sound-radiating patterns in the horizontal plane around the noise source under test (ST) and the reference sound source (RSS) in its various locations. The zones are used in choosing locations for the reference sound source and the microphone positions. The different zones are identified and given notations in Table 1.

Table 1 — Zones of the test environment

Direct line of sight to sound-emitting areas		**Distances from the microphone position**	**Effect on the sound power estimation**	**Notation of the zone**
of ST	of RSS	d_{m} [a]		
Yes	No	—	Strong overestimate	++
No	Yes	—	Strong underestimate	–
Yes	Yes	$d_{\text{m(ST)}} < d_{\text{m(RSS)}}$	Overestimate	+
Yes	Yes	$d_{\text{m(ST)}} > d_{\text{m(RSS)}}$	Underestimate	–
Yes	Yes	$d_{\text{m(ST)}} \approx d_{\text{m(RSS)}}$ (within 10 %)	Negligible over- or underestimate	+/–
No	No	—	Either strong over- or underestimate	++/–

[a] (ST) indicates source under test; (RSS) indicates reference sound source.

7.4.3 Selection of microphone positions

If the noise source under test is omnidirectional and the reference sound source is located on top of it, all the zones fall into one or other of the notations + or +/– and one microphone position shall be selected on each free side of the source under test, in compliance with the requirements of 7.4.1.

In all other cases, microphone positions shall be sought in a +/– zone. If this is not possible, one microphone position shall be selected in a + zone, one in a +/– zone and one or two positions in – zones.

Unless the test environment is highly reverberant (no acoustic treatment of walls or ceiling, no large absorbing obstacles) no microphone positions should be located in a ++/– zone.

NOTE It can prove impossible to have all microphone positions in direct line of sight of the reference sound source (see B.2 and B.4).

7.5 Measurement of sound pressure levels for a noise source which emits steady or non-steady noise

Time-averaged sound pressure levels from the noise source under test, for each octave band within the frequency range of interest, $L'_{pi\text{(ST)}}$, shall be obtained, at each microphone position, i (i = 1, 2 … n), and from the reference sound source, $L'_{pi\text{(RSS)}}$. A suitable averaging time for the reference sound source is 30 s. If the sound output from the noise source under test is as stable as that of the reference sound source, then a similar averaging time is satisfactory, but if it is less stable or undergoes periodic cycles, a longer averaging time is required.

In addition, either immediately before or immediately after the sound pressure levels from the noise source under test are measured, the time-averaged sound pressure levels of the background noise for each octave band, $L_{pi\text{(B)}}$, shall be obtained at each microphone position, over the same measurement time interval as that used for the noise source under test.

7.6 Measurement of sound pressure levels for a noise source which emits impulsive noise

Single event sound pressure levels from the noise source under test for each octave band within the frequency range of interest, $L'_{Ei(\mathrm{ST})}$, shall be obtained, at each microphone position, i ($i = 1, 2 \dots n$), either for one single sound event at a time (in which case the process shall be repeated N times, where $N \geqslant 5$), or from several successive, N, sound events (where again $N \geqslant 5$). The measurement time interval shall be long enough to contain all that part of the noise of the event(s), including the decay, which make a significant contribution to the single event sound pressure level. The time-averaged sound pressure levels from the reference sound source, $L'_{pi(\mathrm{RSS})}$, shall also be measured, with an averaging time of 30 s.

In addition, either immediately before or immediately after the sound pressure levels from the noise source under test are measured, the time-averaged octave-band sound pressure levels of the background noise, $L_{pi(\mathrm{B})}$, shall be obtained once at each microphone position, over a representative time interval.

8 Calculation of sound power levels and sound energy levels

8.1 Corrections for background noise

The background noise correction, K_{1i}, at the ith microphone position and in each octave band, shall be calculated using Equation (7):

$$K_{1i} = -10 \lg(1 - 10^{-0,1\Delta L_{pi}}) \text{ dB} \tag{7}$$

where

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

in which

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

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

If, at all microphone positions, $\Delta L_{pi} \geqslant 6$ dB, the measurement is valid according to this International Standard. If, at any microphone position, $\Delta L_{pi} > 15$ dB, K_{1i} is assumed equal to zero at that position. For values of ΔL_{pi} between 6 dB and 15 dB, corrections shall be calculated according to Equation (7).

If, at any microphone position, $\Delta L_{pi} < 6$ dB, the accuracy of the result(s) is reduced. The maximum correction to be applied to these measurements is 1,3 dB. The result may, however, be reported and may be useful for determining an upper boundary to the sound power level of the noise source under test. If such data are reported, it shall be clearly stated in the text of the report, as well as in graphs and tables of results, that the background noise requirements of this International Standard have not been fulfilled.

8.2 Mean time-averaged sound pressure levels for a noise source which emits steady or non-steady noise

The mean corrected time-averaged sound pressure level for the noise source under test in each octave band, $\overline{L_{p(\mathrm{ST})}}$, for the chosen mode of operation, shall be calculated using Equation (8):

$$\overline{L_{p(\mathrm{ST})}} = 10\ \lg\left[\frac{1}{n}\sum_{i=1}^{n}10^{0,1L_{pi(\mathrm{ST})}}\right]\mathrm{dB} \tag{8}$$

where

$$L_{pi(\mathrm{ST})} = L'_{pi(\mathrm{ST})} - K_{1i}$$

in which

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

K_{1i} is the octave-band background noise correction at the ith microphone position, in decibels.

The mean corrected time-averaged sound pressure level for the reference sound source in each octave band, $\overline{L_{p(\mathrm{RSS})}}$, shall be calculated using Equation (9):

$$\overline{L_{p(\mathrm{RSS})}} = 10\ \lg\left[\frac{1}{n}\sum_{i=1}^{n}10^{0,1L_{pi(\mathrm{RSS})}}\right]\mathrm{dB} \tag{9}$$

where

$$L_{pi(\mathrm{RSS})} = L'_{pi(\mathrm{RSS})} - K_{1i(\mathrm{RSS})}$$

in which

$L'_{pi(\mathrm{RSS})}$ is the octave-band time-averaged sound pressure level of the reference sound source, measured at the ith microphone position, corrected for speed, temperature and static pressure according to the manufacturer's specifications, but without correction for background noise, in decibels;

$K_{1i(\mathrm{RSS})}$ is the octave-band background noise correction at the ith microphone position for the measurement of the reference sound source, in decibels.

For several locations of the reference sound source, the mean corrected time-averaged sound pressure level of the reference sound source at each location j ($j = 1 \dots m$) in each octave band, $\overline{L_{pj(\mathrm{RSS})}}$, shall be calculated using Equation (10):

$$\overline{L_{pj(\mathrm{RSS})}} = 10\ \lg\left[\frac{1}{n}\sum_{i=1}^{n}10^{0,1L_{pji(\mathrm{RSS})}}\right]\mathrm{dB} \tag{10}$$

where

$$L_{pji(\mathrm{RSS})} = L'_{pji(\mathrm{RSS})} - K_{1i(\mathrm{RSS})}$$

in which $L'_{pji(\mathrm{RSS})}$ is the uncorrected octave-band time-averaged sound pressure level of the reference sound source located at the jth position, measured at the ith microphone position, in decibels.

8.3 Sound power levels

8.3.1 One location of reference sound source

The sound power level of the noise source under test in each octave band, L_W, for the meteorological conditions at the time and place of the test, shall be calculated using Equation (11):

$$L_W = L_{W(\mathrm{RSS})} - \overline{L_{p(\mathrm{RSS})}} + \overline{L_{p(\mathrm{ST})}} \tag{11}$$

where $L_{W(\mathrm{RSS})}$ is the sound power level of the calibrated reference sound source in the respective octave band, in decibels.

The sound power level, $L_{W\mathrm{ref,atm}}$, corresponding to the reference static pressure of 1,013 25 × 10^5 Pa and reference atmospheric temperature 23,0 °C shall be calculated, if required, according to Annex C.

8.3.2 Several locations of reference sound source

The sound power level of the noise source under test in each octave band, from m locations of the reference sound source, L_W, for the meteorological conditions at the time and place of the test, shall be calculated from the following Equation (12):

$$L_W = 10\lg\left[\frac{1}{m}\sum_{j=1}^{m}10^{0,1L_{Wj(\mathrm{RSS})}}\right] - 10\lg\left[\frac{1}{m}\sum_{j=1}^{m}10^{0,1\overline{L_{pj(\mathrm{RSS})}}}\right] + \overline{L_{p(\mathrm{ST})}}\ \mathrm{dB} \tag{12}$$

where $L_{Wj(\mathrm{RSS})}$ is the sound power level of the calibrated reference sound source in the respective octave band, in decibels, in a calibration position similar to the one used for the test.

The sound power level, $L_{W\mathrm{ref,atm}}$, corresponding to the reference static pressure of 1,013 25 × 10^5 Pa and reference atmospheric temperature 23,0 °C shall be calculated, if required, according to Annex C.

8.4 Mean single event sound pressure level for a noise source which emits impulsive noise

If N single event sound pressure levels have been measured one at a time at a given microphone position i, they shall each be corrected for background noise using Equation (13):

$$L_{Ei,q(\mathrm{ST})} = L'_{Ei,q(\mathrm{ST})} - K_{1i} \tag{13}$$

where

$L_{Ei,q(\mathrm{ST})}$ is the corrected octave-band single event sound pressure level at the ith microphone position for the qth event (q = 1, 2 ... N), with the noise source under test in operation, in decibels;

$L'_{Ei,q(\mathrm{ST})}$ is the measured (uncorrected) octave-band single event sound pressure level at the ith microphone position for the qth event (q = 1, 2 ... N), with the noise source under test in operation, in decibels;

K_{1i} is the background noise correction, in decibels.

The background noise correction, K_{1i}, in each octave band and for each fixed microphone position shall be calculated in a similar manner to that of 8.1, using instead the difference between the measured single event sound pressure level and the background noise level:

$$K_{1i} = -10\lg\left(1 - 10^{-0,1\Delta L_{Ei}}\right)\ \mathrm{dB} \tag{14}$$

where

$$\Delta L_{Ei} = L'_{Ei,q(\mathrm{ST})} - L_{pi(\mathrm{B})}$$

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

The integration time, $T = t_2 - t_1$, and other measurement parameters shall be the same for the measurement of the single event sound pressure level, $L'_{Ei,q(\mathrm{ST})}$, and background noise level, $L_{pi(\mathrm{B})}$.

The mean single event sound pressure level at that microphone position, $L_{Ei(\mathrm{ST})}$, shall then be calculated using Equation (15):

$$L_{Ei(\mathrm{ST})} = 10 \lg \left[\frac{1}{N} \sum_{q=1}^{N} 10^{0,1 L_{Ei,q(\mathrm{ST})}} \right] \mathrm{dB} \tag{15}$$

If one single event sound pressure level has been measured at a given microphone position i encompassing N sound emission events, it shall be corrected for background noise to give the corrected level for N events, $L_{Ei,N(\mathrm{ST})}$, using Equation (16):

$$L_{Ei,N(\mathrm{ST})} = L'_{Ei,N(\mathrm{ST})} - K_{1i} \tag{16}$$

and the mean single event sound pressure level at that microphone position for one event, $L_{Ei(\mathrm{ST})}$, shall then be calculated using Equation (17):

$$L_{Ei(\mathrm{ST})} = L_{Ei,N(\mathrm{ST})} - 10 \lg N \ \mathrm{dB} \tag{17}$$

The mean corrected octave-band single event sound pressure level for the noise source under test, $\overline{L_{E(\mathrm{ST})}}$, for the chosen mode of operation, shall then be calculated using Equation (18):

$$\overline{L_{E(\mathrm{ST})}} = 10 \lg \left[\frac{1}{n} \sum_{i=1}^{n} 10^{0,1 L_{Ei(\mathrm{ST})}} \right] \mathrm{dB} \tag{18}$$

The mean corrected octave-band time-averaged sound pressure level for the reference sound source at one location, $\overline{L_{p(\mathrm{RSS})}}$, and, in the case of several locations of the reference sound source, at each location j ($j = 1 \ldots m$), $\overline{L_{pj(\mathrm{RSS})}}$, shall again be calculated from Equations (9) and (10).

8.5 Sound energy levels

8.5.1 One location of reference sound source

The sound energy level of the noise source under test in each octave band, L_J, for the meteorological conditions at the time and place of the test, shall be calculated using the Equation (19):

$$L_J = L_{W(\mathrm{RSS})} - \overline{L_{p(\mathrm{RSS})}} + \overline{L_{E(\mathrm{ST})}} \tag{19}$$

The sound energy level, $L_{J\mathrm{ref,atm}}$, corresponding to the reference static pressure of 1,013 25 × 10^5 Pa and reference atmospheric temperature 23,0 °C shall be calculated, if required, according to Annex C.

8.5.2 Several locations of reference sound source

The sound energy level of the noise source under test in each octave band from m locations of the reference sound source, L_J, for the meteorological conditions at the time and place of the test, shall be calculated from Equation (20):

$$L_J = 10\ \lg\left[\frac{1}{m}\sum_{j=1}^{m}10^{0{,}1\,L_{Wj(\text{RSS})}}\right] - 10\ \lg\left[\frac{1}{m}\sum_{j=1}^{m}10^{0{,}1\,\overline{L_{pj(\text{RSS})}}}\right] + \overline{L_{E(\text{ST})}}\ \text{dB} \tag{20}$$

where $L_{Wj(\text{RSS})}$ is the sound power level of the calibrated reference sound source in the respective octave band, in decibels, in a calibration position similar to the one used for the test.

The sound energy level, $L_{J\text{ref,atm}}$, corresponding to the reference static pressure of 1,013 25 × 10^5 Pa and reference atmospheric temperature 23,0 °C shall be calculated, if required, according to Annex C.

8.6 A-weighted sound power level and A-weighted sound energy level

Calculation of the A-weighted sound power level, $L_{W\text{A}}$, or the A-weighted sound energy level, $L_{J\text{A}}$, of the noise source under test from the measurements made in octave bands shall be performed using the procedure given in Annex D.

9 Measurement uncertainty

9.1 Methodology

The uncertainties of sound power levels, $u(L_W)$, in decibels, and sound energy levels, $u(L_J)$, in decibels, determined in accordance with this International Standard are estimated by the total standard deviation, in decibels:

$$u\left(L_W\right) \approx u\left(L_J\right) \approx \sigma_{\text{tot}} \tag{21}$$

This total standard deviation is obtained using the modelling approach described in ISO/IEC Guide 98-3. This requires a mathematical model which in case of lack of knowledge can be replaced by results from measurements, including results from round robin tests.

In this context this standard deviation is expressed by the standard deviation of reproducibility of the method, σ_{R0}, in decibels, and the standard deviation, σ_{omc}, in decibels, describing the uncertainty due to the instability of the operating and mounting conditions of the source under test according to:

$$\sigma_{\text{tot}} = \sqrt{\sigma_{R0}^2 + \sigma_{\text{omc}}^2} \tag{22}$$

Equation (22) shows that variations of operating and mounting conditions expressed by σ_{omc} should be taken into account before a measurement procedure with a certain grade of accuracy (characterized by σ_{R0}) is selected for a specific machine family (see 9.5 and E.3).

NOTE If different measurement procedures offered by the ISO 3741[2] to ISO 3747 series are used, systematic numerical deviations (biases) may additionally occur.

Derived from σ_{tot}, the expanded measurement uncertainty U, in decibels, shall be calculated from

$$U = k\ \sigma_{\text{tot}} \tag{23}$$

The expanded measurement uncertainty depends on the degree of confidence that is desired. For a normal distribution of measured values, there is 95 % confidence that the true value lies within the range ($L_W - U$) to ($L_W + U$), [or ($L_J - U$) to ($L_J + U$)]. This corresponds to a coverage factor of $k = 2$.

If the purpose of determining the sound power level is to compare the result with a limit value, it might be more appropriate to apply the coverage factor for a one-sided normal distribution. In that case, the coverage factor k = 1,6 corresponds to a 95 % confidence level.

9.2 Determination of σ_{omc}

The standard deviation σ_{omc} [see Equation (E.1)], which describes the uncertainty associated with the instability of the operating and mounting conditions for the particular source under test, shall be taken into account when determining the measurement uncertainty. It can be determined separately from repeated measurements carried out on the same source at the same location by the same persons, using the same measuring instruments and the same measurement position(s). To determine σ_{omc} repeated sound pressure levels are measured either at the microphone position associated with the highest sound pressure level, $L'_{pi(\text{ST})}$, or measured and averaged over all measured positions, $\overline{L'_{p(\text{ST})}}$. Measurements are then corrected for background noise. For each of these repeated measurements, the mounting of the machine and its operating conditions are to be readjusted. σ_{omc} is designated as σ'_{omc} for the individual sound source under test. A noise test code may provide a value of σ_{omc} representative for the machine family concerned. This value should take into account all possible variations of operating and mounting conditions that are within the scope of the noise test code.

NOTE If the sound power has only a small variation with time and the measurement procedure is defined properly, a value of 0,5 dB for σ_{omc} may be applicable. In other cases, for example, a large influence of the material flow in and out of the machine or material flow that may vary in an unforeseeable manner, a value of 2 dB may be appropriate. However, in extreme cases such as strongly varying noise generated by the processed material (stone breaking machines, metal cutting machines and presses operating under load) a value of 4 dB may result.

9.3 Determination of σ_{R0}

9.3.1 General

The standard deviation σ_{R0} includes uncertainty due to all conditions and situations allowed by this International Standard (different radiation characteristics of the source under test, different instrumentation, different realizations of the measurement procedure) except the influence due to instability of the sound power of the source under test. The latter is considered separately by σ_{omc}.

The values of σ_{R0} given in Table 2 reflect the current knowledge. They are typical upper bounds taking into consideration the great variety of machines and equipment covered by this international standard. Machinery-specific values may be derived from round robin tests (see 9.3.2) or by using the mathematical modelling approach (see 9.3.3). They should be given in noise test codes specific to machinery families (see 9.2 and Annex E).

9.3.2 Round robin test

The round robin test for determining σ_{R0} shall be carried out according to ISO 5725, where the sound power level of the source under test is determined under reproducibility conditions, i.e. different persons carrying out measurements at different testing locations with different measuring instruments. Such a test provides the total standard deviation σ'_{tot} relevant for the individual sound source which has been used for the round robin test. Participating laboratories in round robin tests should cover all possible practical situations.

This total standard deviation σ'_{tot}, in decibels, of all results obtained with a round robin test includes the standard deviation σ'_{omc} and allows σ'_{R0} to be determined by using

$$\sigma'_{R0} = \sqrt{{\sigma'_{\text{tot}}}^2 - {\sigma'_{\text{omc}}}^2} \tag{24}$$

If σ'_{R0} values obtained from many different pieces of machinery belonging to the same family deviate within a small range only, their mean value can be regarded as typical for the application of this International Standard to this particular family and used as σ_{R0}. Whenever available, such a value should be given in the noise test code specific to the machine family concerned (together with σ_{omc}) and used in particular for the purpose of declaring noise emission values.

If no round robin test has been carried out, the existing knowledge about the noise emission from a particular family of machines may be used to estimate realistic values of σ_{R0}.

For certain applications, the effort for the round robin test can be reduced by omitting measurements for different locations, e.g. if machines under test usually are installed under conditions with a small background noise correction K_1 and a small or similar influence of reverberation in the environment or if the noise emission of a machine is rechecked at the same location. Results of such delimited tests should be denoted by $\sigma_{R0,\mathrm{DL}}$, and this designation should also be used for tests on large machines being not movable in space.

Values for $\sigma_{R0,\mathrm{DL}}$ can be expected lower than those given in Table 2.

The determination of σ_{R0} using Equation (24) is imprecise if σ_{tot} is only slightly higher than σ_{omc}. In this case Equation (24) provides a small value of σ_{R0} but with a low accuracy. To limit this inaccuracy σ_{omc} should not exceed $\sigma_{\mathrm{tot}} / \sqrt{2}$.

9.3.3 Modelling approach for σ_{R0}

Generally σ_{R0}, in decibels, is dependent upon several partial uncertainty components, $c_i\, u_i$, associated with the different measurement parameters such as uncertainties of instruments, environmental corrections, and microphone positions. If these contributions are assumed to be uncorrelated, σ_{R0} can be described by the modelling approach presented in ISO/IEC Guide 98-3, as follows:

$$\sigma_{R0} \approx \sqrt{\left(c_1\, u_1\right)^2 + \left(c_2\, u_2\right)^2 + \ldots + \left(c_n\, u_n\right)^2} \tag{25}$$

In Equation (25) the uncertainty components due to the instability of the sound emission of the source are not included. These components are covered by σ_{omc}. Annex E discusses each component of the uncertainty σ_{R0} in accordance with existing knowledge.

NOTE If the uncertainty components in the modelling approach are correlated, Equation (25) does not apply. Furthermore, the modelling approach requires detailed knowledge for determining the individual terms in Equation (25).

By contrast, the estimation of σ_{R0} based on a round robin test does not require assumptions about possible correlations between the individual terms of Equation (25). A round robin test is currently more realistic than determining possible correlations between the single terms of Equation (25) and their dependencies on all other influencing parameters using the modelling approach. However, round robin tests are not always possible and are often replaced by experience from earlier measurements.

9.4 Typical upper bound values of σ_{R0}

Table 2 shows typical upper bound values of the standard deviation, σ_{R0}, for accuracy grades 2 and 3 that may cover most of the applications of this International Standard. In special cases or if certain requirements of this International Standard are not met for a machine family or if it is anticipated that actual values of σ_{R0} for a given family of machines are smaller than those given in Table 2, a round robin test is recommended in order to obtain machine-specific values of σ_{R0}.

Table 2 — Typical upper bound values of the standard deviation of reproducibility of the method, σ_{R0}, for A-weighted sound power levels and sound energy levels determined in accordance with this International Standard

Grade of accuracy	Indicator values dB	Standard deviation of reproducibility[a] σ_{R0} dB
Engineering (grade 2)	$\Delta L_{f\mathrm{A}} \geqslant 7$ at all microphone positions and source directivity range $\leqslant \pm 7$ dB	1,5
Survey (grade 3)	$\Delta L_{f\mathrm{A}} < 7$ or not determined and source directivity range $\leqslant \pm 7$ dB	4,0
Survey (grade 3)	$\Delta L_{f\mathrm{A}} \geqslant 7$ at all microphone positions and source directivity range $> \pm 7$ dB	4,0

[a] These values are applicable to noise sources which emit sound with a relatively "flat" spectrum in the frequency range 100 Hz to 10 000 Hz, i.e. when the octave bands with centre frequencies from 250 Hz to 4 000 Hz have most influence on the A-weighted sound power level or sound energy level. However, if sound at frequencies below 500 Hz is predominant, the reproducibility of sound power level or sound energy level determinations is poorer than that indicated. If there is substantial sound emission at frequencies greater than 2 000 Hz, the noise source can be highly directional. If, in such cases, there are strongly absorbing surfaces (e.g. an absorbing ceiling) close to the noise source under test, again the reproducibility of results can be poorer.

9.5 Total standard deviation, σ_{tot}, and expanded uncertainty, U

The total standard deviation and the expanded uncertainty shall be determined using Equation (22) and Equation (23) respectively. For the purpose of this International Standard, a normal distribution is assumed. Thus a coverage factor of $k = 2$ shall be used corresponding to a coverage probability of 95 %. The coverage factor and coverage probability shall be reported together with the expanded uncertainty.

EXAMPLE Accuracy grade 2; $\sigma_{\mathrm{omc}} = 2{,}0$ dB; coverage factor $k = 2$; measured $L_{W\mathrm{A}} = 82$ dB. Machine-specific determinations of σ_{R0} have not been undertaken thus the value is taken from Table 2 ($\sigma_{R0} = 1{,}5$ dB). Using Equations (23) and (22) it follows

$$U = 2 \times \sqrt{1{,}5^2 + 2^2}\ \mathrm{dB} = 5\ \mathrm{dB}$$

Additional examples of calculated values for σ_{tot} are given in E.3.

NOTE The expanded uncertainty as described in this International Standard does not include the standard deviation of production which is used in ISO 4871[8] for the purpose of making a noise declaration for batches of machines.

10 Information to be recorded

10.1 General

The information listed in 10.2 to 10.5, when applicable, shall be compiled and recorded for all measurements made in accordance with this International Standard.

10.2 Noise source under test

The following information shall be recorded:

a) a description of the noise source under test (including the manufacturer, type, technical data, dimensions, serial number, and year of manufacture);

b) a description of any treatment of auxiliary equipment for the purpose of the test;

c) the mode(s) of operation used for the test(s), the relevant measurement time interval(s), and description of relevant secondary operating parameters (see 6.3);

d) the mounting conditions;

e) the location(s) of the noise source in the test environment.

10.3 Test environment

The following information shall be recorded:

a) a description of the test environment, showing the nature of the building, the construction and any treatment of the walls, floor and ceiling, and a sketch showing the location of the noise source under test and any other contents of the environment;

b) a description of the suitability of the environment for the purpose of the test in accordance with 4.1 (giving value(s) for ΔL_f), as appropriate;

c) the air temperature, in degrees Celsius, and the static pressure, in pascals, near the noise source at the time of test.

10.4 Instrumentation

The following information shall be recorded:

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 the reference sound source, and to verify the performance of the instrumentation system, in accordance with 5.2;

c) the sound power levels of the calibrated reference sound source in the various positions used.

10.5 Acoustic data

The following information shall be recorded:

a) the dimensions of the reference box and the measurement distance;

b) the microphone positions used for the measurements (with a sketch if necessary);

c) the locations used for the reference sound source.

For each mode of operation under which the noise source was tested:

d) remarks on the subjective impression of the noise emitted by the source under test from aural examinations (directivity, discrete tones or components in narrow bands of frequency, temporal characteristics, etc.);

e) the time-averaged or single event sound pressure levels measured at each microphone position, in octave bands;

f) the sound pressure levels of the background noise;

g) the sound power levels or sound energy levels, in decibels, in octave bands and A-weighted (if appropriate) rounded to the nearest 0,1 dB — a graphical representation may optionally be recorded in addition;

NOTE ISO 9296 requires that the declared A-weighted sound power levels, $L_{W\mathrm{Ad}}$, of computers and business equipment are expressed in bels, using the identity 1 B = 10 dB.

h) the expanded uncertainty of the results, in decibels, together with the associated coverage factor and coverage probability;

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

11 Test report

Only those recorded data (see Clause 10) which are required for the purpose of the measurements shall be reported. The report shall also contain any statements required to be reported by certain clauses in the main body of this International Standard.

As this International Standard includes two grades of accuracy, test results shall always state explicitly the uncertainty determined by the grade of accuracy achieved [accuracy grade 2 (engineering) or accuracy grade 3 (survey)]. Additionally information may be given on the basis of Annex E.

If the reported sound power levels or sound energy levels have been obtained in full conformity with the requirements of this International Standard, the report shall state this fact. If the levels have not been obtained in full conformity, the report shall not state or imply that they have been. If one or a small number of identifiable discrepancies exist between the reported levels and the requirements of this International Standard, then the report may state that the measurements have been conducted “in conformity with the requirements of this International Standard, except for…” and the discrepancies clearly identified. In this case, the term “full conformity” shall not be stated or implied.

Annex A
(normative)

Evaluation of the excess of sound pressure level at a given distance

For a suitable location of the reference sound source (see 7.3.2 and 7.3.3), the sound pressure level due to the reference sound source, $L_{p(\text{RSS}),r}$, shall be measured along a straight path with a direct line of sight, at varying distances, r. The excess of sound pressure level at any given distance shall be determined from Equation (A.1):

$$\Delta L_f(r) = L_{p(\text{RSS}),r} - L_{W(\text{RSS})} + 11\ \text{dB} + 20\ \lg \frac{r}{r_0}\ \text{dB} \tag{A.1}$$

where

$L_{W(\text{RSS})}$	is the sound power level of the reference sound source calibrated in a position similar to that used for the measurement, in decibels;
$L_{p(\text{RSS}),r}$	is the sound pressure level measured at a distance r, in metres, from the reference sound source, in decibels;
r	is the distance from the microphone to the reference sound source, in metres;
r_0	is the reference distance, 1 m.

If initial measurements show the frequency spectrum of sound emitted by the noise source under test is broad band, and is similar to that from the reference sound source, A-weighted sound pressure levels can be measured directly and the subscript “A” should be added to the relevant quantities in Equation (A.1). If the spectra are not similar, the measurements shall be made in octave bands of frequency.

Annex B
(informative)

Recommendations for the location of the reference sound source and the microphones, if only one position is used for the reference sound source

B.1 General

Favourable locations of the reference sound source and the microphones relative to the noise source under test depend on the pattern of sound emission from the source under test. Whether the source under test radiates sound omnidirectionally or predominantly in one or more horizontal directions can be determined by making measurements with a sound level meter along a path around the source under test at 1,2 m above the floor and 1 m from the external surfaces of the source under test. If the variation of the measured sound pressure levels is less than ±2 dB, the source under test can be considered as having a fairly omnidirectional sound emission pattern.

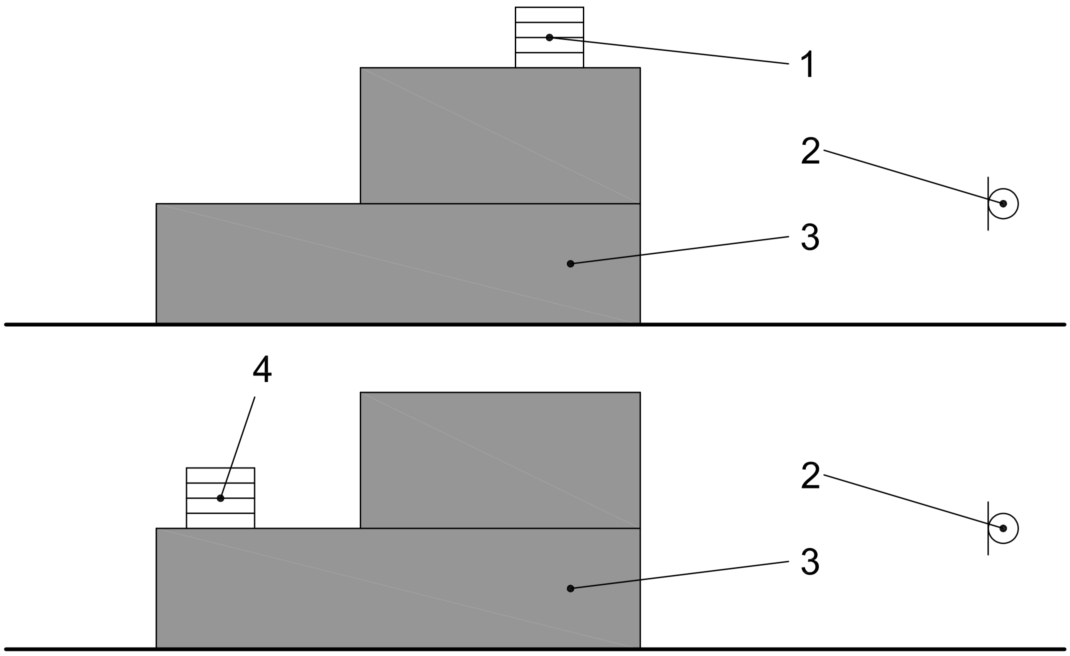
If the variation of the measured sound pressure levels is greater than or equal to ±2 dB, horizontal direction(s) where the source under test emits sound preferentially can be identified.

B.2 Recommendation 1

It is preferable to locate the reference sound source in such a position that its sound emission pattern, in the presence of the noise source under test, is similar to that of the latter.

For a noise source under test that radiates sound fairly omnidirectionally in space, reference sound source positions above the source under test are particularly favourable, see Figure B.1.

For a noise source under test that emits sound preferentially in one horizontal direction, reference sound source positions on the side of the source under test facing in that direction are favourable, see Figure B.2.



Key

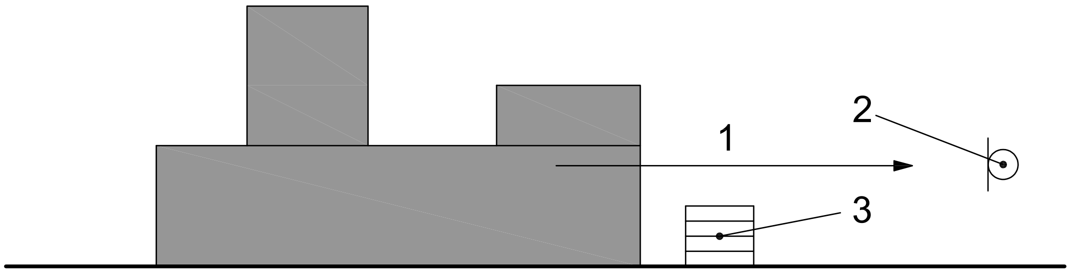
1 favourable position for reference sound source

2 microphone

3 omnidirectional noise source under test

4 unfavourable position for reference sound source

Figure B.1 — Positions for the reference sound source when the noise source under test is fairly omnidirectional



Key

1 direction of dominant sound emission

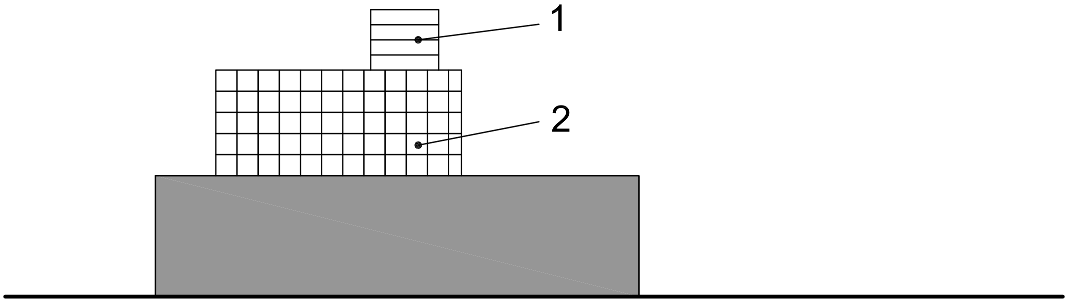
2 microphone

3 favourable position for reference sound source

Figure B.2 — Positions for the reference sound source when the noise source under test is fairly directional

B.3 Recommendation 2

When the noise source under test has a dominant sound-emitting component, the location of which is known, it is recommended that the reference sound source be located as near as possible to that dominant component, and preferably above the noise source under test if the dominant component emits sound fairly omnidirectionally, see Figure B.3. If it is impractical to locate the reference sound source above the noise source under test, a position to the side where the dominant component is located can be used, see Figure B.4.

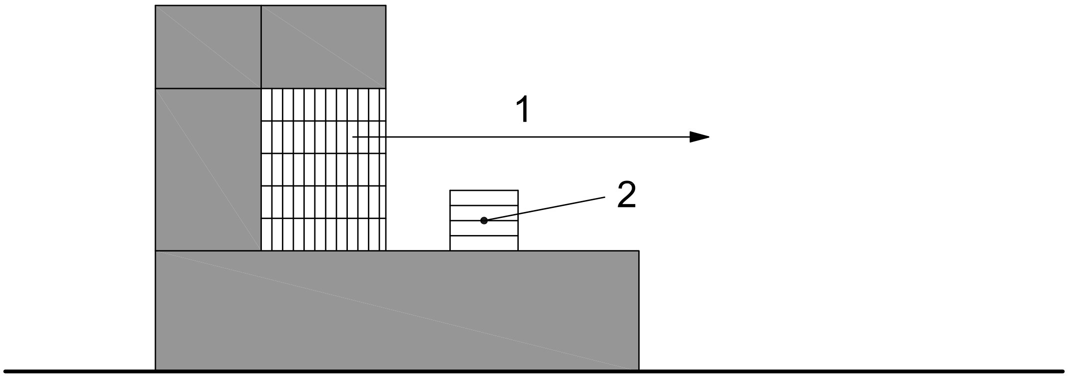


Key

1 favourable position for reference sound source

2 dominant omnidirectional component of noise source under test

Figure B.3 — Position for the reference sound source when the dominant component of the noise source under test is fairly omnidirectional



Key

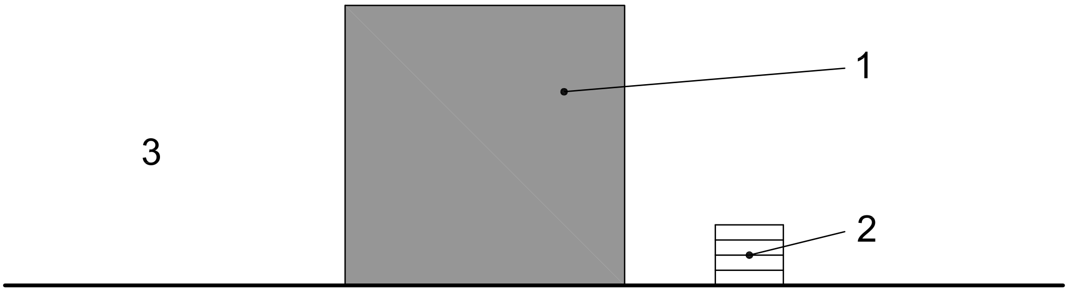
1 direction of dominant sound emission

2 favourable position for reference sound source

Figure B.4 — Position for the reference sound source when the dominant component of the noise source under test is fairly directional

B.4 Recommendation 3

For a given location of the reference sound source to the side of the noise source under test, it is likely that there is a zone where the source under test screens the reference sound source. If the source under test emits some sound into this zone, it is recommended that a single microphone position be located here, see Figure B.5.



Key

1 noise source under test, screening reference sound source

2 position of reference sound source

3 zone which is screened from the reference sound source but not from the noise source under test, where one microphone is to be positioned

Figure B.5 — Zone where one microphone is to be located when the reference sound source is screened by the noise source under test

B.5 Recommendation 4

It is recommended that positioning of microphones close to the imaginary vertical plane containing both the source and the reference sound source be avoided when the latter is located to the side of the noise source under test. It is also recommended that areas close to the dominant sound-emitting component of the noise source under test be avoided.

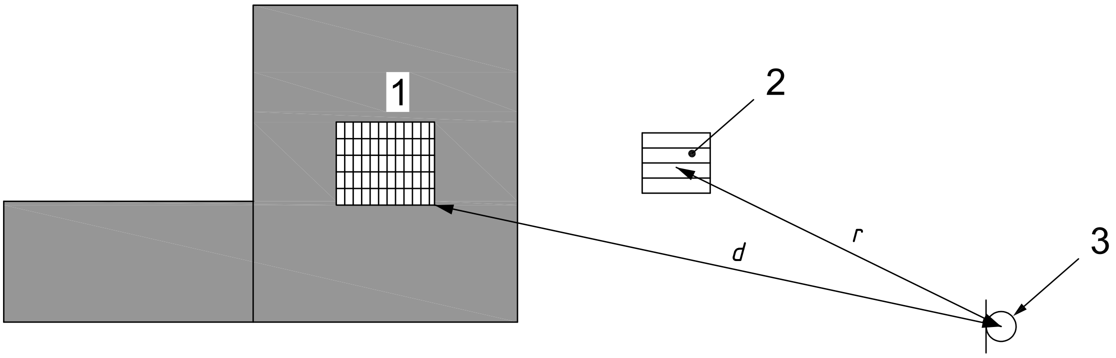
A recommended criterion for positioning a microphone is given by Condition (B.1):

$$0{,}8 \leqslant \frac{r}{d} \leqslant 1{,}2 \tag{B.1}$$

where

r is the distance from the microphone to the reference sound source;

d is the distance from the microphone to the position of the dominant sound-emitting component of the noise source under test, see Figure B.6.



Key

1 dominant sound-emitting component of noise source under test

2 position of reference sound source

3 microphone

d distance from the microphone to the position of the dominant sound-emitting component

r distance from the microphone to the reference sound source

Figure B.6 — Plan view of the noise source under test and reference sound source, showing microphone positioning

Annex C
(normative)

Sound power level and sound energy level under reference meteorological conditions

The sound power level under reference meteorological conditions of static pressure 1,013 25 × 10^5 Pa and atmospheric temperature 23,0 °C, $L_{W\text{ref,atm}}$, shall be calculated using Equation (C.1) (Reference [24]):

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

where

L_W is the sound power level, in decibels, under the meteorological conditions which occurred at the time and place of the test, from Equation (11);

C_2 is the radiation impedance correction, in decibels, a meteorological correction to account for changes in sound power with temperature and pressure, whose value shall be obtained from the appropriate noise test code wherever possible, but in the absence of a noise test code, the following equation is valid for a monopole source, and is a mean value for other sources (see Reference [25]):

$$C_2 = -10 \lg \frac{p_\text{s}}{p_\text{s,0}} \text{dB} + 15 \lg \left[\frac{(273{,}15 + \theta)}{\theta_\text{ref}} \right] \text{dB}$$

in which

p_s is the static pressure at the time and place of the test, in pascals;

$p_\text{s,0}$ is the reference static pressure, 1,013 25 × 10^5 Pa;

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

$\theta_\text{ref} = 296$ K.

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

$$p_\text{s} = p_\text{s,0} \left(1 - aH_\text{a}\right)^b \tag{C.2}$$

where

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

$a = 2{,}2560 \times 10^{-5}\ \text{m}^{-1}$;

$b = 5{,}255\ 3$.

The sound energy level under reference meteorological conditions of static pressure 1,013 25 × 10^5 Pa and atmospheric temperature 23,0 °C, $L_{J\text{ref,atm}}$, shall be calculated using Equation (C.3):

$$L_{J\text{ref,atm}} = L_J + C_2 \tag{C.3}$$

where L_J is the sound energy level, in decibels, under the meteorological conditions which occurred at the time and place of the test, from Equation (19).

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

Annex D
(normative)

Calculation of A-weighted sound power levels and A-weighted sound energy levels from octave-band levels

D.1 A-weighted sound power levels

The A-weighted sound power level, $L_{W\mathrm{A}}$, shall be calculated from Equation (D.1):

$$L_{W\mathrm{A}} = 10\,\lg \sum_{k=k_{\min}}^{k_{\max}} 10^{0,1(L_{Wk}+C_k)}\ \mathrm{dB} \tag{D.1}$$

where

L_{Wk} is the sound power level in the kth octave, in decibels;

k, C_k are given in Table D.1;

$k_{\min}$, $k_{\max}$ are the values of k corresponding, respectively, to the lowest and highest octave bands of measurement.

D.2 A-weighted sound energy levels

The A-weighted sound energy level, $L_{J\mathrm{A}}$, shall be calculated from Equation (D.2):

$$L_{J\mathrm{A}} = 10\,\lg \sum_{k=k_{\min}}^{k_{\max}} 10^{0,1(L_{Jk}+C_k)}\ \mathrm{dB} \tag{D.2}$$

where

L_{Jk} is the sound energy level in the kth octave, in decibels;

k, C_k are given in Table D.1;

$k_{\min}$, $k_{\max}$ are the values of k corresponding, respectively, to the lowest and highest octave bands of measurement.

D.3 Values of k and C_k for use in calculations

For calculations with octave-band data, values of k and C_k are given in Table D.1.

Table D.1 — Values of k and C_k for mid-band frequencies of octave-bands

k	Octave mid-band frequency Hz	C_k dB
1	63	−26,2[a]
2	125	−16,1
3	250	−8,6
4	500	−3,2
5	1 000	0,0
6	2 000	1,2
7	4 000	1,0
8	8 000	−1,1

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

Annex E
(informative)

Guidance on the development of information on measurement uncertainty

E.1 General

The accepted format for the expression of uncertainties generally associated with methods of measurement is that given in ISO/IEC Guide 98-3. This format incorporates a budget of uncertainty components, in which all the various sources of uncertainty are identified and from which the combined total measurement uncertainty can be obtained.

To determine the noise emission of machines and equipment, it is advisable to split up its total uncertainty into two different groups of uncertainty components:

a) those that are intrinsic to the measurement procedure;

b) those that result from the instability of the sound emission of the machine.

Based on knowledge current at the time of publication, this annex provides additional explanations and information by which ISO/IEC Guide 98-3 could be applied in practice for this International Standard.

This annex complements Clause 9.

E.2 Considerations on the total standard deviation, σ_{tot}

The measurement uncertainty used in this International Standard is determined by the expanded uncertainty, U, which is derived directly from the total standard deviation, σ_{tot} [Equation (23)], with σ_{tot} being the approximation of the relevant $u(L_W)$ as defined in ISO/IEC Guide 98-3.

This total standard deviation, σ_{tot}, results from the two components, σ_{R0} and σ_{omc} [see Equation (22)], which are significantly different in nature.

Both quantities are assumed to be statistically independent and are determined separately.

The machinery-specific standard deviation, σ_{omc}, cannot be calculated and has to be determined by repeated measurements as described in E.3. Information on the standard deviation, σ_{R0}, is given in E.4.

NOTE 1 The expanded uncertainty as described in this International Standard does not include the standard deviation of production which is used in ISO 4871[8] for the purpose of making a noise declaration for batches of machines.

NOTE 2 Poorer reproducibility can result in the case of noise sources that emit narrow-band noise or discrete tones. Another cause of poor reproducibility is use of locations different from those in which the reference sound source has been calibrated, giving rise to calibration errors. Such errors occur at low frequencies where the distances of the reference sound source to nearby reflecting surfaces are different during calibration and determinations of sound power levels or sound energy levels of a noise source.

E.3 Considerations on σ_{omc}

The standard deviation, σ_{omc}, described in 9.2, is calculated by

$$\sigma_{\text{omc}} = \sqrt{\frac{1}{N-1}\sum_{j=1}^{N}\left(L_{p,j} - L_{p\text{av}}\right)^2} \text{ dB} \qquad (\text{E.1})$$

where

$L_{p,j}$ is the sound pressure level measured at a prescribed position and corrected for background noise for the jth repetition of the prescribed operating and mounting conditions;

$L_{p\text{av}}$ is its arithmetic mean level calculated for all these repetitions.

These measurements are carried out at the microphone position associated with the highest sound pressure level. When measurements are averaged over all measurement positions, $L_{p,j}$ and $L_{p\text{av}}$ are replaced in Equation (E.1), by $\overline{L_{p,j}}$, and $\overline{L_{p\text{av}}}$, respectively.

In general, the mounting and operating conditions to be used for noise emission measurements are prescribed by machinery-specific noise test codes. Otherwise, these conditions have to be defined precisely and described in the test report.

Some recommendations for defining these conditions and consequences for the expected values of σ_{omc} are given in the following.

The test conditions shall represent normal usage and conform to manufacturers' and users' recommended practice. However, even in normal usage, slightly different modes of operation, variations in material flow, and other conditions varying between different phases of operation may occur. This uncertainty covers both the uncertainty due to variation in long-term operating conditions (e.g. from day to day) and fluctuations of noise emission measurements repeated immediately after readjusting mounting and operating conditions.

Machines that stand exclusively on soft springs or on heavy concrete floors do not normally exhibit any effect of mounting. However, there can be large discrepancies between measurements on heavy concrete floors and those made *in situ*. The uncertainty due to mounting can be highest for machinery that is connected to auxiliary equipment. Hand-held machines may also cause problems. This parameter should be investigated if movement of the machine or mounts causes changes in noise. If there is a range of possible mounting conditions to be included in a single declaration, then σ_{omc} is estimated from the standard deviation of the sound levels for these mounting conditions. If there is any known effect due to mounting, recommended mounting conditions should be documented in the relevant noise test code or manufacturers' recommended practice.

In respect to the main uncertainty quantity, σ_{tot}, investigations on σ_{omc} have a higher priority compared to those on the other uncertainty components leading to σ_{R0} [see Equation (22)]. This is because σ_{omc} may be significantly larger in practice than e.g. σ_{R0} = 1,5 dB for accuracy grade 2 measurements as given in Table 2.

If $\sigma_{\text{omc}} > \sigma_{R0}$, the application of measurement procedures with a high accuracy, i.e. a low value of σ_{R0} makes no sense economically because this is not going to result in a lower value of the total uncertainty.

The examples in Table E.1 show that it might be superfluous to extend the measuring effort to ensure a measurement of accuracy grade 1 if the uncertainty associated with the mounting and operating conditions is large.

Furthermore, $\sigma_{\text{omc}} > \sigma_{R0}$ may create substantial misunderstandings with respect to the true relevant total standard deviation, σ_{tot}, because the different grades of accuracy of this International Standard are presently defined by the value of σ_{R0} only.

Table E.1 — Examples of calculated total standard deviations, σ_{tot}, for three different cases

Standard deviation of reproducibility of the method σ_{R0} dB	**Operating and mounting conditions**		
	stable	unstable	very unstable
	Standard deviation, σ_{omc}, dB		
	0,5	2	4
	Total standard deviation, σ_{tot}, dB		
0,5 (accuracy grade 1)	0,7	2,1	4,0
1,5 (accuracy grade 2)	1,6	2,5	4,3
3 (accuracy grade 3)	3,0	3,6	5,0

E.4 Considerations on σ_{R0}

E.4.1 General

Upper bound values of σ_{R0} are given in Table 2. Additionally in 9.3, the investigation of values of σ_{R0} that are relevant to individual machines or machine families in order to achieve more realistic values is recommended. These investigations shall be carried out either by measurements under reproducibility conditions as defined in ISO 5725 or by calculations using the so-called modelling approach based on Equation (25) which requires more detailed information.

If certain uncertainty components are not relevant for specific applications or are difficult to investigate, delimited definitions of σ_{R0} should be given by noise test codes both for round robin tests (see comments on $\sigma_{R0,\text{DL}}$ in 9.3.2) and for the modelling approach analogously.

The budget approach, however, implies that both components c_i, u_i are statistically independent and the existence of equations which allow assessment of these uncertainty components by considering either measurement parameters and environmental conditions or a reasonably large body of practical experience. However, relevant well-founded data for this International Standard were not available at the time of publication. Nonetheless, the following information may give a rough impression of the relevant quantities without being definitive.

E.4.2 Contributions to the uncertainty, σ_{R0}

E.4.2.1 General

Preliminary estimations show that when corrected for meteorological conditions, the sound power level, $L_{W\text{ref,atm}}$, is a function of a number of parameters, indicated by Equation (E.2):

$$\begin{aligned} L_{W\text{ref,atm}} &= \delta_{\text{method}} + \delta_{\text{omc}} + \overline{L'_{p(\text{ST})}} - K_1 + C_2 + \delta_r + \delta_{\text{mic}} + \delta_{\text{slm}} + \delta_\theta + \\ &+ L_{W(\text{RSS})} - \overline{L'_{p(\text{RSS})}} + K_{1(\text{RSS})} \end{aligned} \tag{E.2}$$

where

$L_{W\text{ref,atm}}$ is the final result of the sound power level measurement including all corrections prescribed by this International Standard and with all relevant uncertainties;

δ_{method} is an input quantity to allow for any uncertainty due to the measurement method applied including the derivation of results and associated uncertainties;

δ_{omc} is an input quantity to allow for any uncertainty due to operating and mounting conditions — this quantity is not included in the calculation of σ_{R0} [see Equation (22)];

$L_{W(\text{RSS})}$ is the sound power level of the calibrated reference sound source in the respective octave band, in decibels (see 8.3.1), including effects of any deviation in the operating conditions of the reference sound source from the nominal conditions;

$\overline{L'_{p(\text{RSS})}}$ is the mean one-third-octave-band time-averaged sound pressure level of the reference sound source, in decibels (see 8.2);

$K_{1(\text{RSS})}$ is the background noise correction for the reference sound source, in decibels (see 8.1);

$\overline{L'_{p(\text{ST})}}$ is the mean octave-band time-averaged sound pressure level of the noise source under test, in decibels (see 8.2);

K_1 is the background noise correction in decibels (see 8.1);

C_2 is the radiation impedance correction (see Annex C) for the sound power level that will be emitted by a noise source under different meteorological conditions, in decibels;

δ_r is an input quantity to allow for any uncertainty due to the separation between noise source and microphone;

δ_{mic} is an input quantity to allow for any uncertainty due to the finite number of microphone and source positions;

δ_{slm} is an input quantity to allow for any uncertainty in the measuring instrumentation;

δ_θ is an input quantity to allow for any uncertainty due to fluctuations in air temperature in the reverberation test room.

NOTE 1 A similar expression to that of Equation (E.2) applies to sound energy levels.

NOTE 2 Similar expressions to that of Equation (E.2) apply with respect to sound power levels determined in frequency bands and with A-weighting applied.

NOTE 3 The quantities included in Equation (E.2) to allow for uncertainties are those thought to be applicable in the state of knowledge at the time of publication of this International Standard, but further research could reveal that there are others.

A probability distribution (normal, rectangular, Student-t, etc.) is associated with each of the input quantities. Its expectation (mean value) is the best estimate for the value of the input quantity and its standard deviation is a measure of the dispersion of values, termed uncertainty.

The uncertainty components relating to mounting and operating conditions are already covered by σ_{omc}, whereas σ_{R0} includes the rest of the uncertainty components.

For accuracy grade 2, Table E.2 and the following numerical example provide information about expectations current at the time of publication for the values of the components, c_i, u_i, that are necessary to calculate $\sigma_{R0} = \sqrt{\sum_i (c_i u_i)^2}$ dB.

The calculation of σ_{R0} assumes that the individual uncertainty contributions are not correlated.

At the time of publication, standard uncertainties from some contributions remain to be established by research.

An explanation and numerical examples of each of the uncertainty parameters in Table E.2 are given in E.4.2.2 to E.4.2.11. Examples and formulae are given to show the expected range of measurement uncertainties, but further research may reveal additional considerations.

NOTE 4 Uncertainty components relating to mounting and operating conditions are not included in this example as they are already covered by σ_{omc}.

Table E.2 — Uncertainty budget for determinations of σ_{R0} for sound power level and sound energy level, valid for frequencies from 500 Hz to 4 kHz, or for A-weighted measurements of a source with a relatively flat frequency spectrum

Quantity	**Estimate**[a] dB	**Standard uncertainty**[a] u_i dB	**Probability distribution**	**Sensitivity coefficient**[a] c_i
δ_{method}, method	0	0,5	Normal	1
$\overline{L'_{p(\mathrm{ST})}}$, mean time-averaged sound pressure level	$\overline{L'_{p(\mathrm{ST})}}$	$s_{r(\mathrm{stat})}$, standard deviation of repeatability	Normal	$1+\dfrac{1}{10^{0,1\Delta L_p}-1}$
K_1, background noise correction	K_1	$s_{r(\mathrm{stat})}$, standard deviation of repeatability	Normal	$\dfrac{1}{10^{0,1\Delta L_p}-1}$
C_2, radiation impedance correction	C_2	0,3	Triangular	1
δ_r, measurement distance (radius)	0	$\dfrac{D}{\sqrt{6}}$	Rectangular	$10^{-0,1\left(L_f-3\right)}\,8,7/r$
δ_{mic}, sampling	0	$s_{r(\mathrm{stat})}\ /\ \sqrt{n}$	Normal	0,5
δ_{slm}, sound level meter	0	0,5	Normal	0,5
δ_θ, temperature	0	$\Delta\theta/\sqrt{3}$	Rectangular	$\dfrac{6,5}{273+\theta}+\dfrac{-0,57+0,25\log\left(2,6\,f\right)}{1+0,001\,1\,H+0,007\,\theta}$
$L_{W(\mathrm{RSS})}$, calibrated sound power level	$L_{W(\mathrm{RSS})}$	0,5	Normal	1
$\overline{L'_{p(\mathrm{RSS})}}$, mean time-averaged sound pressure level	$\overline{L'_{p(\mathrm{RSS})}}$	$s_{r(\mathrm{stat})}$, standard deviation of repeatability	Normal	$1+\dfrac{1}{10^{0,1\Delta L_{p(\mathrm{RSS})}}-1}$
$K_{1(\mathrm{RSS})}$, background noise correction	$K_{1(\mathrm{RSS})}$	$s_{r(\mathrm{stat})}$, standard deviation of repeatability	Normal	$\dfrac{1}{10^{0,1\Delta L_{p(\mathrm{RSS})}}-1}$

[a] Quantities are described in the numerical examples presented in E.4.2.2 to E.4.2.11.

E.4.2.2 Measurement method, δ_{method}

The uncertainty due to the measurement method applied, u_{method}, includes the derivation of results and associated uncertainties. Assuming known biases are accounted for, this uncertainty can only be derived from practical experience or round robin testing. This uncertainty approaches zero as the modelling approach becomes more sophisticated. If, however, there is a lack of knowledge or if it is difficult or impractical to model certain uncertainty components, this component of uncertainty could become the sole determinant of measurement reproducibility, σ_{R0}. An example of this latter case is the implementation of standards by inexperienced users.

The uncertainties in this International Standard have been derived empirically for noise sources which emit sound with a relatively “flat” spectrum in the frequency range from 100 Hz to 10 000 Hz. In this case, the octave bands with centre frequencies from 250 Hz to 4 000 Hz have the most influence on the A-weighted sound power level. However, if sound at frequencies below 500 Hz is predominant, the reproducibility of sound power level or sound energy level determinations is poorer than that indicated above. If substantial amounts of sound are emitted at frequencies greater than 2 000 Hz, the noise source can be highly directional, and if in such cases there are strongly absorbing surfaces (e.g. an absorbing ceiling) close to the noise source under test, the reproducibility of results can be poorer.

Assuming the full modelling approach as implemented in this example is complete and correct, for noise sources which emit sound with a relatively “flat” spectrum in the frequency range from 100 Hz to 10 000 Hz, the assumed value of $u_{\text{method}} = 0{,}5$ dB.

Uncertainties related to the method directly affect results, so that $c_{\text{method}} = 1$. In this example, the uncertainty contribution, $u_{\text{method}}\, c_{\text{method}}$, is 0,5 dB.

E.4.2.3 Sound pressure measurement repeatability, $\overline{L'_{p(\text{ST})}}$

The uncertainty, $u_{L'p(\text{ST})}$, due to the repeatability of measurements of the sound pressure level, $\overline{L'_{p(\text{ST})}}$, is the closeness of agreement between results of successive measurements carried out under the same conditions; it may be obtained from the standard deviation of repeatability, $s_{r(\text{stat})}$, using six measurements of the decibel sound pressure levels at a single microphone position:

$$u_{L'_{p(\text{ST})}} = s_{r(\text{stat})} = \sqrt{\frac{1}{N-1}\sum_{j=1}^{N}\left(L_{p,j} - L_{p\text{av}}\right)^2}\ \text{dB}$$

These measurements are made under repeatability conditions, which are defined as: same measurement procedure; same observer; same measuring instrument; same location; and repetition over a short period of time. Although not specified in ISO/IEC Guide 98-3, it is common to take down, then set up, instrumentation and equipment between trials.

The sensitivity coefficient, $c_{L'_{p(\text{ST})}}$, due to the repeatability is influenced by background noise levels. It is obtained from the derivative of $L_{W_{\text{ref,atm}}}$ [Equation (E.1)], with respect to $\overline{L'_{p(\text{ST})}}$. After substitution for K_1 [Equation (7)], the sensitivity coefficient reduces to:

$$c_{L'_{p(\text{ST})}} = 1 + \frac{1}{10^{0{,}1\Delta L_p} - 1}$$

This may be further simplified to $c_{L'_{p(\mathrm{ST})}} = 1 + c_{K_1}$. Measurement repeatability can be strongly influenced by averaging time. Using the same extreme scenario as for c_{K_1} results in $c_{L'_{p(\mathrm{ST})}} = 1{,}3$. A background noise standard deviation of 3 dB causes the noise source standard deviation to be a minimum of 0,6 dB giving an uncertainty contribution of 0,7 dB. Typically, with better control of background noise, this uncertainty can be reduced to 0,4 dB. If the averaging time does not cover a sufficient number of machinery cycles, the total uncertainty can be unacceptably large. This component of uncertainty can often be made negligible with a sufficiently long averaging time consisting of an integer number of work cycles. Reduction of background noise can reduce the sensitivity coefficient and hence total uncertainty by up to a factor of 2.

E.4.2.4 Background noise correction, K_1

The uncertainty, u_{K_1}, due to the background noise correction, K_1, can be obtained from the standard deviation, s, of the decibel values from repeated measurements of background noise at a single microphone position.

The sensitivity coefficient, c_{K_1}, due to the background noise $\overline{L_{p(\mathrm{B})}}$ is obtained from the derivative of $L_{W_{\mathrm{ref,atm}}}$ with respect to $\overline{L_{p(\mathrm{B})}}$. After substitution for K_1 [Equation (7)], the sensitivity coefficient reduces to:

$$\left| c_{K_1} \right| = \frac{1}{10^{0{,}1\Delta L_p} - 1}$$

This may also be expressed as $\left| c_{K_1} \right| = 10^{-0{,}1\left(\overline{L_{p(\mathrm{ST})}} - \overline{L_{p(\mathrm{B})}}\right)}$ (using the corrected $\overline{L_{p(\mathrm{ST})}}$, instead of $\overline{L'_{p(\mathrm{ST})}}$). For the extreme scenario, high background noise levels with a standard deviation of 3 dB are assumed. The extreme case is taken where ΔL_p is assumed to be 6 dB (the minimum allowable at mid-frequencies in 8.1), resulting in a sensitivity coefficient of $c_{K_1} = 0{,}3$. In the extreme case, the total contribution to uncertainty is 1,0 dB, although typically the value is closer to 0,4 dB. Lowering fluctuations in background noise can reduce this uncertainty component. Significant reductions in the sensitivity coefficient are obtained by reducing background noise by systematically tracking down and blocking or absorbing noise from unwanted sources (through proper grounding, lead wrapping, vibration isolation, adding mass, adding absorptive materials, etc., as appropriate). The uncertainty, u_{K_1}, is typically halved each time the averaging time is increased by a factor of 4. In large rooms, the reverberant field strength is stronger near noise sources, and background noise can be reduced by measuring closer to the source under test.

The uncertainty $u_{K_1(\mathrm{RSS})}$ and sensitivity coefficient $c_{K_1(\mathrm{RSS})}$ for the reference sound source are calculated in a similar manner as above. In this example, the uncertainty contribution is assumed to be 0,4 dB for the reference sound source.

E.4.2.5 Radiation impedance correction, C_2

The uncertainty, u_{C_2}, remaining after the correction for radiation impedance (see Annex C) is $u_{C_2} = 0{,}3$ dB. For altitudes less than 500 m above sea level, no meteorological correction is required. At 120 m altitude and 23 °C, the correction is 0 dB and at 500 m altitude, the correction is 0,6 dB. Assuming a triangular distribution for this uncertainty, the standard deviation is $u_{C_2} = 0{,}6/\sqrt{6} = 0{,}3$ dB. This correction has a direct effect on the measurement so that $c_{C_2} = 1$ and the total uncertainty contribution is 0,3 dB. A lower uncertainty contribution can be obtained by using a more accurate correction from the appropriate test code, or by measuring under the reference conditions of 101,325 kPa absolute pressure (i.e. at sea level) and 23 °C.

E.4.2.6 Excess sound pressure, effect of δ_r and δ_{mic}

E.4.2.6.1 General

The method presented in this International Standard is surprisingly robust and the largest contribution to uncertainty is well predicted by the indicator $\Delta L_{f\text{A}}$. For $\Delta L_{f\text{A}} \geqslant 7$ the contribution to uncertainty $u_\delta c_\delta$ is less than 1 dB. For $\Delta L_{f\text{A}} < 7$ the uncertainty contribution that would be calculated using the method in E.4.2.6.2 and E.4.2.6.3 can approach 4 dB. This uncertainty component is likely related to errors in measurement distance and sampling: $u_\delta^2\, c_\delta^2 = u_r^2\, c_r^2 + u_{\text{mic}}^2\, c_{\text{mic}}^2$. Details are provided in E.4.2.6.2 and E.4.2.6.3.

E.4.2.6.2 Excess sound pressure, measurement distance effect, δ_r

In the direct field of the source, sound pressure is dependent on measurement distance. Modelling the machine as a point source, the uncertainty in the distance to the measuring microphone has a rectangular distribution with a range of $\pm D/2$, where D is the largest dimension of the machine, and the standard deviation is $D/2\sqrt{3}$. The position of the reference sound source is often beside the machine, so that the same uncertainty applies for the distance to the reference sound source. Combining these uncertainties as squares, the net uncertainty due to distance at each microphone position is approximately $u_r = D/\sqrt{6}$.

This uncertainty can be reduced if the n measurement positions are distributed evenly around the machine. In such a case, the uncertainty can be modified to $u_r = D\big/\sqrt{6n}$.

At any point, the measured sound pressure level, $\overline{L'_{p(\text{RSS})}}$, is the sum of the direct, $L_{p,\text{direct}}$, and reverberant, $L_{p,\text{reverb}}$, sound fields $\overline{L'_{p(\text{RSS})}} = 10\ \lg\left(10^{0{,}1L_{p,\text{direct}}} + 10^{0{,}1L_{p,\text{reverb}}}\right)$ where the directly radiated pressure is approximately $L_{p,\text{direct}} = L_W + 10 \lg\,(2\pi r^2/r_0^2)$ dB. Rearranging Equation (A.1) using $L_{p,\text{direct}}$, gives $L_{p(\text{RSS}),r} = L_{p,\text{direct}} + \Delta L_f - 3$ dB. Assuming $L_{p,\text{reverb}}$ is independent of r, and taking the derivative of $L_{W_{\text{ref,atm}}}$ using these equations, the resulting sensitivity coefficient for an uncertainty in measurement radius r relative to the reference sound source is $c_r = 10^{-0{,}1\left(\Delta L_f - 3\ \text{dB}\right)} 8{,}7/r$. The same sensitivity coefficient applies for measurement radius r relative to the noise source.

For the extreme scenario, assume $\Delta L_f = 7{,}1$, all microphone positions on one side of the machine, with machine dimension $D = 3$ m and a measurement radius $r = 6$ m. Then $u_r = 1{,}2$ and the sensitivity coefficient $c_r = 0{,}6$ with resulting uncertainty contribution, $u_r\, c_r$, of 0,7 dB. Typically, measurement at a greater distance can reduce this uncertainty to 0,4 dB. A lower contribution can be obtained by increasing the measurement distance, making the room more reverberant, or distributing the microphones around the machine.

E.4.2.6.3 Excess sound pressure, sampling effect, δ_{mic}

In both free and reverberant fields, the uncertainty due to the finite number of microphone positions is $u_{\text{mic}} = u_{\Delta L'_{p(\text{ST-RSS})}}/\sqrt{n}$, where n is the number of microphone positions, and $u_{\Delta L'_{p(\text{ST-RSS})}}$ is the standard deviation of $\Delta L'_{p(\text{ST-RSS})} = L'_{p(\text{ST})} - L'_{p(\text{RSS})}$, with $\Delta L'_{p(\text{ST-RSS})}$ evaluated at each microphone position. When multiple positions are used for the reference sound source, the results should be averaged so that there is only one value for the reference sound source at each microphone position; this is necessary to avoid undue influence if the reference sound source is shielded from one or more microphone positions. Sampling directly affects the total uncertainty so $c_{\text{mic}} = 1$. For the extreme scenario, with three measurement points and assuming $u_{\Delta L'_{p(\text{ST-RSS})}} = 3$ dB, then $u_{\text{mic}} = 1{,}7$ dB. Typically, $u_{\Delta L'_{p(\text{ST-RSS})}}$ is smaller, and the uncertainty contribution is 0,7 dB. The uncertainty contribution can be reduced by increasing the number of source and measurement positions, increasing ΔL_f by increasing the reverberation time (reducing room absorption), increasing ΔL_f by moving farther from the source (to a maximum distance of 20 m), or adding diffusers. When microphone positions are distributed around the machine, this uncertainty contribution is correlated with the measurement distance effect, and the net effect of the two uncertainties is lower than calculated here.

E.4.2.7 Sound level meter, δ_{slm}

The uncertainty in the measuring instrumentation, u_{slm}, for a class 1 instrument is $u_{\text{slm}} = 0{,}5$ dB. When measurements with the same sound level meter are repeated over a short time span, systematic errors related to calibration, directional response, frequency weighting, temperature pressure and humidity can cancel. The sensitivity coefficient is reduced so that the combined uncertainty is less than u_{slm}. Setting $c_{\text{slm}} = 0{,}5$ results in an uncertainty contribution of 0,3 dB for both the reference sound source and noise source under test. Adding these values squared results in an uncertainty contribution of 0,4 dB. Additional details regarding parameters affecting the uncertainty of sound level meters can be found in IEC 61672-1.

E.4.2.8 Temperature, δ_θ

The uncertainty due to changes in temperature is u_θ. Assuming that the temperature, θ, in degrees Celsius, falls within a range, $\pm\Delta\theta$ °C, with a rectangular distribution, the uncertainty is given by $\delta_\theta = \Delta\theta/\sqrt{3}$.

The sensitivity coefficient due to the temperature, c_θ, is obtained from a rough curve fit to the derivative of L_W with respect to temperature. The equation for L_W comes from ISO 3741[2] with the C_1 term omitted. Estimates of air absorption in the room were obtained from ISO 9613-1[16]. The pressure absorbed with each wall reflection was estimated from the absorption per metre in air, α_{dBm}, and the Sabine estimate ($4V/S$) of the mean free path (approximately 3,3 m for 70 m$^3 < V <$ 200 m^3)

$$c_\theta = \frac{6{,}5}{273+\theta} + 17{,}4\,\frac{V}{S}\left[1 + \frac{1}{\alpha_{\text{room}} + 4(V/S)\alpha_{\text{dBm}}}\right]\frac{\partial \alpha_{\text{dBm}}}{\partial \theta} \approx \frac{6{,}5}{273+\theta} + \frac{-0{,}57 + 0{,}25\,\lg(2{,}6f)}{1 + 0{,}0011H + 0{,}007\theta}$$

where

H is the relative humidity (RH), expressed as a percentage;

f is the highest frequency significantly affecting the A-weighted levels.

For both the reference sound source and the noise source under test, the highest values for this parameter occur at 10 kHz in a dry room at low temperature. An extreme worst case occurs when the source under test changes the room temperature by say 10 °C, so that $u_\theta = 2{,}9$ °C. Assuming most of the sound produced by the source is below 1 kHz, at 20 °C and 10 % RH the sensitivity coefficient is approximately 0,3 so that $u_\theta c_\theta = 1$ dB. Typically, better control of temperature, allowing the room to come to temperature equilibrium before testing, or shorter measurement time intervals can reduce this uncertainty to 0,2 dB. Higher temperature and humidity are typically associated with a lower sensitivity coefficient per degree change in temperature. Recommended temperature and humidity ranges given in ISO 3741[2] are ±1 °C and ±3 % RH below 20 °C when below 30 % RH, to a maximum of ±5 °C and ±10 % RH above 20 °C when above 30 % RH.

E.4.2.9 Reference sound source calibration, $L_{W(\text{RSS})}$

The uncertainty of reproducibility of a reference sound source calibration, $u_{L_{W(\text{RSS})}}$, under optimal conditions, and after application of the manufacturer-supplied corrections for meteorological and operating conditions, is typically 0,5 dB. The value of this uncertainty component should be obtained from the calibration certificate. This uncertainty directly affects measurement results and the sensitivity coefficient $c_{L_{W(\text{RSS})}} = 1$. The measured sound pressure levels are also affected by reflecting surfaces at low frequencies. Any hard surfaced object with dimensions larger than a wavelength, λ, can be considered a reflecting surface. Moving the reference sound source closer than $\lambda/2$ from a reflecting surface can increase its radiated power by up to 3 dB. Similarly, raising the reference sound source off the floor more than $\lambda/2$ can reduce its radiated power by up to 3 dB. This uncertainty can be reduced by calibration of the reference sound source at a known distance from a reflecting surface.

E.4.2.10 Measured sound pressure of the reference sound source, $\overline{L'_{p(\mathrm{RSS})}}$

A reference sound source is extremely stable and produces a high sound level. Typically $u_{L_{p(\mathrm{RSS})}}$ is negligible. An exception occurs when the difference between the level of the reference sound source and the background noise is less than 15 dB. This can cause a significant variation in levels measured from the reference sound source. The uncertainty contribution is calculated similarly to E.4.2.3; repeatability is assessed using the standard deviation of repeatability, s, of six measurements of the decibel sound pressure levels at a single microphone position:

$$u_{L_{p(\mathrm{RSS})}} = s = \sqrt{\frac{1}{N-1}\sum_{j=1}^{N}\left(L_{p,j} - L_{p\mathrm{av}}\right)^2}\ \mathrm{dB}$$

And the sensitivity coefficient is:

$$c_{L'_{p(\mathrm{RSS})}} = 1 + \frac{1}{10^{0,1\Delta L_{p(\mathrm{RSS})}} - 1}$$

where $\Delta L_{p(\mathrm{RSS})}$ is the difference between the measured sound pressure levels with the reference sound source on and the measured level with the reference sound source off (i.e. background noise).

Although the reference sound source is stable, changes in background noise affect the measured levels, so that the extreme case can be the same as in E.4.2.3, with an uncertainty contribution of 0,7 dB. In this example, the uncertainty contribution is assumed to be 0,4 dB for the reference sound source due to better control of background noise. This uncertainty component is managed with better control of background noise. If the background noise is repeatable, this component of uncertainty can be reduced with a sufficiently long averaging time (for both the reference sound source and the background noise). Reduction of background noise can significantly reduce $u_{L_{p(\mathrm{RSS})}}$, as well as reducing the sensitivity coefficient.

E.4.2.11 Background noise correction for reference sound source, $K_{1(\mathrm{RSS})}$

When the difference between the level of the reference sound source and the background noise is less than 15 dB, background noise can affect the measurement uncertainty. This uncertainty contribution is calculated similarly to E.4.2.4; repeatability is assessed using the standard deviation of repeatability of six measurements of the decibel sound pressure levels as obtained in E.4.2.4, i.e. $u_{K_{1(\mathrm{RSS})}} = u_{K_1}$.

The sensitivity coefficient, $c_{K_{1(\mathrm{RSS})}}$, is given by:

$$\left|c_{K_{1(\mathrm{RSS})}}\right| = \frac{1}{10^{0,1\Delta L_{p(\mathrm{RSS})}} - 1}$$

Changes in background noise affect the correction to the measured levels, the extreme case can be the same as in E.4.2.4, with an uncertainty contribution of 0,7 dB. In this example, the uncertainty contribution is assumed to be 0,4 dB for the reference sound source due to better control of background noise. Significant reductions in the sensitivity coefficient are obtained by reducing background noise by systematically tracking down and blocking or absorbing noise from unwanted sources (through proper grounding, lead wrapping, vibration isolation, adding mass, adding absorptive materials, etc., as appropriate). The uncertainty, u_{K_1}, is typically halved each time the averaging time is increased by a factor of 4. In large rooms, the reverberant field strength is stronger near the reference sound sources, and background noise can be reduced by measuring closer to the reference sound source.

E.4.2.12 Typical value for σ_{R0}

For an accuracy grade 2 (engineering) evaluation, using the typical values from above, σ_{R0}, based on Equation (E.2), is

$$\begin{aligned}\sigma_{R0} &= \sqrt{\sum_i \left(u_i\ c_i\right)^2} \\ &= \sqrt{0{,}5^2 + 0{,}4^2 + 0{,}4^2 + 0{,}3^2 + 0{,}4^2 + 0{,}7^2 + 0{,}4^2 + 0{,}2^2 + 0{,}5^2 + 0{,}4^2 + 0{,}4^2} \\ &= 1{,}4\ \text{dB}\end{aligned}$$

E.5 Combined standard uncertainty

In the case of negligible correlation between the input quantities, the combined standard uncertainty of the determination of the sound power level, $u(L_{W\text{ref,atm}})$, in decibels, is given by Equation (E.3):

$$u\left(L_{W\text{ref,atm}}\right) \approx \sigma_{\text{tot}} = \sqrt{\sigma_{R0}^2 + \sigma_{\text{omc}}^2} = \sqrt{\sum_i \left(c_i\ u_i\right)^2 + \sigma_{\text{omc}}^2} \quad \text{(E.3)}$$

E.6 Measurement uncertainty based on reproducibility data

In the absence of data for uncertainty contributions and possible correlations between input quantities, values for the standard deviation of reproducibility as given in Clause 9 may be used as an estimate of the combined standard uncertainty of determinations of sound power levels, $u(L_{W\text{ref,atm}})$. A value may then be selected for the coverage factor, k, and the product, $k\ \sigma_{\text{tot}}$, yields an estimate of the expanded uncertainty, U, with the chosen coverage probability. By convention, a coverage probability of 95 % is usually chosen, and assuming a normal distribution the associated two-sided coverage factor is 2. To avoid misinterpretation, the coverage probability should be stated in test reports, together with the expanded uncertainty.

Bibliography

[1] ISO 3740, *Acoustics — Determination of sound power levels of noise sources — Guidelines for the use of basic standards*

[2] ISO 3741, *Acoustics — Determination of sound power levels and sound energy levels of noise sources using sound pressure — Precision methods for reverberation test rooms*

[3] ISO 3743-1, *Acoustics — Determination of sound power levels and sound energy levels of noise sources using sound pressure — Engineering methods for small movable sources in reverberant fields – Part 1: Comparison method for a hard-walled test room*

[4] ISO 3743-2, *Acoustics — Determination of sound power levels of noise sources using sound pressure — Engineering methods for small, movable sources in reverberant fields — Part 2: Methods for special reverberation test rooms*

[5] 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*

[6] ISO 3745, *Acoustics — Determination of sound power levels and sound energy levels of noise sources using sound pressure — Precision methods for anechoic test rooms and hemi-anechoic test rooms*

[7] ISO 3746, *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*

[8] ISO 4871, *Acoustics — Declaration and verification of noise emission values of machinery and equipment*

[9] ISO 7574-1, *Acoustics — Statistical methods for determining and verifying stated noise emission values of machinery and equipment — Part 1: General considerations and definitions*

[10] ISO 7574-2, *Acoustics — Statistical methods for determining and verifying stated noise emission values of machinery and equipment — Part 2: Methods for stated values for individual machines*

[11] ISO 7574-3, *Acoustics — Statistical methods for determining and verifying stated noise emission values of machinery and equipment — Part 3: Simple (transition) method for stated values for batches of machines*

[12] ISO 7574-4, *Acoustics — Statistical methods for determining and verifying stated noise emission values of machinery and equipment — Part 4: Methods for stated values for batches of machines*

[13] ISO/TS 7849-1, *Acoustics — Determination of airborne sound power levels emitted by machinery using vibration measurement — Part 1: Survey method using a fixed radiation factor*

[14] ISO/TS 7849-2, *Acoustics — Determination of airborne sound power levels emitted by machinery using vibration measurement — Part 2: Engineering method including determination of the adequate radiation factor*

[15] ISO 9296, *Acoustics — Declared noise emission values of computer and business equipment*

[16] ISO 9613-1, *Acoustics — Attenuation of sound during propagation outdoors — Part 1: Calculation of the absorption of sound by the atmosphere*

[17] ISO 9614-1, *Acoustics — Determination of sound power levels of noise sources using sound intensity — Part 1: Measurement at discrete points*

[18] ISO 9614-2, *Acoustics — Determination of sound power levels of noise sources using sound intensity — Part 2: Measurement by scanning*

[19] ISO 9614-3, *Acoustics — Determination of sound power levels of noise sources using sound intensity — Part 3: Precision method for measurement by scanning*

[20] ISO 14257:2001, *Acoustics — Measurement and parametric description of spatial sound distribution curves in workrooms for evaluation of their acoustical performance*

[21] ISO/TR 25417:2007, *Acoustics — Definitions of basic quantities and terms*

[22] ISO 80000-8, *Quantities and units — Part 8: Acoustics*

[23] WITTSTOCK, V. On the uncertainty of meteorological corrections in sound power determination. In: *Proceedings Inter-Noise 2004* (CD-ROM), Prague, 2004

[24] HÜBNER, G. Sound power related to normalized meteorological conditions. In: *Proceedings Inter-Noise 1999* (CD-ROM), Fort Lauderdale, FL, 1999

[25] JONASSON, H.G. *Accurate sound power measurements using a reference sound source*. Borås: Swedish National Testing Institute, 1985. 50 p. (Technical report SP-RAPP 1984:19.)

[26] JONASSON, H.G. *Sound power measurements* in situ *using a reference sound source*. Borås: Swedish National Testing Institute, 1988. (SP report 1988:03.)

[27] JONASSON, H.G. *Determination of emission sound pressure level and sound power level* in situ. Borås: Swedish National Testing and Research Institute, 1999. 80 p. (SP report 1999:18.)

[28] PROBST, W. *Checking of sound emission values*. Bremerhaven: Wirtschaftsverlag NW, Verlag für Neue Wissenschaft, 1999. 102 p. (*Schriftenreihe der Bundesanstalt für Arbietsschutz und Arbeitsmedizin: Forschung, Special report*, 851.)

[29] TACHIBANA, H., YANO, H., YOSHIHISA, K. Definition and measurement of sound energy level of a transient sound source. *J. Acoust. Soc. Jpn* 1987, **8**, pp. 235-240

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