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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

Acoustique — Détermination des niveaux de puissance et d'énergie acoustiques émis par les sources de bruit à partir de la pression acoustique — Méthodes d'expertise pour des conditions approchant celles du champ libre sur plan réfléchissant

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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 3744 was prepared by Technical Committee ISO/TC 43, *Acoustics*, Subcommittee SC 1, *Noise*.

This third edition of ISO 3744 cancels and replaces the second edition (ISO 3744:1994) and ISO 4872:1978, of which it constitutes a merger and a technical revision.

Introduction

This International Standard is one of the series ISO 3741[2] to ISO 3747[6], which specify various methods for determining the sound power levels and sound energy levels of noise sources including machinery, equipment and their sub-assemblies. General guidelines to assist in the selection are provided in ISO 3740[1]. The selection depends on the environment of the available test facility and on the precision of the sound power level or sound energy level values required. It may be necessary to establish a noise test code (see ISO 12001) for the individual noise source in order to select the appropriate sound measurement surface and microphone array from among those allowed in each member of the ISO 3741[2] to ISO 3747[6] series, and to give requirements on test unit mounting, loading and operating conditions under which the sound power levels or sound energy levels are to be obtained. The sound power emitted by a given source into the test environment is calculated from the mean square sound pressure that is measured over a hypothetical measurement surface enclosing the source, and the area of that surface. The sound energy for a single sound event is calculated from this sound power and the time over which it existed.

The methods specified in this International Standard permit the determination of the sound power level and the sound energy level in frequency bands optionally with frequency A-weighting applied.

For applications where greater accuracy is required, reference can be made to ISO 3745, ISO 3741[2] or ISO 9614[13]-[15]. 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 ISO 9614[13]-[15].

This International Standard describes methods of accuracy grade 2 (engineering grade) as defined in ISO 12001, when the measurements are performed in a space that approximates an acoustically free field over a reflecting plane. Such an environment can be found in a specially designed room, or within industrial buildings or outdoors. Ideally, the test source should be mounted on a sound-reflecting plane located in a large open space. For sources normally installed on the floor of machine rooms, corrections are defined to account for undesired reflections from nearby objects, walls and the ceiling, and for the residual background noises that occur there.

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

1 Scope

1.1 General

This International Standard specifies methods for determining the sound power level or sound energy level of a noise source from sound pressure levels measured on a surface enveloping the noise source (machinery or equipment) in an environment that approximates to an acoustic free field near one or more reflecting planes. 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 or with A-weighting applied, is calculated using those measurements.

NOTE Differently shaped measurement surfaces can yield differing estimates of the sound power level of a given noise source and an appropriately drafted noise test code (see ISO 12001) gives detailed information on the selection of the surface.

1.2 Types of noise and noise sources

The methods specified in this International Standard are suitable for all types of noise (steady, non-steady, fluctuating, isolated bursts of sound energy, etc.) defined in ISO 12001.

This International Standard is applicable to all types and sizes of noise source (e.g. stationary or slowly moving plant, installation, machine, component or sub-assembly), provided the conditions for the measurements can be met.

NOTE It is possible that the conditions for measurements given in this International Standard are impracticable for very tall or very long sources such as chimneys, ducts, conveyors and multi-source industrial plants. A noise test code for the determination of noise emission of specific sources can provide alternative methods in such cases.

1.3 Test environment

The test environments that are applicable for measurements made in accordance with this International Standard can be located indoors or outdoors, with one or more sound-reflecting planes present on or near which the noise source under test is mounted. The ideal environment is a completely open space with no bounding or reflecting surfaces other than the reflecting plane(s) (such as that provided by a qualified hemi-anechoic chamber), but procedures are given for applying corrections (within limits that are specified) in the case of environments that are less than ideal.

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 limited bands of frequency and with frequency A-weighting applied. The uncertainty conforms to ISO 12001:1996, accuracy grade 2 (engineering grade).

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 3382-2, *Acoustics — Measurement of room acoustic parameters — Part 2: Reverberation time in ordinary rooms*

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*

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 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 in 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 terms and definitions apply.

3.1
sound pressure
p
difference between instantaneous pressure and static pressure

NOTE 1 Adapted from ISO 80000-8:2007[21], 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[20], 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. $L_{p\mathrm{A}}$ denotes the A-weighted sound pressure level.

NOTE 2 This definition is technically in accordance with ISO 80000-8:2007[21], 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

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

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[20], 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

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

where the reference value, E_0, is (20 µPa)^2 s = 4 × 10^{-10} Pa^2 s

NOTE 1 This quantity can be obtained by $L_{p,T} + 10\ \lg \left[\frac{T}{T_0} \right] \mathrm{dB}$, 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[20]).

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
acoustic free field

sound field in a homogeneous, isotropic medium free of boundaries

NOTE In practice, an acoustic free field is a field in which the influence of reflections at the boundaries or other disturbing objects is negligible over the frequency range of interest.

3.7
acoustic free field over a reflecting plane

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

3.8
reflecting plane

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

3.9
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 (including one-third octave bands with mid-band frequencies from 100 Hz to 10 000 Hz)

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

3.10
reference box

hypothetical right parallelepiped terminating on the reflecting plane(s) 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

NOTE If required, the smallest possible test table can be used for compatibility with emission sound pressure measurements at bystander positions in accordance with, for example, ISO 11201[18].

3.11
characteristic source dimension

d_O

distance from the origin of the co-ordinate system to the farthest corner of the reference box

NOTE Characteristic source dimension is expressed in metres.

3.12
measurement distance

d

distance from the reference box to a parallelepiped measurement surface

NOTE Measurement distance is expressed in metres.

3.13
measurement radius

r

radius of a hemispherical, half-hemispherical or quarter-hemispherical measurement surface

NOTE Measurement radius is expressed in metres.

3.14

measurement surface

hypothetical surface of area, S, on which the microphone positions are located at which the sound pressure levels are measured, enveloping the noise source under test and terminating on the reflecting plane(s) on which the source is located

3.15

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.

3.16

background noise correction

K_1

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

NOTE 1 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, and that in the case of A-weighting is denoted $K_{1\mathrm{A}}$.

3.17

environmental correction

K_2

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

NOTE 1 Environmental correction is expressed in decibels.

NOTE 2 The environmental correction is frequency dependent; the correction in the case of a frequency band is denoted K_{2f}, where f denotes the relevant mid-band frequency, and that in the case of A-weighting is denoted $K_{2\mathrm{A}}$.

NOTE 3 In general, the environmental correction depends on the area of the measurement surface and usually K_2 increases with S.

3.18

surface time-averaged sound pressure level

$\overline{L_p}$

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

NOTE Surface time-averaged sound pressure level is expressed in decibels.

3.19

surface single event time-integrated sound pressure level

$\overline{L_E}$

mean (energy average) of the single event time-integrated sound pressure levels at all the microphone positions, or traverses, on the measurement surface, with the background noise correction, K_1, and the environmental correction, K_2, applied

NOTE Surface single event time-integrated sound pressure level is expressed in decibels.

3.20
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[21], 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.

3.21
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

$$L_W = 10 \lg \frac{P}{P_0} \text{ dB} \qquad (4)$$

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 is indicated by appropriate subscripts; e.g. $L_{W\mathrm{A}}$ denotes the A-weighted sound power level.

NOTE 2 This definition is technically in accordance with ISO 80000-8:2007[21], 8-23.

[ISO/TR 25417:2007[20], 2.9]

3.22
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)

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

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[20], 2.10]

3.23
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

$$L_J = 10 \lg \frac{J}{J_0} \text{ dB} \qquad (6)$$

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 is indicated by appropriate subscripts; e.g. $L_{J\mathrm{A}}$ denotes the A-weighted sound energy level.

[ISO/TR 25417:2007[20], 2.11]

3.24
apparent directivity index

$D_{\mathrm{I}i}^{*}$

measure of the extent to which a noise source under test radiates sound in the direction of the ith microphone position on a measurement surface, relative to the mean sound radiation over the measurement surface

$$D_{\mathrm{I}i}^{*} = L_{pi(\mathrm{ST})} - \left[\overline{L'_{p(\mathrm{ST})}} - K_1 \right] \tag{7}$$

where

$L_{pi(\mathrm{ST})}$ is the background noise-corrected time-averaged (or single event time-integrated) sound pressure level for the ith microphone position on the measurement surface, with the noise source under test (ST) in operation, in decibels;

$\overline{L'_{p(\mathrm{ST})}}$ is the mean (energy average) time-averaged (or single event time-integrated) sound pressure level over all the microphone positions on the measurement surface for the noise source under test, in decibels;

K_1 is the background noise correction, in decibels.

NOTE 1 Apparent directivity index is expressed in decibels.

NOTE 2 The apparent directivity index is determined using measured sound pressure levels from the noise source under test corrected for background noise, but with no corrections for the influence of the acoustic environment.

3.25
apparent surface sound pressure level non-uniformity index

V_{I}^{*}

measure of the variability of measured sound pressure levels over the measurement surface

$$V_{\mathrm{I}}^{*} = \sqrt{\frac{1}{N_{\mathrm{M}} - 1} \sum_{i=1}^{N_{\mathrm{M}}} \left[L_{pi(\mathrm{ST})} - L_{p\mathrm{av}} \right]^2} \tag{8}$$

where

$L_{pi(\mathrm{ST})}$ is the background noise-corrected time-averaged (or single event time-integrated) sound pressure level for the ith microphone position on the measurement surface, with the noise source under test (ST) in operation, in decibels;

$L_{p\mathrm{av}}$ is the arithmetic average of the background noise-corrected time-averaged (or single event time-integrated) sound pressure levels over all the microphone positions on the measurement surface for the noise source under test, in decibels;

N_{M} is the number of microphone positions.

NOTE 1 Apparent surface sound pressure level non-uniformity index is expressed in decibels.

NOTE 2 When V_{I}^{*} is determined over the specific measurement surface given by the measurement radius, r, or measurement distance, d, the value is denoted $V_{\mathrm{I}r}^{*}$ or $V_{\mathrm{I}d}^{*}$, respectively.

NOTE 3 The apparent surface sound pressure level non-uniformity index is determined using measured sound pressure levels from the noise source under test, corrected for background noise, but with no corrections for the influence of the acoustic environment.

4 Test environment

4.1 General

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

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

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

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

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

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

4.2 Criteria for background noise

4.2.1 Relative criteria

4.2.1.1 General

The time-averaged sound pressure level of the background noise measured and averaged (see 8.2.2) over the microphone positions, or traverses, on the measurement surface, shall be at least 6 dB, and preferably more than 15 dB, below the corresponding uncorrected time-averaged sound pressure level of the noise source under test when measured in the presence of this background noise. For measurements in frequency bands, this requirement shall be met in each frequency band within the frequency range of interest.

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

NOTE 1 A similar criterion is applied to single event sound pressure levels: the measurement time interval for the time average is the same as the measurement time interval associated with the single event.

NOTE 2 The noise associated with the microphone traversing mechanism, if one is used for the measurements, is considered to be part of the background noise. In such cases, the background noise is measured with the traversing mechanism operating.

4.2.1.2 Frequency band measurements

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

4.2.1.3 A-weighted measurements

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

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

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

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

NOTE If it is necessary to make measurements where the difference between the sound pressure levels of the background noise and the source together with the background noise is less than 6 dB, ISO 9614-1[13] or ISO 9614-2[14] can be used to give results of accuracy grade 2.

4.2.2 Absolute criteria

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

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

4.2.3 Statement of non-conformity with criteria

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

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

One-third-octave mid-band frequency Hz	Maximum band sound pressure level dB
50	44
63	38
80	32
100	27
125	22
160	16
200	13
250	11
315	9
400	8
500	7
630	7
800	7
1 000	7
1 250	7
1 600	7
2 000	7
2 500	8
3 150	8
4 000	8
5 000	8
6 300	8
8 000	12
10 000	14
12 500	11
16 000	46
20 000	46

4.3 Criterion for acoustic adequacy of test environment

4.3.1 General

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

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

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

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

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

Annex A specifies procedures for determining the magnitude of the environmental correction, K_2, to account for deviations of the test environment from the ideal condition. Measurements in accordance with this International Standard are only valid where $K_{2\mathrm{A}} \leqslant 4$ dB (see 4.3.2, Reference [25]).

NOTE 3 If the environmental correction $K_{2\mathrm{A}}$ exceeds 4 dB, ISO 3743[3][4], ISO 3747[6], ISO 9614-1[13] or ISO 9614-2[14] can be used for results of accuracy grade 2, or ISO 3746[5] can be used for results of accuracy grade 3.

NOTE 4 In some specific cases, the horizontal testing plane cannot be reflecting (e.g. lawnmowers, some types of earth-moving machines). In such cases, a relevant noise test code describes in detail the nature of the plane on which the noise source is mounted and indicates the possible consequences on the measurement uncertainty.

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

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

4.3.2 Criterion for environmental correction

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

a) if $K_{2\mathrm{A}} > 4$ dB, this International Standard is not applicable (see 4.3.1);

b) if $K_{2\mathrm{A}} \leqslant 4$ dB, measurements may be made in accordance with this International Standard, either in frequency bands or A-weighted, using measurement surfaces described in Annexes B, C and D — in addition, for direct measurement of A-weighted sound pressure levels, the alternative microphone array described in Annex F may be used.

Where it is decided to make measurements in frequency bands, the relevant environmental correction K_2 shall be determined in each band over the frequency range of interest in accordance with A.2 or A.3.4 and all measurements to determine L_W or L_J of a noise source shall be made in frequency bands. $L_{W\mathrm{A}}$ or $L_{J\mathrm{A}}$ shall be calculated using the frequency-band levels, see Annex E.

5 Instrumentation

5.1 General

The instrumentation system, including the microphones, cables and windscreen, if used, shall meet the requirements of IEC 61672-1:2002, class 1, and the filters shall meet the requirements of IEC 61260:1995, class 1.

5.2 Calibration

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

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

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

6 Definition, location, installation, and operation of noise source under test

6.1 General

The manner in which the noise source under test is installed and operated may have a significant influence on the sound power or sound energy emitted by a noise source. This clause specifies conditions that are intended to minimize variations in the noise emission due to the installation and operating conditions of the noise source under test. Relevant instructions of a noise test code, if any exists for the family of machinery or equipment to which the noise source under test belongs, shall be followed. The same installation, mounting and operating conditions of the noise source under test shall be used for the determination of emission sound pressure levels and sound power levels. A noise test code for the noise source under test, if any exists, describes the installation, mounting and operating conditions in detail.

Particularly for large machines, it is necessary to decide which components, sub-assemblies, auxiliary equipment, power sources, etc., constitute integral parts of the noise source.

6.2 Auxiliary equipment

Care shall be taken to ensure that any electrical conduits, piping or air ducts connected to the noise source under test do not radiate significant amounts of sound energy into the test environment.

If practical, all auxiliary equipment necessary for the operation of the noise source under test that is not a part of it shall be located outside the test environment. If this is impractical, care shall be taken to minimise 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 7.1) shall be extended appropriately.

6.3 Noise source location

The noise source to be tested shall be installed with respect to, or driven on, the reflecting plane or planes, as if it were in normal use. The noise source shall be located at a sufficient distance from any reflecting wall or ceiling or any reflecting object so that the requirements given in Annex A are satisfied on the measurement surface.

Typical installation conditions for some machines involve two or more reflecting surfaces (e.g. an appliance installed against a wall), or free space (e.g. a hoist), or an opening in an otherwise reflecting plane (so that radiation may occur on both sides of the vertical plane). Detailed information on installation conditions should be based on the general requirements of this International Standard and on the relevant noise test code, if one exists.

6.4 Mounting of the noise source

6.4.1 General

In many cases, the sound power or sound energy emitted by a source is affected by support or mounting conditions. Whenever a typical mounting condition exists for the noise source under test, that condition shall be used or simulated, if feasible.

Mounting conditions specified or recommended by the manufacturer of the noise source under test shall be used unless otherwise specified in any relevant noise test code. If a typical mounting condition does not exist, or cannot be utilized for the test, or if there are several alternative possibilities, care shall be taken to ensure that the mounting arrangement does not induce a variability in the sound output of the source which is atypical. Precautions shall be taken to reduce any sound radiation from the structure on which the noise source is mounted.

Many small noise 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 mounting shall be interposed, if possible, between the noise source under test and the supporting structure, so that the transmission of vibration to the support and the reaction of 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. However, resilient mounts shall be used only if the noise source under test is resiliently mounted in typical field installations.

Coupling conditions, e.g. between prime movers and driven machines, can exert a 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.

6.4.2 Hand-held machinery and equipment

Such machinery and equipment shall be suspended or guided by hand, so that no structure-borne sound is transmitted via any attachment that does not belong to the noise source under test. If the noise source under test requires a support for its operation during testing, the support structure shall be small, considered to be a part of the noise source under test, and comply with the requirements of the relevant noise test code, if any exists.

6.4.3 Base-mounted, wall-mounted, and tabletop machinery and equipment

Such machinery and equipment shall be placed on a reflecting (acoustically hard) plane (floor or wall). Base-mounted machinery or equipment intended exclusively for mounting in front of a wall shall be installed on an acoustically hard surface in front of an acoustically hard wall. Tabletop machinery or equipment shall be placed on the floor at least 1,5 m from any wall of the room, unless a table or stand is required for operation in accordance with the noise test code for the machinery or equipment under test. The table or stand shall be at least 1,5 m from any absorptive surface of the test room. Such machinery or equipment shall be placed at the centre of the top of a standard test table.

NOTE An example of a test table is given in ISO 11201[18].

6.5 Installation and mounting conditions for moving noise sources

The sound power emitted by a moving noise source is determined with the source traversing a defined segment of a straight path. The wheels, tracks or other supports on which the source runs, together with the suspension system, shall be the same for the purpose of test as in normal use.

6.6 Operation of source during test

The sound power or sound energy emitted by a source, whether stationary or moving, 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.

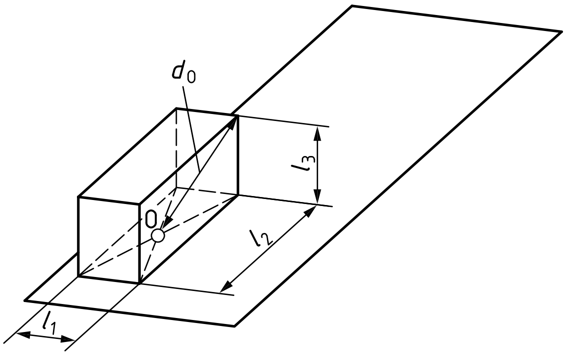
If the sound power or sound energy emission depends on secondary operating parameters, e.g. the type of material being processed or the design of cutting tool, those parameters shall be selected, as far as is practicable, that give the smallest variations and that are typical of normal use. If simulated 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 Reference box and measurement surface

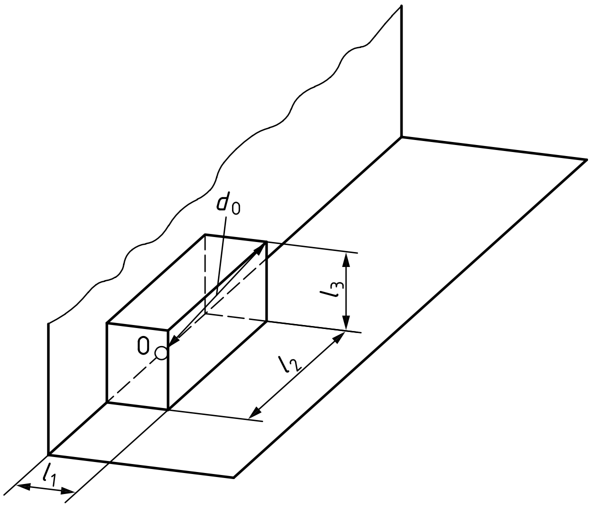
7.1 Reference box

In order to facilitate the selection of the shape and dimensions of the measurement surface, the reference box shall first be delineated. The reference box is a hypothetical surface defined by the smallest right parallelepiped that just encloses the source under test. When defining the dimensions of the reference box, elements protruding from the source which are known not to be significant radiators of sound may be disregarded.

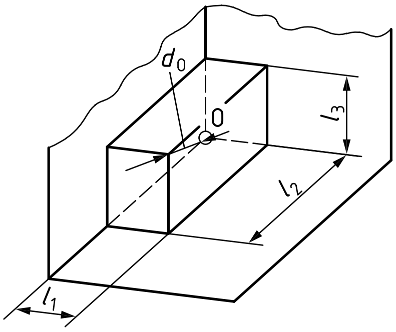
The locations of the reference box, the measurement surface and the microphone positions for measurements, are defined with respect to a co-ordinate system with origin O in the ground plane, shown in Figure 1. The point O is the middle point of a box consisting of the reference box and its images in the adjoining reflecting plane(s). The horizontal axes x and y of the co-ordinate system also lie in the ground plane, parallel to the length and width of the reference box. The characteristic source dimension, d_O, used to determine the dimensions of the measurement surface, is shown in Figure 1 for reference boxes on one, two and three reflecting planes.



a) **Reference box on one reflecting plane,** $d_\mathrm{O} = \sqrt{(l_1/2)^2 + (l_2/2)^2 + l_3^2}$



b) **Reference box on two reflecting planes,** $d_\mathrm{O} = \sqrt{l_1^2 + (l_2/2)^2 + l_3^2}$



c) **Reference box on three reflecting planes,** $d_\mathrm{O} = \sqrt{l_1^2 + l_2^2 + l_3^2}$

Key

d_O characteristic source dimension

l_1 reference box width

l_2 reference box length

l_3 reference box height

O origin

Figure 1 — Reference box and origin of co-ordinates for one, two and three reflecting planes

7.2 Measurement surface

7.2.1 General

This International Standard gives specifications relating to the shape of the measurement surface.

The microphone positions, or traverses, at which the sound pressure levels are measured lie on the measurement surface, a hypothetical surface of area S which envelops the reference box and terminates on the reflecting plane(s). The measurement surface shall be of one of the following four shapes:

a) a hemisphere, half-hemisphere or quarter-hemisphere of radius r (the measurement radius), see Annex B;

b) a right parallelepiped with sides parallel to those of the reference box, each side being spaced a distance d (the measurement distance) from the corresponding side of the reference box, see Annex C;

c) a cylinder, half-cylinder or quarter-cylinder of diameter $2R$ and height h shown in Annex D;

d) a combination of two segments, each being hemispherical, rectangular or cylindrical in form.

In general, the type of measurement surface may be selected based on the shape and size of the noise source, with a goal of having the distances from each microphone to the noise source be roughly equivalent. In addition, measured power levels tend to be the lowest and most accurate when most sound energy passes through the measurement surface at normal incidence. Thus, for a relatively small source, a hemisphere may be preferable; for a long box-like source, a parallelepiped may be preferable; and for a tall, but not wide or long, source, a cylinder may be the preferred measurement surface. However, because different measurement surfaces have different requirements for the minimum distance between the microphones and the source, other considerations, such as the amount of background or reverberant noise in the test room and size of source relative to the usable measurement space of the test environment, may enter into the choice of an appropriate measurement surface.

NOTE For purposes where the sound power or sound energy levels are compared with limit values, it may be possible to reduce the uncertainty due to measurement reproducibility, if the associated noise test code specifies the size and shape of the measurement surface.

For measurements on a series of similar noise sources (e.g. machines of the same type or machines from the same family of a similar size), the same shape of measurement surface shall be used.

7.2.2 Microphone orientation

The microphone shall be oriented so that the reference direction of the microphone (as specified in IEC 61672-1) is normal to the measurement surface. At a corner of a parallelepiped measurement surface, the microphone shall be oriented so that the reference direction of the microphone (as specified in IEC 61672-1) points towards the origin of the reference box (shown by point O in Figure 1).

NOTE Generally, for free-field response microphones, the reference direction is the long axis of the microphone-preamplifier. For diffuse-field response microphones, the reference direction is perpendicular to the long axis of the microphone-preamplifier body.

7.2.3 Hemispherical measurement surface

The hemisphere shall be centred on the co-ordinate origin, O, see Figure 1. For any noise source, the measurement radius, r, shall be equal to or greater than twice the characteristic source dimension, d_O, not less than 1 m and not greater than 16 m.

For small products where measurements are made over a limited frequency range (see 3.9) the measurement radius may be less than 1 m, but shall not be less than 0,5 m.

NOTE A radius less than 1 m can impose limits on the low frequency range of the measurements.

If it is necessary to use a measurement radius that is so large that the requirements for the acoustic environment (see Clause 4) are not fulfilled, a hemispherical measurement surface should not be used and the measurement surface should be a parallelepiped, cylinder or a combination of forms.

If there is only one reflecting plane, the measurement surface is a full hemisphere and its area (see 8.2.5 and 8.3.6) $S = 2\pi r^2$. If the source under test stands against a wall, the measurement surface is a half-hemisphere, of area $S = \pi r^2$. If the source stands in a corner, the measurement surface is a quarter-hemisphere, of area $S = \pi r^2/2$.

7.2.4 Parallelepiped measurement surface

The parallelepiped shall have the same orientation with respect to the co-ordinate origin, O, as the reference box. The measurement distance, d, shall be at least 0,25 m, but preferably 1 m or more.

NOTE A measurement distance less than 0,5 m can impose limits on the low frequency range of the measurements.

If there is only one reflecting plane, the area S of the measurement surface is given by Equation (9)

$$S = 4(ab + bc + ca) \tag{9}$$

where

$a = 0{,}5l_1 + d$

$b = 0{,}5l_2 + d$

$c = l_3 + d$

in which l_1, l_2 and l_3 are the length, width and height, respectively, of the reference box.

If the source under test stands against a wall (see Figure C.12), the measurement surface area is given by

$$S = 2(2ab + bc + 2ca) \tag{10}$$

where

$a = 0{,}5l_2 + 0{,}5d$

$b = 0{,}5l_1 + d$

$c = l_3 + d$

in which

l_1 is the length of the reference box from the wall to the front face,

l_2, l_3 are the width and height, respectively, of the reference box.

If the source stands in a corner (see Figure C.13), the measurement surface area is given by

$$S = 2(2ab + bc + ca) \tag{11}$$

where

$a = 0{,}5l_1 + 0{,}5d$

$b = 0{,}5l_2 + 0{,}5d$

$c = l_3 + d$

in which

l_1, l_2 are the length and width of the reference box measured from the two walls to the respective opposite faces,

l_3 is the height of the reference box.

7.2.5 Cylindrical measurement surface

The cylinder shall be centred around the reference box, with the cylinder's base centred on the co-ordinate origin, O, see Figure 1. The measurement distances to the sides of the reference box are d_1 and d_2, respectively, and that to the top of the reference box is d_3, see Figure D.1. The radius, R, of the cylinder is

$$R = \frac{l_1}{2} + d_1 = \frac{l_2}{2} + d_2$$

and its height, h, is

$$h = l_3 + d_3$$

where l_1, l_2 and l_3 are the length, width, and height, respectively, of the reference box. For the purposes of this International Standard, the dimensional labels shall be assigned so that $l_1 \geqslant l_2$. Due to the fact that the microphones are associated with unequal sub-areas (see Annex D), d_1 and d_3 may be selected arbitrarily based on the size of the noise source under test or other considerations. It is recommended that both of these be set to the same value, preferably 1 m, but neither shall be less than 0,5 m. Furthermore, none of the distances d_1, d_2 or d_3 shall be greater than 1,5 times either of the others. With d_1 and d_3 selected, h and R are defined, and d_2 defaults to

$$d_2 = R - \frac{l_2}{2}$$

The total area S of the measurement surface is equal to the sum of the area of the top circular surface, S_T, and the area of the side vertical surface, S_S. If there is only one reflecting plane, the area of the top surface is $S_\text{T} = \pi R^2$ and the area of the vertical side surface is $S_\text{S} = 2\pi Rh$. If the source under test stands against a wall, the measurement surface is a half-cylinder and $S_\text{T} = \pi R^2/2$ and $S_\text{S} = \pi Rh$, see Figure D.3. If the source stands in a corner, the measurement surface is a quarter-cylinder and $S_\text{T} = \pi R^2/4$ and $S_\text{S} = \pi Rh/2$, see Figure D.4.

7.2.6 Combination measurement surface

The measurement surface shall be considered as having one of the three basic shapes specified in 7.2.3 to 7.2.5, but with segments to the side and/or top taking one of the other shapes; e.g. one possible combination would be a cylinder with an added hemisphere at one end, and another would be a parallelepiped with an added half-cylinder on top. The rules governing the orientation, selection of the measurement radius and/or distance and the determination of the total measurement surface area shall be the same as those given for the respective basic shapes. The surface as a whole shall have no concave or re-entrant segments.

8 Determination of sound power levels and sound energy levels

8.1 Microphone positions on the measurement surface

8.1.1 Hemispherical measurement surface

For a noise source tested adjacent to one reflecting plane, the microphones shall be located at the 10 key positions numbered 1 to 10, the co-ordinates of which are given in Table B.1 and are illustrated in Figure B.1.

In the case of noise sources which do not emit audible discrete tones, i.e. sources which emit only broadband sound, the microphones may optionally follow the traverse lines illustrated in Figure B.2, or be located at the key positions 1 to 10 in Table B.2, illustrated in Figure B.2, instead.

NOTE 1 The overhead positions, numbered 1 to 10 in Table B.1 and Table B.2, may be omitted for safety reasons, if so stated in the relevant noise test code.

When the purpose of the measurements is to determine the A-weighted sound power level directly from measurements of A-weighted sound pressure levels on a hemisphere, the microphone array described in Annex F may be used.

NOTE 2 The noise test code, if any exists, for the machinery family to which the source under test belongs prescribes the microphone array to be used from among those offered by this International Standard.

For a noise source tested adjacent to two reflecting planes, the microphones shall be located at the five key positions numbered 2, 3, 6, 7, and 9, the coordinates of which are given in Table B.2, and illustrated in Figure B.3.

For a noise source tested adjacent to three reflecting planes, the microphones shall be located at the three key positions numbered 1, 2, and 3, the co-ordinates of which are given in Table B.3 and illustrated in Figure B.4.

Additional microphone positions shall be used to make further measurements if at least one of conditions a) to c) applies:

a) the range of A-weighted sound pressure levels (i.e. the difference in decibels between the highest and lowest levels) measured in accordance with 8.2 at positions 1 to 10 exceeds 10 dB, in the case of only one reflecting plane, or that measured at positions 2, 3, 6, 7 and 9 exceeds 5 dB in the case of two reflecting planes, or that measured at positions 1, 2, and 3 exceeds 3 dB in the case of three reflecting planes;

b) the noise source under test emits noise with an apparent A-weighted directivity index (see 8.4) exceeding 5 dB in any direction;

NOTE 3 The apparent directivity index may be influenced by background noise. When $L_{pi(\mathrm{B})}$ at any microphone position is within 6 dB of the highest $L'_{pi(\mathrm{ST})}$, priority should be given to reducing background noise prior to increasing the number of microphone positions.

c) the noise from a large source is emitted only from a small portion of the source, e.g. the openings of an otherwise enclosed machine.

For condition a), the additional microphone positions shall be those numbered 11 to 20 in Table B.1 and Figure B.1, or in Table B.2 and Figure B.2, or 11, 14, 15 and 18 in Figure B.3, or 4, 5 and 6 in Figure B.4, depending upon the type of noise source and the number of reflecting planes. Optionally, the required additional positions on the full hemisphere may be obtained with another measurement at the key microphone positions with the noise source under test rotated clockwise through –60° for the array in accordance with Table B.1, and rotated through 180° for the array in accordance with Table B.2.

For conditions b) or c), extra localized measurement positions on the measurement surface in the region of high noise radiation shall be used in order to make a detailed investigation over a restricted portion of the measurement surface. The procedure is to locate the position of the highest sound pressure level and to concentrate a number of extra microphone positions around it, numerically equal to the range of sound pressure levels (i.e. the difference between the highest and lowest levels) found. If this procedure is followed, the localized microphone positions are associated with unequal segment areas on the measurement surface and proper allowance shall be made in the determination of the mean sound pressure levels (see 8.2.2.2).

The number of microphone positions can be reduced if preliminary investigations for a particular family of noise sources show that the surface sound pressure levels determined using the reduced number deviate by no more than 0,5 dB from those using measurements over the complete set of positions. An example is when the pattern of sound emission is shown to be symmetrical. Alternative arrays of six microphone positions are described in Annex F. The selection from the arrays in Annex B or in Annex F shall be made in the relevant noise test code for a particular type of noise source. With the array from Table B.2, the six positions shall be those numbered 1, 11, 4, 14, 7, and 17. With the array from Table F.1, the six positions shall be those numbered 2, 4, 6, 8, 10, and 12.

If the noise source under test emits steady broadband sound, it is permissible to make measurements using a microphone traversing at constant velocity along a minimum of five coaxial circular measurement paths in parallel planes, as described in B.4, instead of at individual microphone positions. If the source emits audible discrete tones, a minimum of 10 coaxial circular paths shall be used. The coaxial paths may be implemented by either rotating the microphones whilst keeping the noise source stationary or rotating the noise source and keeping the microphones stationary.

8.1.2 Parallelepiped measurement surface

The number and locations of the microphone positions or traverses depend upon the dimensions of the reference box (l_1, l_2 and l_3) and the measurement distance (d), and procedures for determining how many and where they shall be are given in Annex C.

Additional microphone positions shall be used to make further measurements if at least one of conditions a) to c) applies:

a) the range of A-weighted sound pressure levels (i.e. the difference in decibels between the highest and lowest levels) measured in accordance with 8.2 exceeds the number of measurement points;

b) the noise source under test emits noise with an apparent A-weighted directivity index (see 8.4) exceeding 5 dB in any direction:

NOTE 1 The apparent directivity index may be influenced by background noise. When $L_{pi(\mathrm{B})}$ at any microphone position is within 6 dB of the highest $L'_{pi(\mathrm{ST})}$, priority is given to reducing background noise prior to increasing the number of microphone positions.

c) the noise from a large source is emitted only from a small portion of the source, e.g. the openings of an otherwise enclosed machine.

For condition a), the number of measurement positions shall be increased as shown in Figure C.2 or Figure C.5.

For conditions b) or c), extra localized measurement positions on the measurement surface in the region of high noise radiation shall be used in order to make a detailed investigation over a restricted portion of the measurement surface (see Figure C.3 or Figure C.6). The procedure is to locate the position of the highest sound pressure level and to concentrate a number of extra microphone positions around it, numerically equal to the range of sound pressure levels (i.e. the difference between the highest and lowest levels) found. If this procedure is followed, the localized microphone positions are associated with unequal segment areas on the measurement surface and proper adaptation shall be made in the determination of the mean sound pressure levels (see 8.2.2.2).

The number of microphone positions can be reduced if preliminary investigations for a particular family of noise sources show that the surface sound pressure levels determined using the reduced number deviate by no more than 0,5 dB from those using measurements over the complete set of positions. An example is when the pattern of sound emission is shown to be symmetrical.

NOTE 2 The overhead positions can be omitted for safety reasons, if so stated in the relevant noise test code.

If the noise source under test emits steady noise, it is permissible to make measurements using a microphone traversing at constant velocity along parallel measurement paths containing the respective microphone positions from Annex C.

8.1.3 Cylindrical measurement surface

The number and locations of the microphone paths or positions depend upon the dimensions of the measurement surface, and procedures for determining how many and where they shall be are given in Annex D.

8.1.4 Combination measurement surface

For each segment of a combination measurement surface, the rules governing the number and location of the microphone positions shall be the same as those given for the respective basic shapes specified in 8.1.1 to 8.1.3.

8.2 Determination of sound power levels

8.2.1 Measurement of sound pressure levels

Time-averaged sound pressure levels from the noise source under test, $L'_{pi(\mathrm{ST})}$, (either in frequency bands or A-weighted) shall be obtained at each microphone position or over each microphone traverse (i = 1, 2 … N_M) over a typical period of operation of the source, for each mode of operation selected (see 6.6). Where the sound pressure levels at individual microphone positions vary with time, it is important to select carefully the measurement time interval and the interval chosen shall be stated in the test report. The measurement time interval should be 20 s or longer, but shall be at least 10 s for all frequency bands or for A-weighting. When using a traversing microphone, the integrating time shall be an integer number of full traverses and shall include at least two full traverses.

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

8.2.2 Calculation of mean time-averaged sound pressure levels

8.2.2.1 Measurement surface with microphone positions or traverses uniformly distributed

For a measurement surface having microphone positions or traverses associated with equal segment areas, the mean time-averaged sound pressure level from the array of microphone positions over the measurement surface, for the chosen mode of operation of the noise source under test, $\overline{L'_{p(\mathrm{ST})}}$, shall be calculated using Equation (12):

$$\overline{L'_{p(\mathrm{ST})}} = 10 \lg \left[\frac{1}{N_\mathrm{M}} \sum_{i=1}^{N_\mathrm{M}} 10^{0,1 L'_{pi(\mathrm{ST})}} \right] \mathrm{dB} \tag{12}$$

where

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

N_M is the number of microphone positions or individual microphone traverses.

The mean time-averaged sound pressure level of the background noise, $\overline{L_{p(\mathrm{B})}}$, shall be calculated using Equation (13):

$$\overline{L_{p(\mathrm{B})}} = 10 \lg \left[\frac{1}{N_\mathrm{M}} \sum_{i=1}^{N_\mathrm{M}} 10^{0,1 L_{pi(\mathrm{B})}} \right] \mathrm{dB} \tag{13}$$

where

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

N_M is the number of microphone positions or individual microphone traverses.

8.2.2.2 Measurement surface with segments having unequal areas

For a measurement surface having microphone positions or traverses associated with unequal segment areas, the mean time-averaged sound pressure level from the array of microphone positions over the measurement surface, for the chosen mode of operation of the noise source under test, $\overline{L'_{p(\mathrm{ST})}}$, shall be calculated using Equation (14):

$$\overline{L'_{p(\mathrm{ST})}} = 10 \lg \left[\frac{1}{S} \sum_{i=1}^{N_\mathrm{M}} S_i \times 10^{0{,}1 L'_{pi(\mathrm{ST})}} \right] \mathrm{dB} \tag{14}$$

where

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

S_i is the partial area, in square metres, of the measurement surface associated with the ith microphone position or ith microphone traverse;

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

$$S = \sum_{i=1}^{N_\mathrm{M}} S_i$$

N_M is the number of microphone positions or individual microphone traverses.

The mean time-averaged sound pressure level of the background noise, $\overline{L_{p(\mathrm{B})}}$, shall be calculated using Equation (15):

$$\overline{L_{p(\mathrm{B})}} = 10 \lg \left[\frac{1}{S} \sum_{i=1}^{N_\mathrm{M}} S_i \times 10^{0{,}1 L_{pi(\mathrm{B})}} \right] \mathrm{dB} \tag{15}$$

where

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

S_i is the partial area, in square metres, of the measurement surface associated with the ith microphone position or ith microphone traverse;

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

N_M is the number of microphone positions or individual microphone traverses.

8.2.3 Corrections for background noise

The background noise correction, K_1, shall be calculated using Equation (16):

$$K_1 = -10 \lg \left(1 - 10^{-0,1\Delta L_p}\right) \text{dB} \tag{16}$$

where

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

in which

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

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

If $\Delta L_p > 15$ dB, K_1 is assumed to be zero, and no correction for background noise shall be applied.

If 6 dB $\leqslant \Delta L_p \leqslant$ 15 dB, corrections shall be calculated in accordance with Equation (16) and corrections shall be applied.

If $\Delta L_p < 6$ dB for one or more one-third-octave bands, the accuracy of the result(s) may be reduced and the value of K_1 to be applied in the case of these bands is 1,3 dB (the value for $\Delta L_p = 6$ dB). In this case, it shall be clearly stated in the text of the report, as well as in graphs or tables of results, that the data in such bands represent upper bounds to the sound power level of the noise source under test.

NOTE Refer to 4.2 for the criteria for background noise and for determining whether the measurements meet the background noise requirements of this International Standard.

8.2.4 Calculation of surface time-averaged sound pressure levels

The surface time-averaged sound pressure level, $\overline{L_p}$, shall be calculated by correcting the mean time-averaged sound pressure level, $\overline{L'_{p(\text{ST})}}$, for background noise ($K_1$, see 8.2.3) and for the influence of the test environment (K_2, see A.2 and A.3) using Equation (17):

$$\overline{L_p} = \overline{L'_{p(\text{ST})}} - K_1 - K_2 \tag{17}$$

8.2.5 Calculation of sound power levels

The sound power level, L_W, for the meteorological conditions at the time and place of the test shall be calculated using Equation (18):

$$L_W = \overline{L_p} + 10 \lg \frac{S}{S_0} \text{ dB} \tag{18}$$

where

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

S_0 = 1 m^2.

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

8.3 Determination of sound energy levels

8.3.1 Measurement of single event time-integrated sound pressure levels

Single event time-integrated sound pressure levels from the noise source under test, $L'_{Ei(\mathrm{ST})}$ (either in frequency bands or A-weighted), shall be obtained at each microphone position (i = 1, 2 … N_M) either for one single sound emission event at a time (in which case the process shall be repeated N_e times, where N_e is at least five) or from several successive (N_e) sound emission events (where again N_e is at least five). The single event time-integrated sound pressure levels shall be measured simultaneously at all microphone positions through a time period that encompasses the full burst. In this case, it is not permitted to use a traversing microphone.

NOTE If the sound emission event has sufficient repeatability, it can be possible to relax the requirement for simultaneous measurement at all microphone positions.

Either immediately before or immediately after the single event time-integrated sound pressure levels from the noise source under test are measured, the time-averaged sound pressure level of the background noise, $L_{pi(\mathrm{B})}$, shall be obtained at each microphone position over the same integration time used for the measurement of the noise source under test.

8.3.2 Calculation of mean single event time-integrated sound pressure levels at each microphone position

If N_e single event time-integrated sound pressure levels have been measured one at a time at the ith microphone position, the mean single event time-integrated sound pressure level at that position, $L'_{Ei(\mathrm{ST})}$, shall be calculated using Equation (19):

$$L'_{Ei(\mathrm{ST})} = 10\lg\left[\frac{1}{N_\mathrm{e}}\sum_{q=1}^{N_\mathrm{e}}10^{0,1L'_{Ei,q(\mathrm{ST})}}\right]\mathrm{dB} \tag{19}$$

where

$L'_{Ei,q(\mathrm{ST})}$ is the frequency-band or A-weighted single event time-integrated sound pressure level at the ith microphone position, for the qth event (q = 1, 2 … N_e) of the noise source under test in operation, in decibels;

N_e is the number of measurements of single sound emission events.

If one single event time-integrated sound pressure level has been measured at the ith microphone position encompassing N_e sound emission events, the mean single event time-integrated sound pressure level at that position for one event, $L'_{Ei(\mathrm{ST})}$, shall be calculated using Equation (20):

$$L'_{Ei(\mathrm{ST})} = L'_{Ei,N_\mathrm{e}(\mathrm{ST})} - 10\lg N_\mathrm{e}\ \mathrm{dB} \tag{20}$$

where

$L'_{Ei,N_\mathrm{e}(\mathrm{ST})}$ is the frequency-band or A-weighted single event time-integrated sound pressure level at the ith microphone position, encompassing N_e successive sound emission events of the noise source under test in operation, in decibels;

N_e is the number of sound emission events encompassed by one measurement of the single event time-integrated sound pressure level.

8.3.3 Calculation of mean single event time-integrated sound pressure levels over the measurement surface

The mean single event time-integrated sound pressure level over the measurement surface, $\overline{L'_{E(\mathrm{ST})}}$, shall be calculated using the mean single event time-integrated sound pressure levels at the individual microphone positions, $L'_{Ei(\mathrm{ST})}$, in the same way as for the time-averaged sound pressure levels described in 8.2.2.

8.3.4 Correction for background noise

The background noise correction, K_{1i}, shall be calculated using Equation (21):

$$K_1 = -10 \lg \left(1 - 10^{-0,1 \Delta L_E}\right) \mathrm{dB} \tag{21}$$

where

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

in which

$\overline{L'_{E(\mathrm{ST})}}$ is the mean frequency-band or A-weighted single event time-integrated sound pressure level from the array of microphone positions over the measurement surface, with the noise source under test in operation, in decibels[1],

$\overline{L_{p(\mathrm{B})}}$ is the mean frequency-band or A-weighted time-averaged sound pressure level of the background noise from the array of microphone positions over the measurement surface, in decibels (see 8.2.2).

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

8.3.5 Calculation of surface single event time-integrated sound pressure levels

The surface single event time-integrated sound pressure level, $\overline{L_E}$, shall be calculated by correcting the respective mean single event time-integrated sound pressure level over the measurement surface, $\overline{L'_{E(\mathrm{ST})}}$, for background noise ($K_1$, see 8.3.4) and for the influence of the test environment (K_2, see A.2 and A.3) using Equation (22):

$$\overline{L_E} = \overline{L'_{E(\mathrm{ST})}} - K_1 - K_2 \tag{22}$$

8.3.6 Calculation of sound energy levels

The sound energy level, L_J, for the meteorological conditions at the time and place of the test shall be calculated using Equation (23):

$$L_J = \overline{L_E} + 10 \lg \frac{S}{S_0} \mathrm{dB} \tag{23}$$

---

[1] This quantity is based on the measurement either of one single sound emission event at a time, or from several successive sound emission events (see 8.3.1).

where

$\overline{L_E}$ is the surface single event time-integrated sound pressure level, in decibels;

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

S_0 = 1 m^2.

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

8.4 Calculation of apparent directivity indices

To validate the number of measurement positions [see 8.1.1 b) or 8.1.2 b)], the apparent directivity indices (3.24) on the actual measurement surface shall be calculated.

8.5 Calculation of apparent surface sound pressure level non-uniformity index

If required, the apparent surface sound pressure level non-uniformity index (3.25) shall be calculated.

8.6 A-weighted sound power level and sound energy level

Calculation of $L_{W\text{A}}$ or $L_{J\text{A}}$ of the noise source under test from measurements made in frequency bands shall be performed using the procedure given in Annex E.

For sources which emit sound at predominantly high or low frequencies, outside of the nominal frequency range of interest (see 3.9), the frequency range of interest shall be extended to include these frequencies in the calculation of $L_{W\text{A}}$ or $L_{J\text{A}}$, and this shall be made clear in the test report.

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, σ_{tot}, in decibels:

$$u\left(L_W\right) \approx u\left(L_J\right) \approx \sigma_{\text{tot}} \tag{24}$$

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 in accordance with:

$$\sigma_{\text{tot}} = \sqrt{\sigma_{R0}^2 + \sigma_{\text{omc}}^2} \tag{25}$$

Equation (25) 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 H.3).

NOTE If different measurement procedures offered by the ISO 3741 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

$$U = k\,\sigma_{\mathrm{tot}} \tag{26}$$

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 can 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 (H.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 measurements are made at the microphone position associated with the highest value of $L'_{pi(\mathrm{ST})}$ [or $L'_{Ei(\mathrm{ST})}$]. For measurements made with microphone arrays, repeated measurements of the corresponding surface average quantities [$\overline{L'_{pi(\mathrm{ST})}}$ or $\overline{L'_{Ei(\mathrm{ST})}}$] are required. The results of the preceding measurements are corrected for background noise. For each of these repeated measurements, the mounting of the machine and its operating conditions shall be readjusted. For the individual sound source under test, σ_{omc} is designated as σ'_{omc}. It is possible that a noise test code provides a value of σ_{omc} which is 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} can apply. In other cases, e.g. a large influence of the material flow into and out of the machine or material flow that varies in an unpredictable manner, it is possible that a value of 2 dB is 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 can result.

9.3 Determination of σ_{R0}

9.3.1 General

The standard deviation σ_{R0} includes all uncertainty due to conditions and situations allowed by this International Standard (different radiation characteristics of the source under test, different instrumentation, different implementations of the measurement procedure) except that 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 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 H).

9.3.2 Round robin test

The round robin test for determining σ_{R0} shall be carried out in accordance with 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

$$\sigma'_{R0} = \sqrt{{\sigma'_{\text{tot}}}^2 - {\sigma'}^2_{\text{omc}}} \tag{27}$$

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 involved in a round robin test can be reduced by omitting measurements for different locations, e.g. if machines under test are usually installed under conditions with a small background noise correction K_1, and a small or similar environmental correction K_2, or if the noise emission of a machine is rechecked at the same location. Results of such delimited tests should be denoted by $\sigma_{R0,\,\text{DL}}$, and this designation should also be used for tests on large machines not movable in space.

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

The determination of σ_{R0} using Equation (27) is imprecise if σ_{tot} is only slightly higher than σ_{omc}. In this case Equation (27) provides a small value of σ_{R0}, but with a low accuracy. To limit this inaccuracy, σ_{omc} should not exceed $\sigma_{\text{tot}} / \sqrt{2}$.

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:

$$\sigma_{R0} \approx \sqrt{(c_1 u_1)^2 + (c_2 u_2)^2 + ... + (c_n u_n)^2} \tag{28}$$

In Equation (28), 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 H 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 (28) does not apply. Furthermore, the modelling approach requires detailed knowledge to determine the individual terms in Equation (28).

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 (28). A round robin test is currently more realistic than determining possible correlations between the single terms of Equation (28) 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 grade 2 that may cover most of the applications of this International Standard (References [25][26]). 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 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 sound power levels and sound energy levels determined in accordance with this International Standard

Frequency bandwidth	One-third-octave mid-band frequency Hz	Standard deviation of reproducibility, σ_{R0} dB
One-third-octave	100 to 160	3,0
	200 to 315	2,0
	400 to 5 000	1,5
	6 300 to 10 000	2,5
A-weighted per Annex E		1,5[a]

[a] Applicable to noise sources which emit sound with a relatively “flat” spectrum in the frequency range from 100 Hz to 10 000 Hz.

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

The total standard deviation and the expanded measurement uncertainty shall be determined using Equation (25) and Equation (26), respectively.

EXAMPLE Accuracy grade 2; σ_{omc} = 2,0 dB; coverage factor k = 2; determined $L_{W\text{A}}$ = 82 dB. Machine-specific determinations of σ_{R0} have not been undertaken thus the value is taken from Table 2 (σ_{R0} = 1,5 dB). Using Equations (26) and (25) it follows

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

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

NOTE The expanded measurement uncertainty as described in this International Standard does not include the standard deviation of production which is used in ISO 4871[7] 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) and the relevant measurement time interval(s);

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:

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

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

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

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

c) the air temperature, in degrees Celsius, and the static pressure, in kilopascals, 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 to verify the calibration of the instrumentation system and, if used, to calibrate the reference sound source, in accordance with 5.2;

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

10.5 Acoustical data

The following information shall be recorded:

a) the dimensions of the reference box, l_1, l_2, and l_3, the shape of the measurement surface and the measurement radius, r, or distance, d;

b) the microphone positions or path(s) used for the measurements (with a sketch if necessary) including any regions where the positions are associated with unequal areas of the measurement surface;

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

c) all measured sound pressure levels, whether time-averaged, $L_{p,T}$, or single event, L_E, in the test environment from the noise source under test;

d) the correction(s), K_1, in decibels, to account for background noise;

e) the correction(s), K_2, in decibels, to account for the test environment, and the method from Annex A used to determine it (them);

f) the surface time-averaged sound pressure levels, $\overline{L}_p$, or surface single event time-integrated sound pressure levels, L_E, in decibels;

g) the sound power levels, L_W or $L_{W\mathrm{A}}$, or sound energy levels, L_E or $L_{E\mathrm{A}}$, in decibels, in frequency bands or A-weighted, as appropriate, rounded to the nearest 0,1 dB; a graphical representation may optionally be recorded in addition;

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

i) if required, the maximum apparent directivity index, $D_{\mathrm{I}i}^*$ and the direction in which it applies;

j) if required, the apparent surface sound pressure level non-uniformity index at the applicable measurement radius, $V_{\mathrm{I}r}^*$ or measurement distance $V_{\mathrm{I}d}^*$;

k) 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. 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)

Qualification procedures for the acoustic environment

A.1 General

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

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

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

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

A.2 Absolute comparison test

A.2.1 General

For noise sources under test where a hemispherical measurement surface is used, a reference sound source meeting the requirements of ISO 6926 shall be mounted in the test environment, in essentially the same position as that of the noise source under test. The sound power level of the reference sound source shall be determined in accordance with the procedure of Clause 8 without the environmental correction, K_2 (i.e. K_2 is initially assumed equal to zero). The same measurement surface shall be used as that for the measurements of the noise source under test.

The environmental correction, K_2, is given by:

$$K_2 = L_W^* - L_{W(\text{RSS})} \qquad \text{(A.1)}$$

where

L_W^* is the environmentally uncorrected sound power level of the reference sound source, determined in accordance with Clause 8 when using the value 0 for K_2, in decibels;

$L_{W(\text{RSS})}$ is the sound power level of the calibrated reference sound source under the meteorological conditions of the test, in decibels.

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

A.2.2 Locations of reference sound source in test environment

If the noise source under test can be removed from the test site, the reference sound source shall be located on the reflecting plane, independent of the height of the noise source under test, except for special cases such as hand-held machine tools.

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

A single location is sufficient for small- and medium-sized sources (l_1, l_2, $l_3 \leqslant 2$ m). For larger sources and for those with ratios of length to width greater than 2, the reference sound source shall be operated on the floor at four points. Assuming that the projection of the noise source under test on the floor is approximately rectangular in shape, the four points are located at the middle points of the sides of the rectangle. To obtain L_W, the surface sound pressure level, $\overline{L_p}$, shall be calculated with the reference sound source located at each of the four points on the floor. At each point on the measurement surface, the sound pressure level shall be averaged for the four source locations on a mean-square basis, i.e. using Equation (12).

If the noise source under test cannot be removed from the test site, the reference sound source shall be placed at one or more positions in the same environment, different from the position of the noise source under test, but equivalent with respect to room reflections. Positions of the reference sound source on top of the noise source under test or adjacent to it, in accordance with ISO 3747[6], may be used.

With regard to a sufficient number of microphone positions, care should be taken to fulfil the requirements of 8.1.1, 8.1.2 or 8.1.3, as appropriate.

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

A.3.1 General

The environmental correction, K_2, shall be calculated from Equation (A.2):

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

where

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

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

A.3.2 Reverberation method

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

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

$$A = 0{,}16 \frac{V}{T_n} \tag{A.3}$$

where

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

T_n is the measured reverberation time (see ISO 3382-2), in seconds, for A-weighting or in frequency bands.

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

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

A.3.3 Two-surface method

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

Two surfaces that surround the noise source shall be selected. The first surface shall be the measurement surface, in accordance with 7.2, for the determination of the sound power level. The area of the first surface shall be designated S_1. The second surface with area S_2 shall be geometrically similar to the first surface and located further away and symmetrical with respect to the noise source under test. On both surfaces, the background noise criteria specified in 4.2 shall be fulfilled.

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

$$\frac{A}{S_1} = \frac{4(M-1)}{1-M(S_1/S_2)} \tag{A.4}$$

where

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

in which

$\overline{L_{p1}}$ is the mean time-averaged sound pressure level on S_1, see Equation (12), corrected for background noise but not for the influence of the environment (see 8.2.4), in decibels,

$\overline{L_{p2}}$ is the mean time-averaged sound pressure level on S_2, see Equation (12), corrected for background noise but not for the influence of the environment (see 8.2.4), in decibels;

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

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

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

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

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

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

The microphone positions shall be on the fixed point array with the co-ordinates given in Table B.2.

The mean background noise-corrected time-averaged sound pressure level from the reference sound source on the hemispherical measurement surface, $\overline{L_{p(\text{in situ})}}$, shall then be determined in accordance with 8.2.2 and 8.2.4.

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

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

where

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

$S_0 = 1\ \text{m}^2$;

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

$L_{W(\text{RSS})}$ is the sound power level of the calibrated reference sound source under the meteorological conditions of the test, in decibels.

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

If $L_{W(\text{RSS})}$ is not known, or if it is not possible to calculate $L_{W(\text{RSS,in situ})}$ from $L_{W(\text{RSS})}$, repetition of the measurements described above with the reference sound source in an acoustic free field over a reflecting plane outdoors to obtain a reference mean time-averaged sound pressure level, $\overline{L_{p(\text{ref})}}$, is recommended. From these measurements the equivalent absorption area in the environment where the noise source under test is mounted is calculated using Equation (A.6):

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

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

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

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

$$A = \alpha\, S_{\text{V}} \tag{A.7}$$

where

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

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

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

Mean sound absorption coefficient, α	Description of room
0,05	Nearly empty room with smooth hard walls made of concrete, brick, plaster or tile
0,10	Partly empty room; room with smooth walls
0,15	Right cuboid room with furniture; right cuboid machinery room or industrial room
0,20	Irregularly shaped room with furniture; irregularly shaped machinery room or industrial room
0,25	Room with upholstered furniture; machinery or industrial room with sound-absorbing material on part of ceiling or walls
0,30	Room with sound-absorbing ceiling, but no sound-absorbing materials on walls
0,35	Room with sound-absorbing materials on both ceiling and walls
0,50	Room with large amounts of sound-absorbing materials on ceiling and walls

Annex B
(normative)

Microphone arrays on a hemispherical measurement surface

B.1 Microphone positions and additional microphone positions

The preferred locations of microphone positions, suitable for all noise sources including those which emit discrete tones, are shown in Table B.1 and Figure B.1. Optionally, for noise sources which emit no audible discrete tones, the locations shown in Table B.2 and Figure B.2 may be used instead. In the case of a source which emits tones, strong interference effects are liable to occur and the locations from Table B.1 shall be used.

In Tables B.1 and B.2, the co-ordinates (x, y, z) of the positions are given, each associated with equal areas on the surface of a hemisphere of radius r and origin at the point O, see Figure 1.

Table B.1 — Preferred microphone positions for all noise sources

Position number	x/r	y/r	z/r
1	0,16	– 0,96	0,22
2	0,78	– 0,60	0,20
3	0,78	0,55	0,31
4	0,16	0,90	0,41
5	– 0,83	0,32	0,45
6	– 0,83	– 0,40	0,38
7	– 0,26	– 0,65	0,71
8	0,74	– 0,07	0,67
9	– 0,26	0,50	0,83
10	0,10	– 0,10	0,99
11	0,91	– 0,34	0,22
12	0,91	0,38	0,20
13	– 0,09	0,95	0,31
14	– 0,70	0,59	0,41
15	– 0,69	– 0,56	0,45
16	– 0,07	– 0,92	0,38
17	0,43	– 0,55	0,71
18	0,43	0,61	0,67
19	– 0,56	0,02	0,83
20	0,14	0,04	0,99

Table B.2 — Microphone positions for a broadband noise source

Position number	*x*/*r*	*y*/*r*	*z*/*r*
1	– 0,99	0	0,15
2	0,50	– 0,86	0,15
3	0,50	0,86	0,15
4	– 0,45	0,77	0,45
5	– 0,45	– 0,77	0,45
6	0,89	0	0,45
7	0,33	0,57	0,75
8	– 0,66	0	0,75
9	0,33	– 0,57	0,75
10	0	0	1,00
11	0,99	0	0,15
12	– 0,50	0,86	0,15
13	– 0,50	– 0,86	0,15
14	0,45	– 0,77	0,45
15	0,45	0,77	0,45
16	– 0,89	0	0,45
17	– 0,33	– 0,57	0,75
18	0,66	0	0,75
19	– 0,33	0,57	0,75
20	0	0	1,00

B.2 Microphone positions for sources adjacent to two reflecting planes

For a noise source to be tested adjacent to two reflecting planes, reference shall be made to Figure B.3 for the purposes of defining a suitable measurement surface and microphone positions. In this case, the radius, r, of the measurement surface shall be at least 3 m. The coordinates of the microphone positions shown in Figure B.3 are as given for the respective position numbers in Table B.2.

B.3 Microphone positions for sources adjacent to three reflecting planes

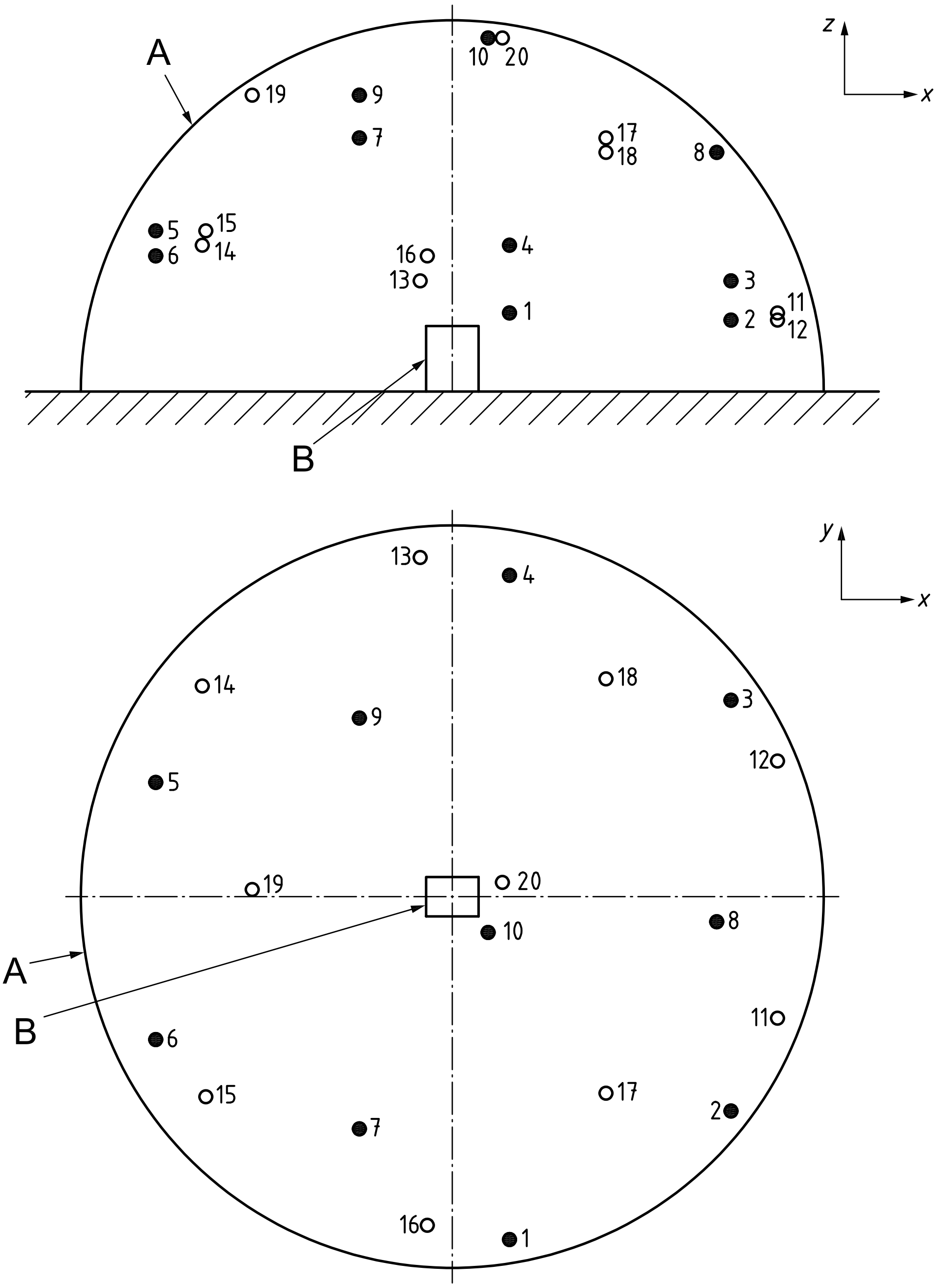
For a noise source to be tested adjacent to three reflecting planes, reference shall be made to Figure B.4 for the purposes of defining a suitable measurement surface and microphone positions. In this case, the radius, r, of the measurement surface shall be at least 3 m. The co-ordinates of the microphone positions shown in Figure B.4 are as given for the respective position numbers in Table B.3.

Table B.3 — Microphone positions for a source adjacent to three reflecting planes

Position number	*x*/*r*	*y*/*r*	*z*/*r*
1	0,86	– 0,50	0,15
2	0,45	– 0,77	0,45
3	0,47	– 0,47	0,75
4	0,50	– 0,86	0,15
5	0,77	– 0,45	0,45
6	0,47	– 0,47	0,75

B.4 Measurement paths

Coaxial circular paths are selected, see Figure B.5, so that the annular areas of the hemisphere associated with each are equal.



Key

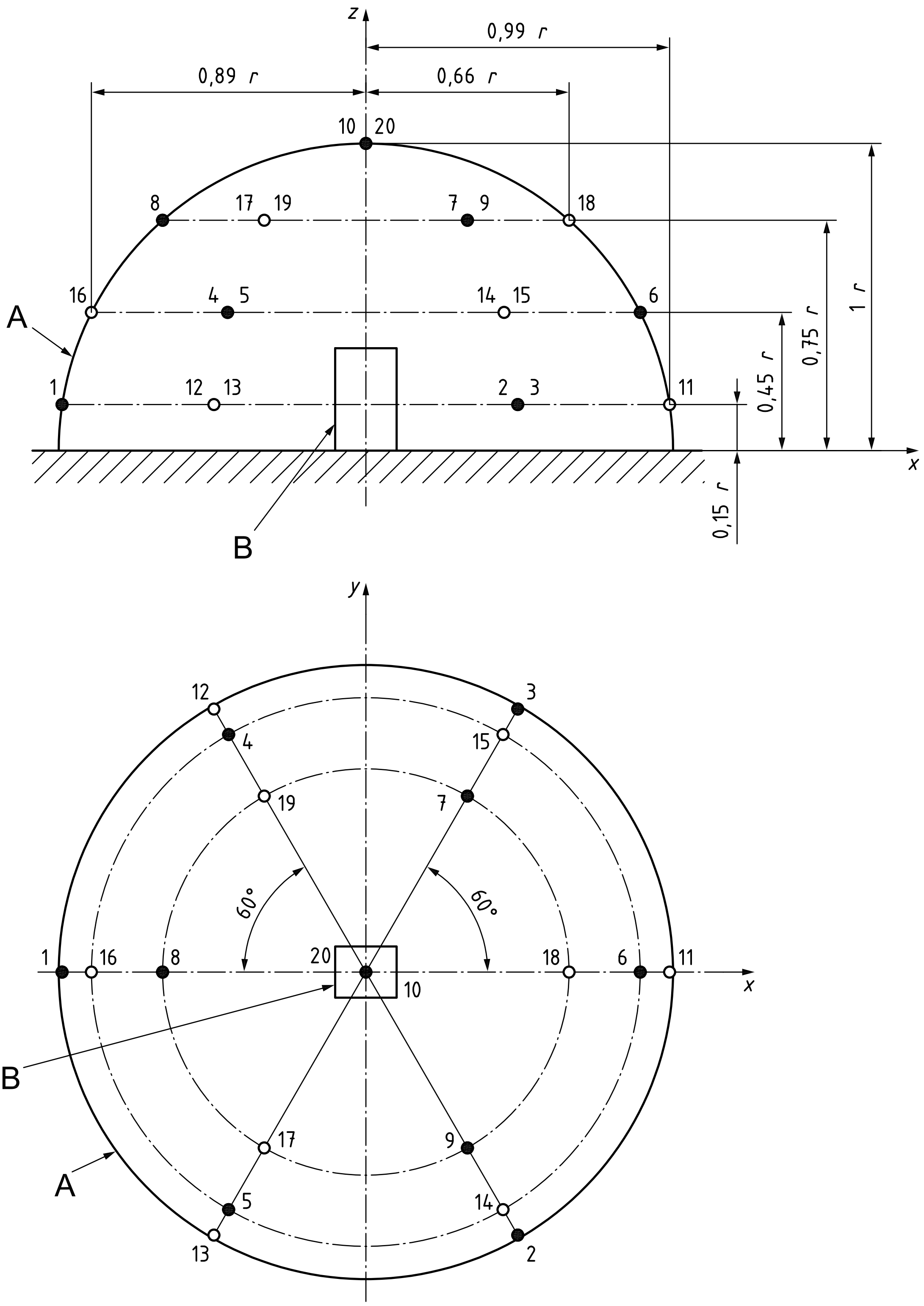
● key microphone positions (1, 2, 3, 4, 5, 6, 7, 8, 9, 10)

○ additional microphone positions (11, 12, 13, 14, 15, 16, 17, 18, 19, 20)

A measurement surface

B reference box

Figure B.1 — Preferred microphone positions on the hemispherical measurement surface for all noise sources (The co-ordinates of the positions are given in Table B.1)



Key

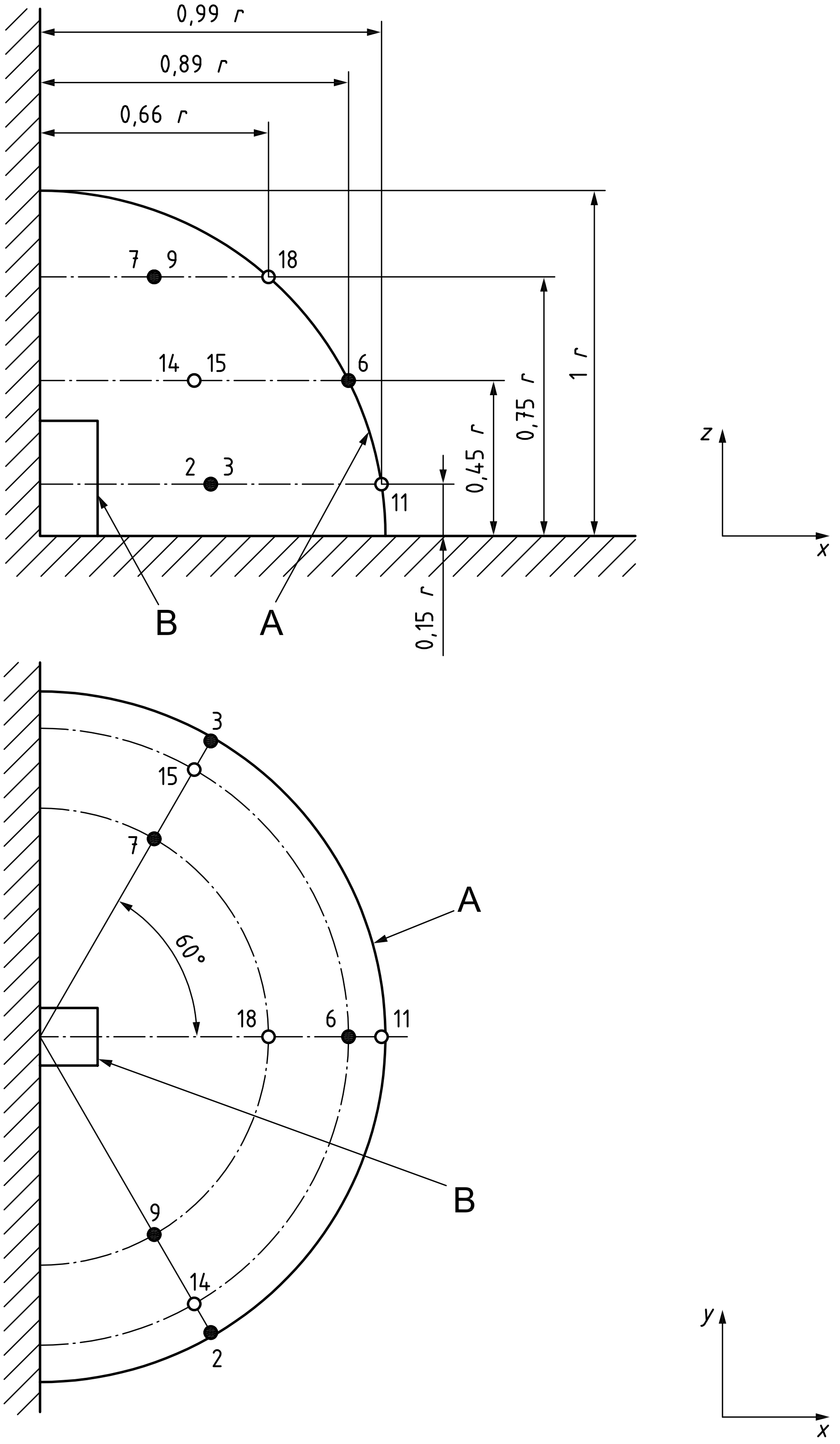
- ● key microphone positions (1, 2, 3, 4, 5, 6, 7, 8, 9, 10)
- ○ additional microphone positions (11, 12, 13, 14, 15, 16, 17, 18, 19, 20)

A measurement surface

B reference box

r radius of the measurement surface

Figure B.2 — Microphone positions on the hemispherical measurement surface for a broadband noise source (The co-ordinates of the positions are given in Table B.2)

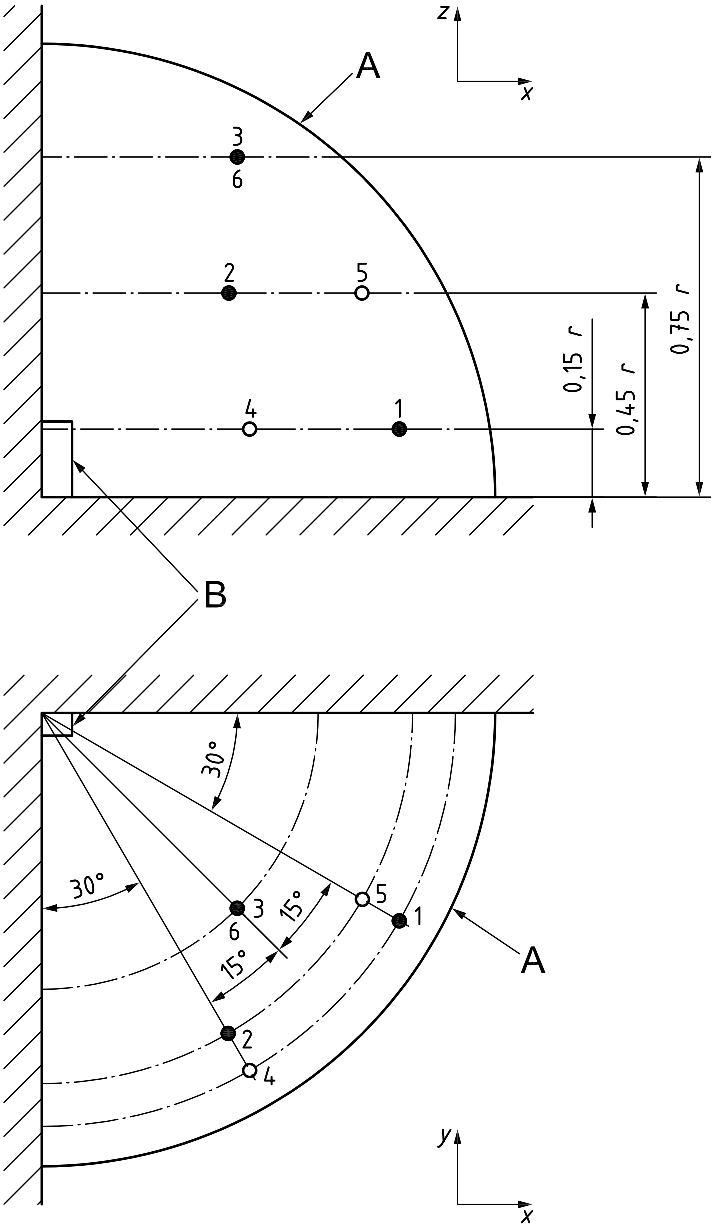


Key

- ● key microphone positions (2, 3, 6, 7, 9)
- ○ additional microphone positions (11, 14, 15, 18)

A	measurement surface
B	reference box
r	radius of the measurement surface

Figure B.3 — Microphone positions on a half-hemispherical measurement surface adjacent to two reflecting planes (The co-ordinates of the positions are given in Table B.2)



Key

● key microphone positions (1, 2, 3)

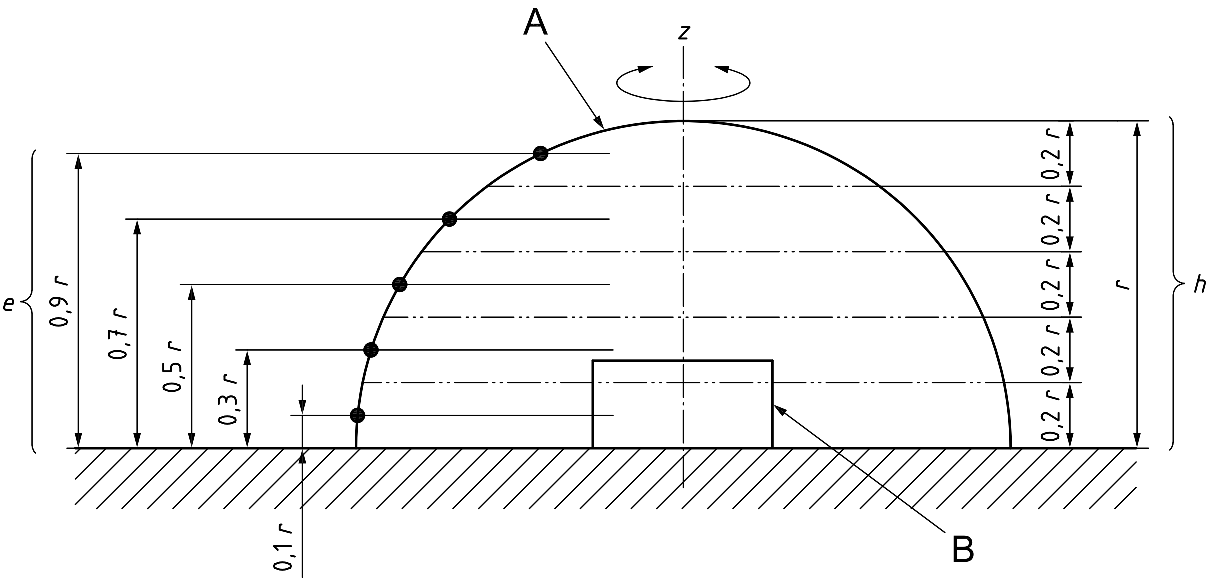
○ additional microphone positions (4, 5, 6)

A measurement surface

B reference box

r radius of the measurement surface

Figure B.4 — Microphone positions on a quarter-hemispherical measurement surface adjacent to three reflecting planes (The co-ordinates of the positions are given in Table B.3)



Key

A	measurement surface
B	reference box
e	elevation of microphone traverses
h	height of corresponding areas of hemisphere
r	radius of the measurement surface
z	axis of rotation of microphone traversing mechanism

NOTE The paths are selected so that the annular area of the hemisphere associated with each path is the same.

Figure B.5 — Coaxial circular paths for a moving microphone

Annex C
(normative)

Microphone arrays on a parallelepiped measurement surface

C.1 Microphone positions for sources mounted on one reflecting plane

Each of the five planes of the measurement surface shall be considered on its own and so subdivided that each plane contains partial areas of equal size with a maximum length of side equal to $3d$, where d is the measurement distance (3.12) (see Figure C.1 which illustrates rectangular partial areas or Figure C.4 which illustrates triangular partial areas). The minimum number of microphone positions is thus 9 for rectangular partial areas [Figures C.1 a) and b)] or 10 for triangular partial areas [Figures C.4 a) and b)].

In Figure C.1, the key microphone positions are in the centre of each partial area and at each corner of the partial area (excluding the corners intruding into the reflecting plane). In this way, the microphone positions for Figures C.7 to C.11 are obtained. Adjacent microphone positions may be connected to make measurement paths as shown in Figures C.7 to C.11.

Additional microphone positions, if required by 8.1.2 a), shall be defined as follows:

a) if using rectangular partial areas additional microphone positions shall be selected in accordance with Figure C.2 — the minimum number of microphones thus increases from 9 to 19;

b) if using triangular partial areas (see Figure C.4), additional microphone positions shall be added as shown in Figure C.5 — the minimum number of microphone positions thus increases from 10 to 20.

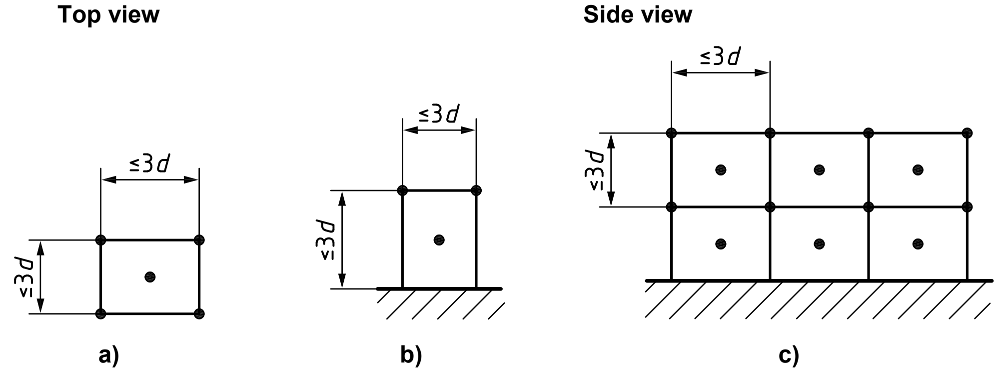
If a localized increase in number of microphone positions is required in accordance with 8.1.2 b) or c), examples for additional localized microphone positions are given in Figures C.3 and C.6.

NOTE 1 The rectangular subdivisions shown in Figures C.1 and C.2 do not represent the assumed subareas associated with each microphone position. For the averaging procedure for the mean sound pressure level over the measurement surface, equal subareas for each of the microphone positions are assumed and Equation (12) of 8.2.2.1 should be used.

NOTE 2 The microphone arrays shown in Figures C.4 to C.6 avoid measurement positions located on edges and corners of the parallelepiped measurement surface. Thereby a clear correlation between each microphone position and the associated subarea is given for determining the mean sound pressure level over the measurement surface by Equation (12) or Equation (14).

C.2 Microphone positions for sources adjacent to two or three reflecting planes

For a noise source to be tested adjacent to more than one reflecting plane, reference shall be made to Figures C.12 and C.13.

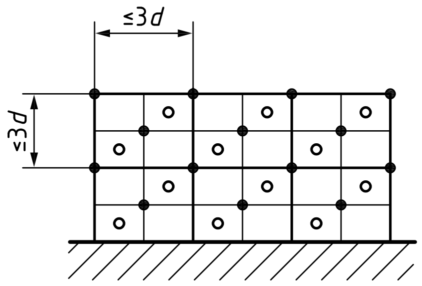


Key

● key microphone positions

d measurement distance

Figure C.1 — Key microphone positions on a parallelepiped measurement surface consisting of rectangular partial areas



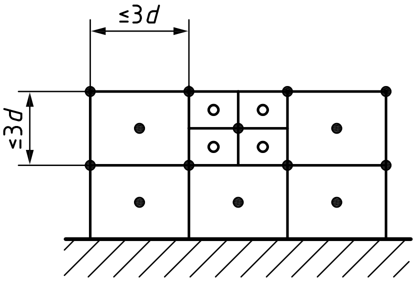
Key

● key microphone positions

○ additional microphone positions when an increase in number of microphones over the whole measurement surface is required

d measurement distance

Figure C.2 —Additional microphone positions over the whole parallelepiped measurement surface consisting of rectangular partial areas

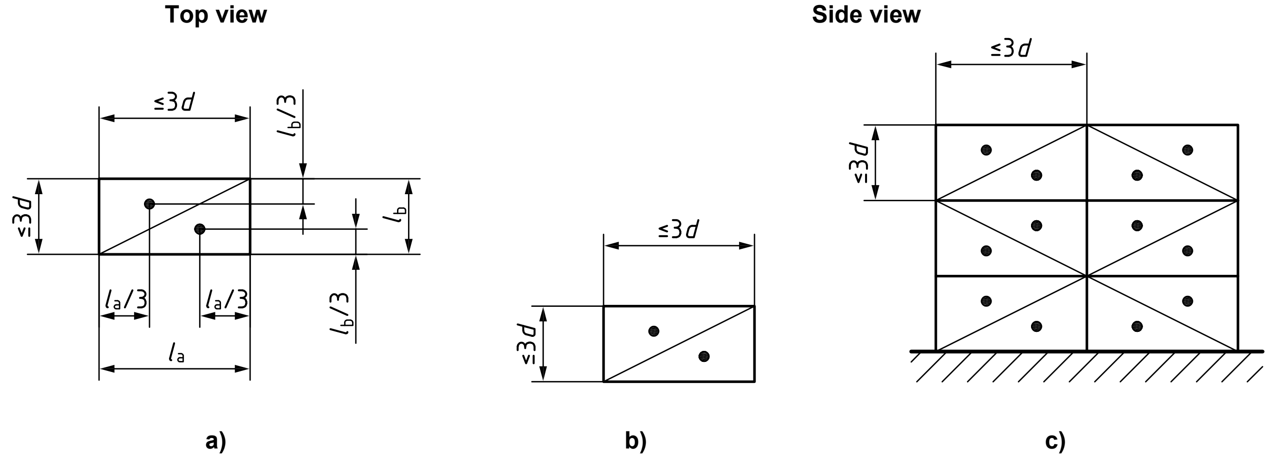


Key

- ● key microphone positions
- ○ additional microphone positions when a localized increase in number of microphones is required
- *d* measurement distance

NOTE Each rectangular partial area is nominally associated with 2 key microphone positions. Additional microphone positions are associated with unequal segment areas on the measurement surface and the mean sound pressure level is determined using 8.2.2.2. In the example above, one key microphone position has been subdivided into five positions, each covering an area one-fifth of that associated with a key microphone position.

Figure C.3 —Example for additional localized microphone positions on a rectangular partial area

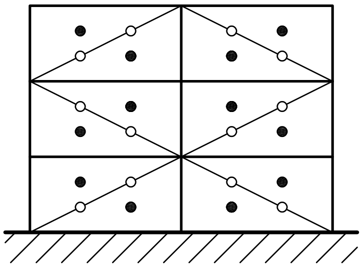


Key

- ● key microphone positions
- *d* measurement distance
- l_a length
- l_b width

$l_a l_b \leqslant (3d)^2$ limitation of size.

Figure C.4 —Key microphone positions on a parallelepiped measurement surface consisting of triangular partial areas

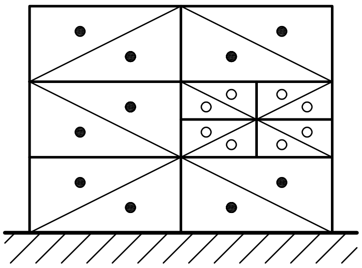


Key

● key microphone positions

○ additional microphone positions when an increase in number of microphones over the whole measurement surface is required

Figure C.5 —Additional microphone positions over the whole parallelepiped measurement surface consisting of triangular partial areas

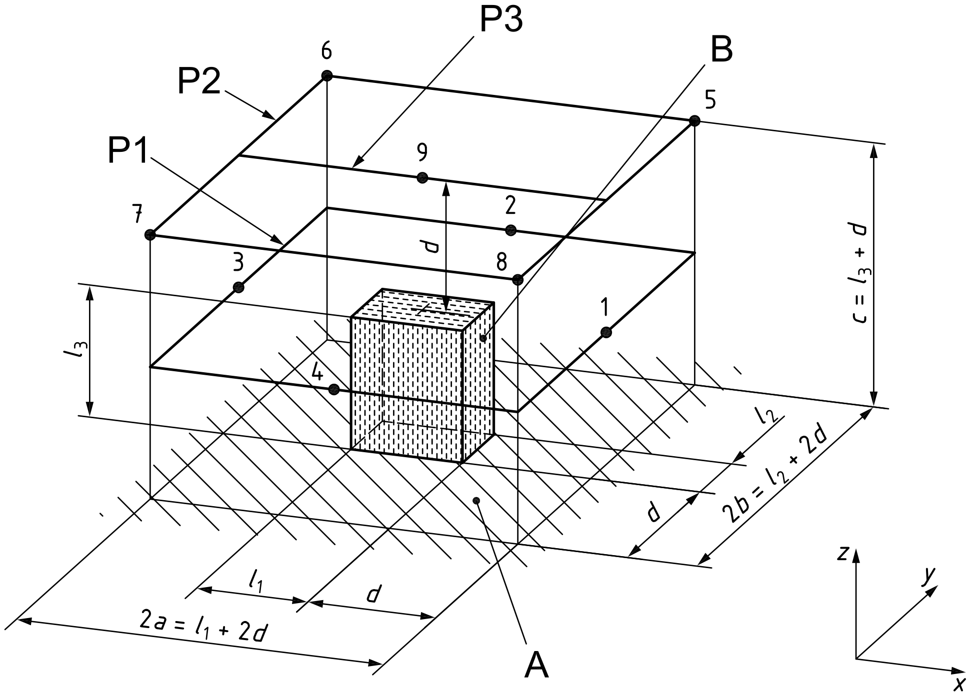


Key

● key microphone positions

○ additional microphone positions when a localized increase in number of microphones is required

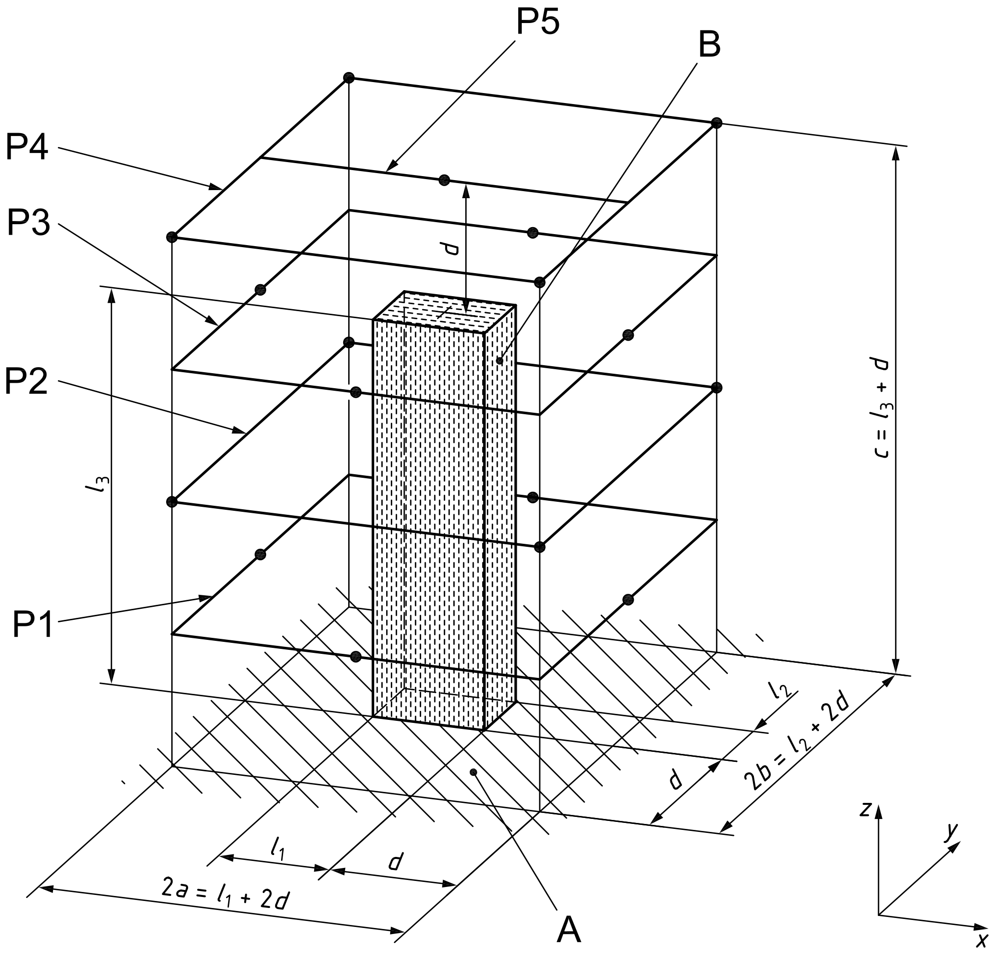
Figure C.6 — Example for additional localized microphone positions on a pair of triangular partial areas



Key

●	key microphone positions
A	reflecting plane
B	reference box
$2a$	measurement surface length
$2b$	measurement surface width
c	measurement surface height
d	measurement distance
l_1	reference box length
l_2	reference box width
l_3	reference box height
P1 to P3	path 1 to path 3

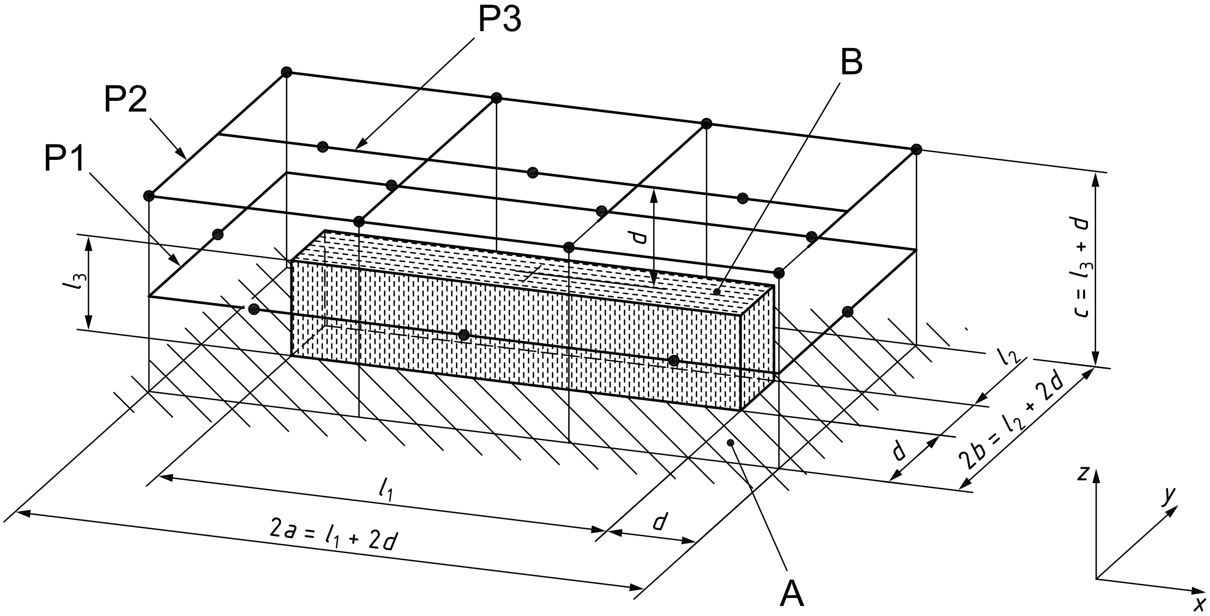
Figure C.7 — Example of a measurement surface with microphone positions and paths for a small machine (with dimensions $l_1 \leqslant d$, $l_2 \leqslant d$, $l_3 \leqslant 2d$)



Key

●	key microphone positions
A	reflecting plane
B	reference box
$2a$	measurement surface length
$2b$	measurement surface width
c	measurement surface height
d	measurement distance
l_1	reference box length
l_2	reference box width
l_3	reference box height
P1 to P5	path 1 to path 5

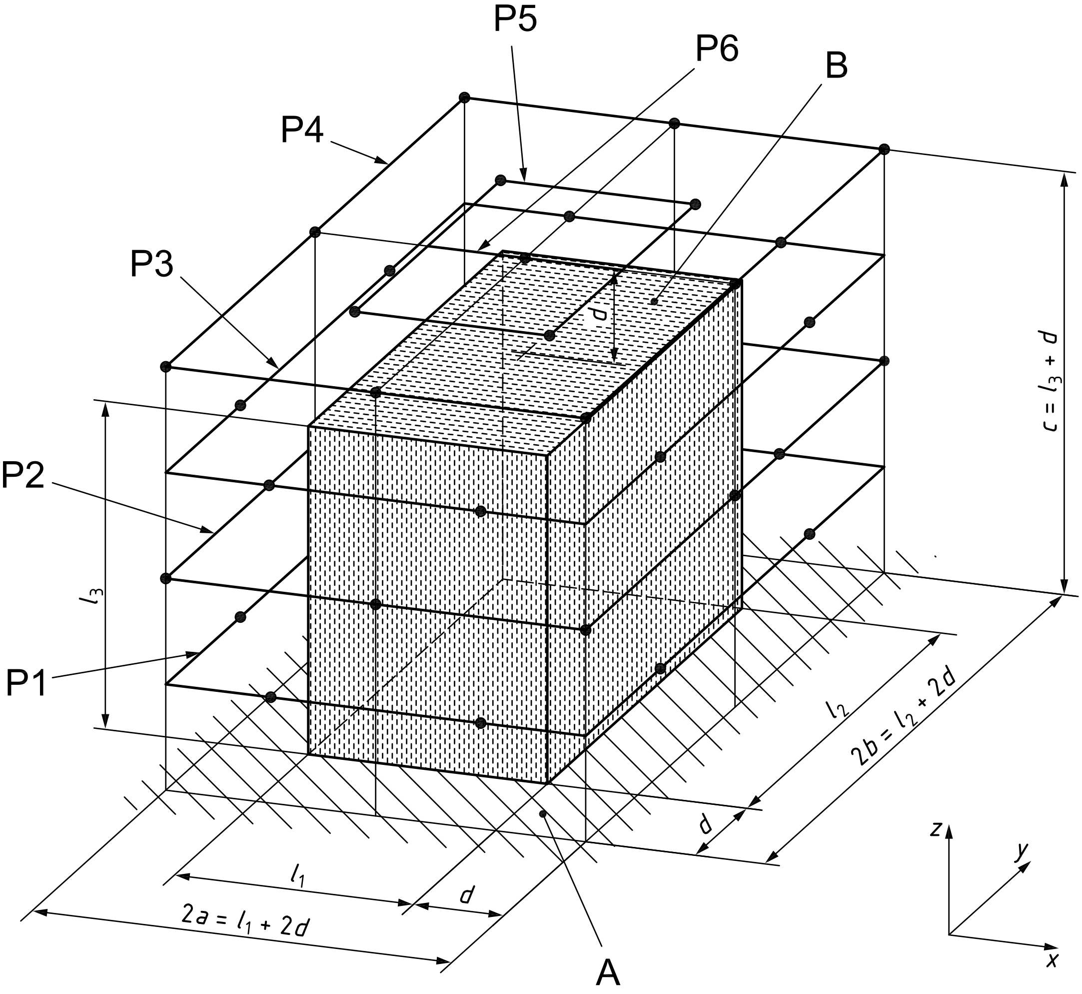
Figure C.8 — Example of a measurement surface with microphone positions and paths for a tall machine with a small base area (with dimensions $l_1 \leqslant d$, $l_2 \leqslant d$, $2d < l_3 \leqslant 5d$)



Key

●	key microphone positions
A	reflecting plane
B	reference box
$2a$	measurement surface length
$2b$	measurement surface width
c	measurement surface height
d	measurement distance
l_1	reference box length
l_2	reference box width
l_3	reference box height
P1 to P3	path 1 to path 3

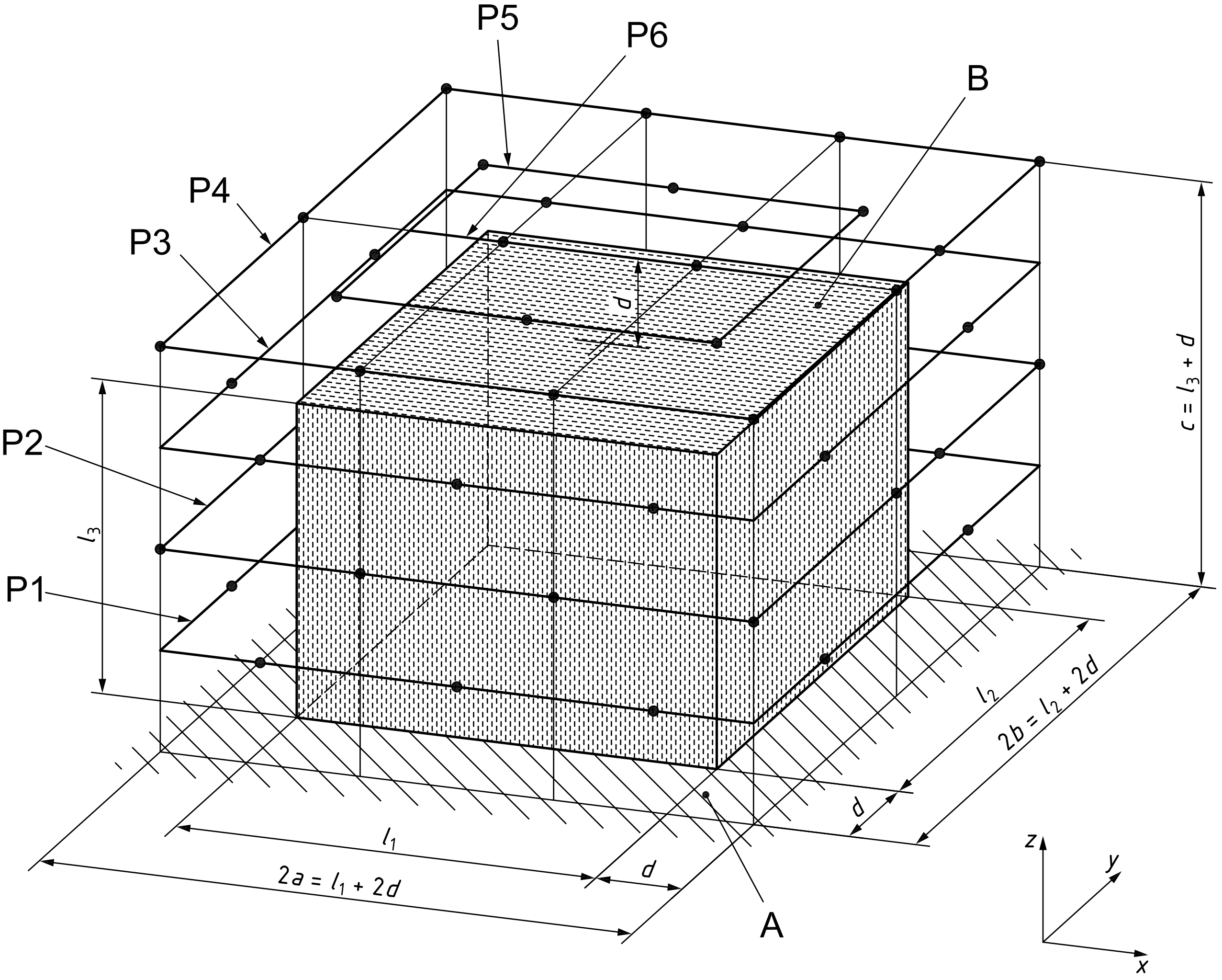
Figure C.9 — Example of a measurement surface with microphone positions and paths for a long machine (with dimensions $4d < l_1 \leqslant 7d$, $l_2 \leqslant d$, $l_3 \leqslant 2d$)



Key

●	key microphone positions
A	reflecting plane
B	reference box
$2a$	measurement surface length
$2b$	measurement surface width
c	measurement surface height
d	measurement distance
l_1	reference box length
l_2	reference box width
l_3	reference box height
P1 to P6	path 1 to path 6

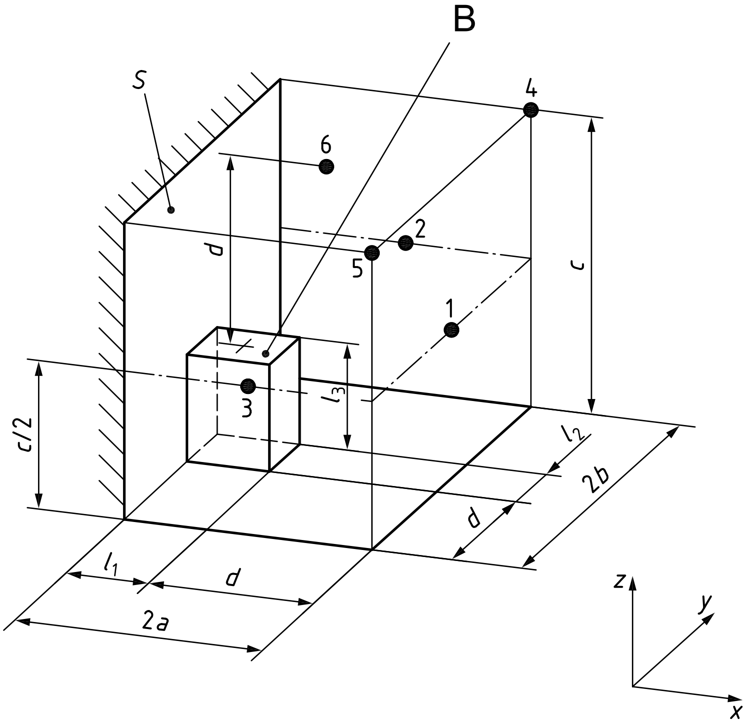
Figure C.10 — Example of a measurement surface with microphone positions and paths for a medium-sized machine (with dimensions $d < l_1 \leqslant 4d$, $d < l_2 \leqslant 4d$, $2d < l_3 \leqslant 5d$)



Key

●	key microphone positions
A	reflecting plane
B	reference box
$2a$	measurement surface length
$2b$	measurement surface width
c	measurement surface height
d	measurement distance
l_1	reference box length
l_2	reference box width
l_3	reference box height
P1 to P6	path 1 to path 6

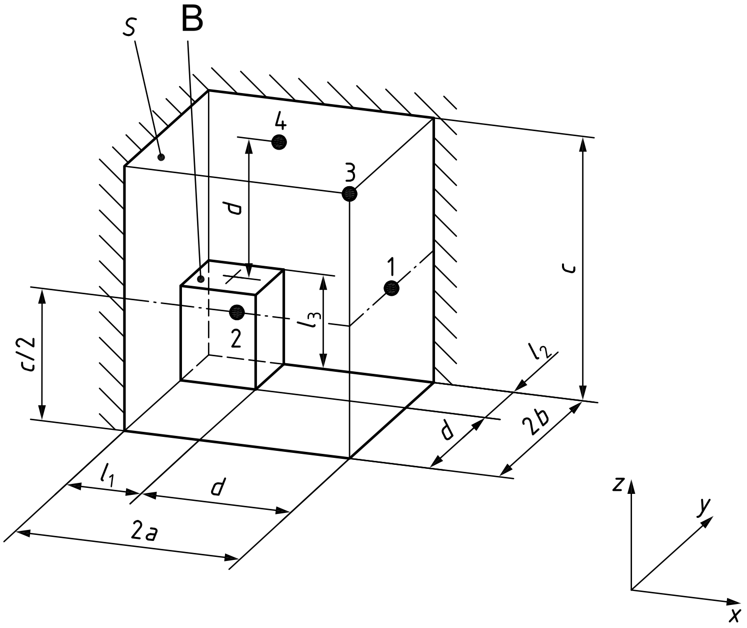
Figure C.11 — Example of a measurement surface with microphone positions and paths for a large machine (with dimensions $4d < l_1 \leqslant 7d$, $d < l_2 \leqslant 4d$, $2d < l_3 \leqslant 5d$)



Key

●	key microphone positions
B	reference box
$2a$	measurement surface length
$2b$	measurement surface width
c	measurement surface height
d	measurement distance
l_1	reference box length
l_2	reference box width
l_3	reference box height
S	measurement surface $S = 2(2ab + bc + 2ca)$

Figure C.12 — Parallelepiped measurement surface with six microphone positions for floor-standing noise sources adjacent to two reflecting planes



Key

●	key microphone positions
B	reference box
$2a$	measurement surface length
$2b$	measurement surface width
c	measurement surface height
d	measurement distance
l_1	reference box length
l_2	reference box width
l_3	reference box height
S	measurement surface $S = 2(2ab + bc + ca)$

Figure C.13 — Parallelepiped measurement surface with four microphone positions for floor-standing noise sources adjacent to three reflecting planes

Annex D
(informative)

Microphone arrays on a cylindrical measurement surface

Figures D.1 and D.2 illustrate two different combinations of numbers of side and top circular paths for microphone traverses on a cylindrical measurement surface.

The number of microphone paths (and segments of measurement surface) on the side of the cylinder, n_S, and on the top, n_T, shall comply with the following requirements:

a) $n_\text{S} \geqslant h_S/0{,}5$ where h_S is the height, in metres, of the measurement surface, to achieve adequate vertical sampling by limiting spacing to 0,5 m or less;

b) as a minimum, $n_\text{S} \geqslant 4$;

c) $n_\text{T} \geqslant n_\text{S}/2$.

The microphone paths on the side are associated with equal segment areas and shall be positioned such that the ith microphone is at a height, h_i, above the reflecting plane of

$$h_i = (i - 1/2)h_S/n_\text{S} \tag{D.1}$$

The top microphone paths are associated with unequal segment areas and shall be spaced equally along the radius of the top surface. The outer radius of the ith segment area, R_i, is

$$R_i = iR/n_\text{T} \tag{D.2}$$

The radius, r_i, of each top microphone path is

$$r_i = R_{i-1} + \left(R_i - R_{i-1}\right)/2 \qquad \text{for } i > 1 \tag{D.3}$$

and

$$r_1 = R_1/2 \tag{D.4}$$

The partial area associated with the ith segment, S_i [see Equation (14)] is:

$$S_i = \pi(R_i^2 - R_{i-1}^2) \qquad \text{for } i > 1 \tag{D.5}$$

and

$$S_1 = \pi R_1^2 \tag{D.6}$$

The microphone traverses may be implemented by rotating either the microphones while keeping the noise source stationary or the noise source and keeping the microphones stationary.

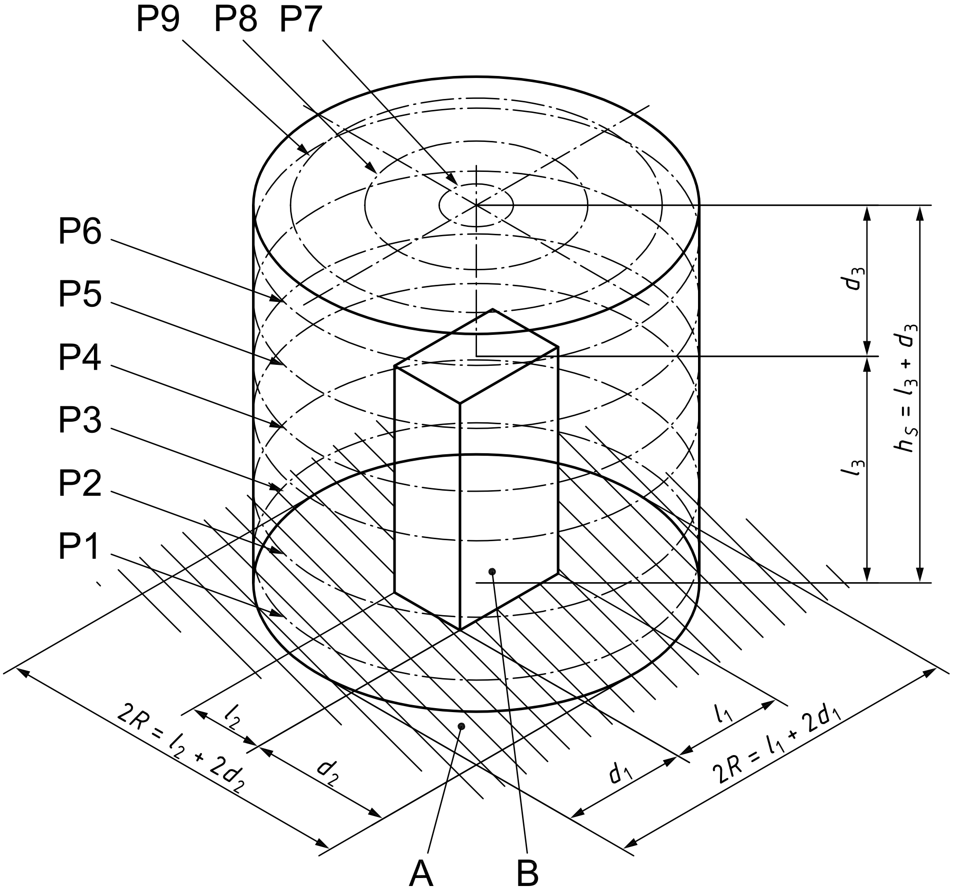
The application of traversing microphones along circular paths is strongly recommended for sources emitting steady noise. Fixed microphone positions shall be used when the source emits non-steady noise. In this case, at least eight equally spaced angular positions shall be used to sample over the circular paths, starting from an initial angular position perpendicular to one of the sides of the reference box.

For a noise source tested adjacent to two reflecting planes, the measurement surface shall be a half-cylinder (see Figure D.3), and for a noise source tested adjacent to three reflecting planes it shall be a quarter-cylinder (see Figure D.4). In these cases, only fixed microphone positions shall be used. For the half-cylinder, there shall be at least three positions at equal angular spacing along each semi-circular path, and for the quarter-cylinder, there shall be at least two positions at equal angular spacing along each quarter-circular path. In both these cases, the number of semi-circular or quarter-circular paths on the side and top surfaces and their positions shall conform to the requirements above for the full cylinder. For the half- and quarter-cylinder, the unequal partial areas for the top surface are, $S_i/2$ or $S_i/4$, respectively, with S_i defined above. Similarly, the equal partial areas for the side surface are 1/2 and 1/4, respectively, of the corresponding full-cylinder partial areas.

The alignment of the cylinder with respect to the reference box is illustrated in Figure D.1 and an example of a microphone array with five microphone paths around the sides of the cylinder and four on the top is shown in Figure D.2.

Figures D.3 and D.4 show plane views of respectively a half-cylindrical and quarter-cylindrical measurement surface with fixed microphone positions distributed on three top half- and quarter-circulars, respectively, and on a minimum of three and two angular positions, respectively.

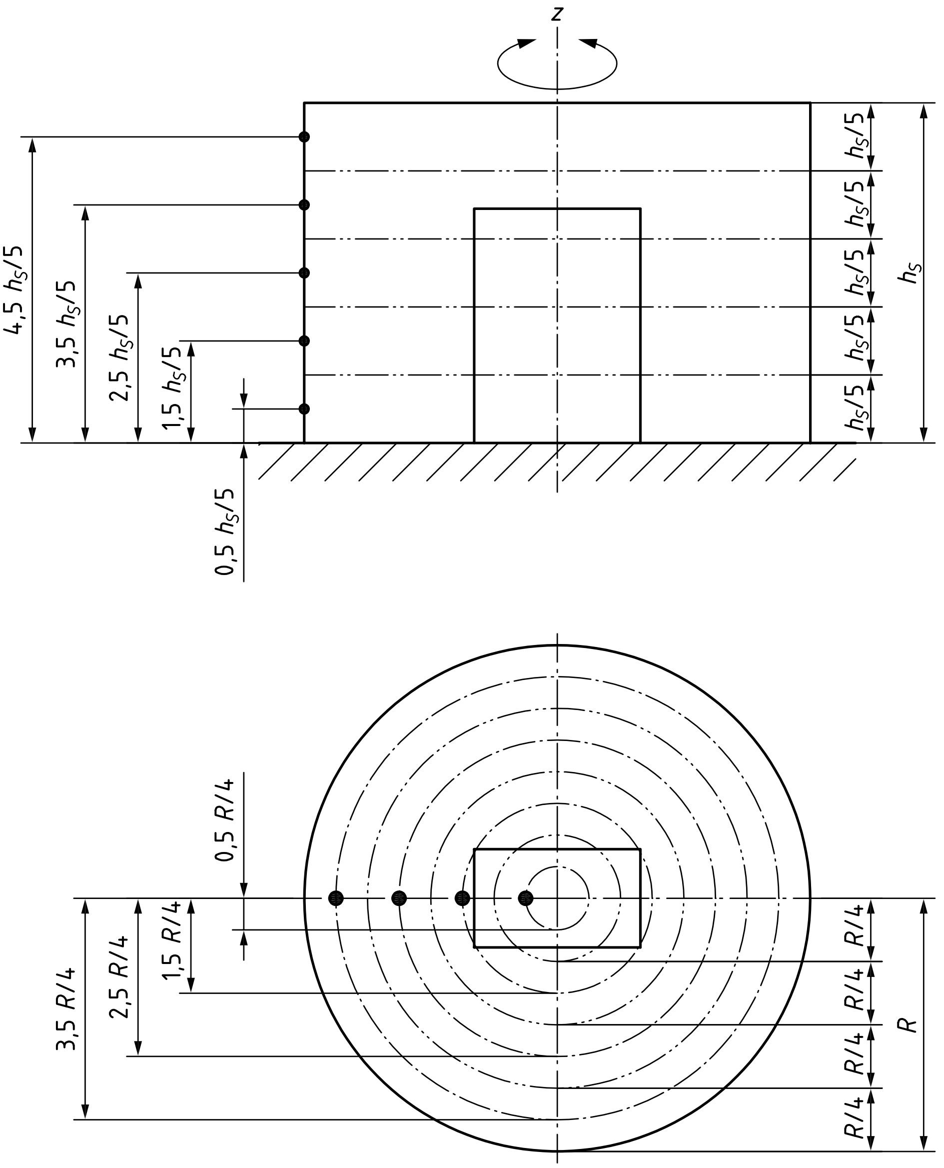
NOTE The vertical positions of the microphone paths on the side of the half- and quarter-cylinder are the same as those which would be used on a full cylinder.



Key

A	reflecting plane	d_3	measurement distance (height)	l_3	reference box height
B	reference box	h_S	height of the measurement surface	P1 to P6	side microphone paths
d_1	measurement distance (length)	l_1	reference box length	P7 to P9	top microphone paths
d_2	measurement distance (width)	l_2	reference box width	$2R$	measurement surface diameter

Figure D.1 — Example of cylindrical measurement surface and microphone array, with six side microphone paths and three top microphone paths



Key

● microphone traverse positions

h_S height of the measurement surface

R measurement surface radius

z axis of rotation of microphone traversing mechanism

Figure D.2 — Example of a microphone array with five side microphone paths and four top microphone paths

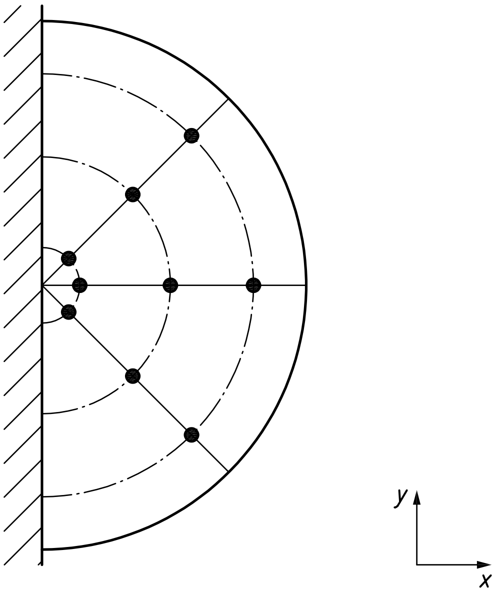


Figure D.3 — Example of a microphone array on a half-cylindrical measurement surface adjacent to two reflecting planes

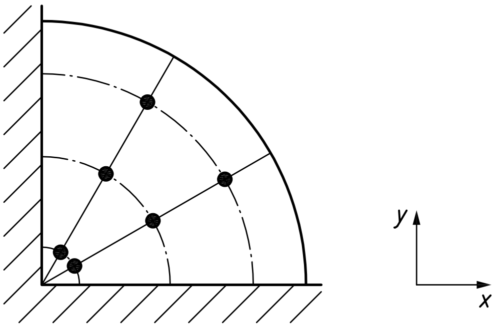


Figure D.4 — Example of a microphone array on a quarter-cylindrical measurement surface adjacent to three reflecting planes

Annex E
(normative)

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

E.1 A-weighted sound power levels

The A-weighted sound power level, $L_{W\mathrm{A}}$, may be calculated using Equation (E.1):

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

where

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

k, C_k are given in Table E.1 for one-third octave bands, and in Table E.2 for octave bands;

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

E.2 A-weighted sound energy levels

The A-weighted sound energy level, $L_{J\mathrm{A}}$, may be calculated using Equation (E.2):

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

where

L_{Jk} is the sound energy level in the kth one-third octave band or in the kth octave band, in decibels;

k, C_k are given in Table E.1 for one-third octave bands, and in Table E.2 for octave bands;

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

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

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

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

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

k	**Mid-band frequency** Hz	C_k dB
1	50	–30,2[a]
2	63	–26,2[a]
3	80	–22,5[a]
4	100	–19,1
5	125	–16,1
6	160	–13,4
7	200	–10,9
8	250	–8,6
9	315	–6,6
10	400	–4,8
11	500	–3,2
12	630	–1,9
13	800	–0,8
14	1 000	0,0
15	1 250	0,6
16	1 600	1,0
17	2 000	1,2
18	2 500	1,3
19	3 150	1,2
20	4 000	1,0
21	5 000	0,5
22	6 300	–0,1
23	8 000	–1,1
24	10 000	–2,5

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

Table E.2 — Values of k and C_k for mid-band frequencies of octave bands

k	**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 given for use only where the test environment and instrumentation are satisfactory for use at the frequencies concerned.

Annex F
(normative)

Alternative microphone array on a hemispherical measurement surface for direct measurements of A-weighted sound pressure levels

F.1 General

This annex describes alternative microphone positions (see 8.1.1) that may be used when the purpose of the measurements is to determine the A-weighted sound power level directly from measurements of A-weighted sound pressure levels on a hemisphere. This annex is applicable to sources used outdoors where noise radiated horizontally (to bystanders) is most important, and where interference patterns are disrupted by one or more of the following conditions: moving sources, non-symmetrical sources, small variations in the hard reflecting surface, wind speed gradients or temperature gradients.

F.2 Microphone positions on the measurement surface

The measurement surface shall be a hemisphere with its origin at the point O and a measurement radius, r, of at least twice the characteristic source dimension, d_O (see Figure 1) extended to the next higher value in the series 4 m, 6 m, 8 m, 10 m, 12 m, 14 m, 16 m.

For a stationary noise source which emits broadband sound and is tested adjacent to one reflecting plane, the microphones shall be located either at the 10 positions numbered 1 to 10 listed in Table B.2 and shown in Figure B.2, or at the 12 positions listed in Table F.1 and shown in Figure F.1. The selection from the arrays in Annex B or in this annex shall be made in the relevant noise test code for a particular type of noise source. No matter whether the positions are taken from Table B.2 or Table F.1, the number of microphone positions may be reduced to six in the noise test code if preliminary investigations for a particular family of machines show that, by using the reduced number, the surface sound pressure levels do not deviate by more than 0,5 dB from those determined over the whole 10 or 12 positions. With the array from Table B.2, these six positions shall be those numbered 1, 11, 4, 14, 7, and 17. With the array from Table F.1, the six positions shall be those numbered 2, 4, 6, 8, 10, and 12.

For a moving noise source tested in motion adjacent to one reflecting plane, the microphones shall be located at the six positions numbered 2, 4, 6, 8, 10, and 12 in Table F.1 and shown in Figure F.1.

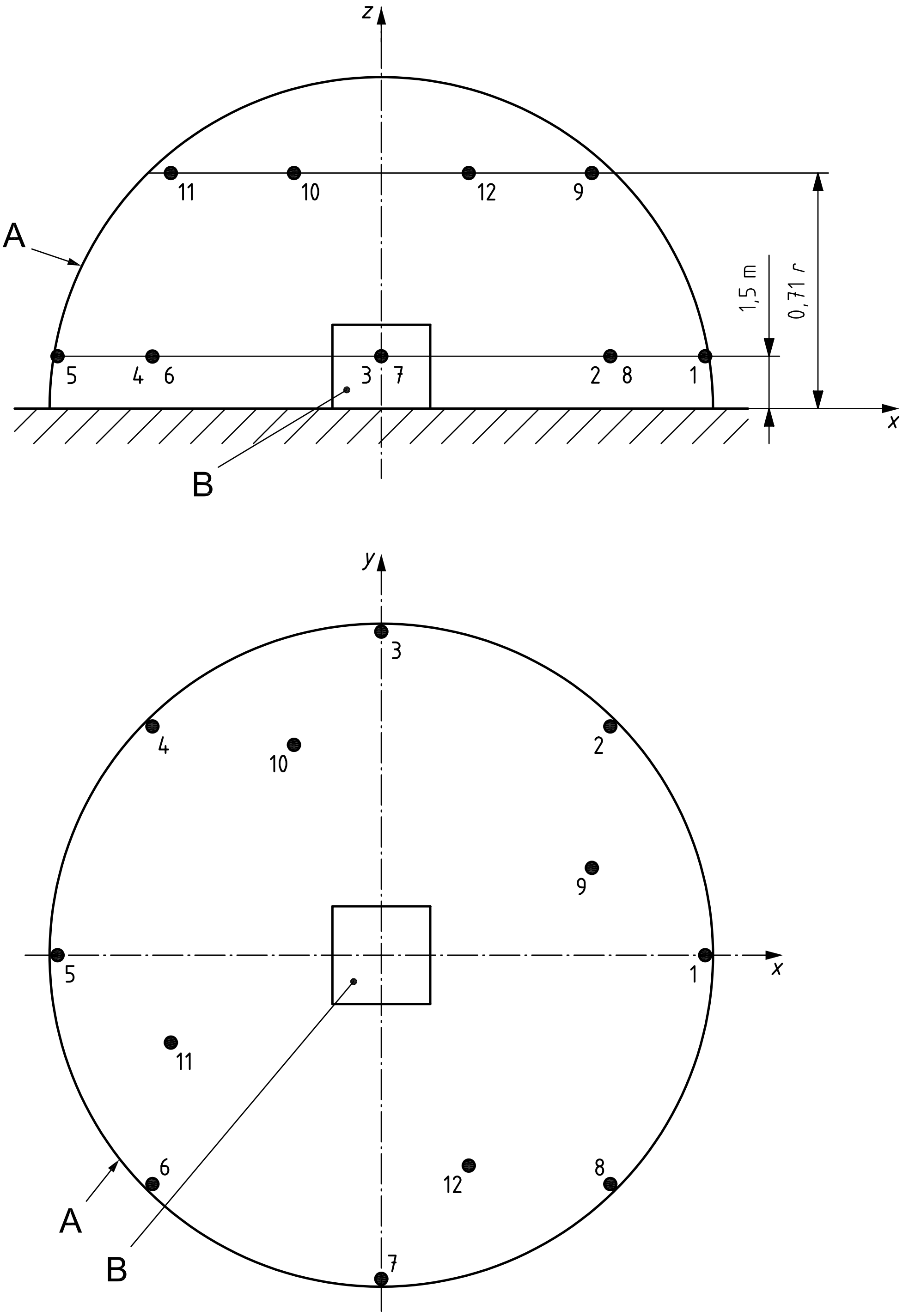
Table F.1 — Co-ordinates of alternative microphone positions

Position number	x/r[a]	y/r[a]	z/r	z
1	1,00a	0	—	1,5 m
2	0,707a	0,707a	—	1,5 m
3	0	1,00a	—	1,5 m
4	−0,707a	0,707a	—	1,5 m
5	−1,00a	0	—	1,5 m
6	−0,707a	−0,707a	—	1,5 m
7	0	−1,00a	—	1,5 m
8	0,707a	−0,707a	—	1,5 m
9	0,65	0,27	0,71	—
10	−0,27	0,65	0,71	—
11	−0,65	−0,27	0,71	—
12	0,27	−0,65	0,71	—

[a] The constant a depends on the measurement radius and is taken from Table F.2.

Table F.2 — Values of the constant, a

r m	a
4	0,927
6	0,968
8	0,982
10	0,989
12	0,992
14	0,994
16	0,996



Key

- ● key microphone positions (1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12)

A	measurement surface
B	reference box
r	measurement surface radius

Figure F.1 — Alternative microphone array on a hemispherical measurement surface for direct measurements of A-weighted sound pressure levels

Annex G
(normative)

Sound power level and sound energy level under reference meteorological conditions

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

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

where

L_W is the sound power level under the meteorological conditions which occurred at the time and place of the test, from Equation (18), in decibels;

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

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

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

C_2 is the radiation impedance correction, in decibels, to change the actual sound power relevant for the meteorological conditions at the time and place of the measurement into the sound power under reference meteorological conditions, the value shall be obtained from the appropriate noise test code, but in the absence of a noise test code, the following equation is valid for a monopole source, and is a mean value for other sources (see References [23][29]):

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

in which

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

$p_{\text{s},0}$ is the reference static pressure, 101,325 kPa,

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

θ_0 = 314 K,

θ_1 = 296 K.

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

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

where

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

$a = 2{,}256\,0 \times 10^{-5}\ \mathrm{m}^{-1}$;

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

NOTE The value given for θ_0 leads to a characteristic impedance of air of 400 N s/m^3 at the reference static pressure 101,325 kPa (References [23][24]):

$$\theta_0 = 273{,}15\ \mathrm{K} \times \left[\frac{331{,}45\ \mathrm{m/s} \times 1{,}292\,9\ \mathrm{kg/m}^3 \times 1\ \mathrm{pW}}{(20\ \mu\mathrm{Pa})^2 \times 1\ \mathrm{m}^2} \right]^2 = 313{,}51\ \mathrm{K} \approx 314\ \mathrm{K}$$

The sound energy level under reference meteorological conditions of static pressure 101,325 kPa and atmospheric temperature 23,0 °C, $L_{J\mathrm{ref,atm}}$, shall be calculated using Equation (G.3):

$$L_{J\mathrm{ref,atm}} = L_J + C_1 + C_2 \tag{G.3}$$

where

L_J is the sound energy level under the meteorological conditions which occurred at the time and place of the test, in decibels, from Equation (23);

C_1, C_2 see Equation (G.1).

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

Annex H
(informative)

Guidelines on the development of information on measurement uncertainty

H.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 current knowledge, 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.

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

The measurement uncertainty used in this International Standard is determined by the expanded measurement uncertainty U, which is derived directly from the total standard deviation σ_{tot} [see Equation (26)] with σ_{tot} being the approximation of the relevant $u(L_W)$ as defined in the ISO/IEC Guide 98-3.

This total standard deviation, σ_{tot}, results from the two components σ_{R0} and σ_{omc} [see Equation (25)], 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 H.3. Information on the standard deviation σ_{R0} is given in H.4.

H.3 Considerations on σ_{omc}

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

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

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 on the measurement surface. When measurements are averaged over the measurement surface, $L_{p,j}$, and $L_{p\text{av}}$, are replaced in Equation (H.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 shall 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 to 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.

With 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 (25)]. This is because σ_{omc} may be significantly larger in practice than, for example, 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.

Table H.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

These examples show that it may 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, situations where $\sigma_{\text{omc}} > \sigma_{R0}$ 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 currently defined by the value of σ_{R0} only.

H.4 Considerations on σ_{R0}

H.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 (28) 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 9.3.2) and for the modelling approach analogously.

The modelling approach, however, implies both statistically independent components c_i, u_i and especially 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 outline of the relevant quantities without being definitive.

H.4.2 Contributions to the uncertainty σ_{R0}

H.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 in Equation (H.2):

$$L_{W\text{ref,atm}} = \delta_{\text{method}} + \delta_{\text{omc}} + \overline{L'_{p\text{(ST)}}} + 10\ \text{lg}\frac{S}{S_0}\ \text{dB} - K_1 - K_2 + C_1 + C_2 + \delta_{\text{slm}} + \delta_{\text{mic}} + \delta_{\text{angle}} + \delta_{\theta} + \delta_{H} \tag{H.2}$$

where

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 (25);

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

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

S_0 is 1 m^2;

K_1 is the background noise correction, in decibels, see Equation (16);

K_2 is the environmental correction, in decibels, see A.2 and A.3;

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

C_2 is the radiation impedance correction, in decibels, to change the actual sound power relevant for the meteorological conditions at the time and place of the measurement into the sound power under reference meteorological conditions, the value shall be obtained from the appropriate noise test code, but in the absence of a noise test code, the following equation is valid for a monopole source, and is a mean value for other sources (see References [23][29]);

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

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

δ_{angle} is an input quantity to account for any difference of angle between the direction in which the sound is emitted by the source and the normal to the measurement surface;

δ_{θ} is an input quantity to allow for any uncertainty due to fluctuations in air temperature;

δ_{H} is an input quantity to allow for any uncertainty due to fluctuations in the relative humidity.

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

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

NOTE 3 The quantities included in Equation (H.2) to allow for uncertainties are those thought to be applicable at the state of knowledge current 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 related to mounting and operating conditions are already covered by σ_{omc} whereas σ_{R0} includes the rest of the uncertainty components.

Table H.2 provides some information about current expectations concerning the values for the components, c_i, u_i, that are necessary to calculate $\sigma_{R0} = \sqrt{\sum_i (c_i u_i)^2}$ dB.

Table H.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	0,4	Normal	1
$\overline{L'_{p(\text{ST})}}$	mean time-averaged sound pressure level	$\overline{L'_{p(\text{ST})}}$	$s_{L'_{p(\text{ST})}}\Big\vert_{\text{rep}}$	Normal	$1+\dfrac{1}{10^{0,1\Delta L_p}-1}$
S	measurement surface area	$10\lg\dfrac{S}{S_0}$	$\Delta r/\sqrt{3}$	Rectangular	$8{,}7/r$
K_1	background noise correction	K_1	$s_{L_{p(\text{B})}}$	Normal	$\dfrac{1}{10^{0,1\Delta L_p}-1}$
K_2	environmental correction	K_2	$K_2/4$	Normal	1
$C_1 + C_2$	meteorological and radiation impedance corrections	$C_1 + C_2$	0,3	Triangular	1
δ_{slm}	sound level meter	0	0,5	Normal	1
δ_{mic}	sampling	0	$V_{\text{I}}^{*}/\sqrt{n}$	Normal	1
δ_{angle}	angle	0	Box: $0{,}05+0{,}6\lg(S/d^2)$ Hemisphere: 0,25	Rectangular	$10^{-K_2/10}$
δ_θ	temperature	0	$\Delta\theta/\sqrt{3}$	Rectangular	$\dfrac{-0{,}57+0{,}25\lg(2{,}6f)}{1+0{,}0011H+0{,}007\theta}\left(1-10^{-K_2/10}\right)$
δ_H	relative humidity	0	$\Delta H/\sqrt{3}$	Rectangular	$\dfrac{-2{,}6+1{,}6\lg(0{,}7f)}{1+0{,}5H}\left(1-10^{-K_2/10}\right)$

[a] Quantities are described in the numerical example following this table.

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

The standard uncertainties from some contributions remain to be established by research.

Explanation and numerical examples for the uncertainty parameters in Table H.2 are given in H.4.2.2 to H.4.2.12. Equations to calculate uncertainties are given with examples to show the expected range of measurement uncertainties.

H.4.2.2 Measurement 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.

Assuming the full modelling approach as implemented in this example is complete and correct, based on Reference [26] the assumed value of this parameter is u_{method} = 0,4 dB.

Uncertainties related to the method directly affect results, so that c_{method} = 1. In this example, the uncertainty contribution, $u_{\text{method}}\, c_{\text{method}}$, is 0,4 dB.

H.4.2.3 Sound pressure measurement repeatability

The uncertainty due to the repeatability of measurements, $u_{\overline{L'_{p(\text{ST})}}}$, 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 using six measurements of the decibel sound pressure levels uncorrected for background noise at a single microphone position:

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

where

$L'_{p,j}$ is the sound pressure level, uncorrected for background noise, measured at a prescribed position 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 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 due to the repeatability influenced by background noise levels, $c_{\overline{L'_{p(\text{ST})}}}$, is obtained from the derivative of the sound power level, $L_{W\text{ref,atm}}$, with respect to $\overline{L'_{p(\text{ST})}}$. Using a derivation similar to that for c_{K_1}, (see the following) the sensitivity coefficient due to repeatability is:

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

This may be further simplified to

$$c_{L'_{p(\text{ST})}} = 1 + c_{K_1}$$

Measurement repeatability can be strongly influenced by averaging time. Using the same extreme scenario as for c_{K_1} results in $c_{L'_{p(\text{ST})}}$ = 1,3. If the averaging time does not cover a sufficient number of machinery cycles, the total uncertainty may be unacceptably large for an engineering grade standard. For extremely low noise sources, reduction of background noise can reduce the sensitivity coefficient and hence total uncertainty by up to a factor of two. This component of uncertainty, $u_{L'_{p(\mathrm{ST})}}$, could be lowered by better control of machinery operating conditions, use of longer averaging times, or by averaging multiple measurements made with appropriately modified conditions to represent a typical case. Other methods that may improve repeatability include increasing the number of microphone positions or enlarging the measurement surface. Reproducibility uncertainties are typically small, in this example the total uncertainty contribution is assumed to be 0,3 dB.

H.4.2.4 Measurement distance

The uncertainty due to the measurement distance, u_S, shown for a radius r (similar results apply for a box surface) is, if the uncertainty in the measurement surface dimensions is assumed to have a rectangular distribution with a range of $\pm\Delta r$, given as a standard deviation by $u_S = \Delta r/\sqrt{3}$.

The sound power level is given by $L_W = \overline{L_p} + 10\lg\frac{2\pi r^2}{S_0}$ dB where r is the radius of the measurement surface. Taking the derivative with respect to r, the resulting sensitivity coefficient, c_S, is given by $c_S = 8{,}7/r$.

For the extreme scenario, the range for Δr is assumed to be 10 % of r, resulting in an uncertainty contribution, $u_S \times c_S$ of 0,5 dB. A lower contribution is obtained with more careful measurements. Typically this uncertainty contribution is 0,3 dB or less.

H.4.2.5 Background noise correction

The uncertainty, u_{K_1}, due to the background noise correction, K_1, may be obtained from the standard deviation, $s_{L_{p(\mathrm{B})}}$, of the decibel values from repeated measurements of background noise at a single microphone position on the measurement surface.

The sensitivity coefficient, c_{K_1}, due to the background noise $\overline{L_{p(\mathrm{B})}}$ is obtained from the derivative of the sound power level, $L_{W\mathrm{ref,atm}}$, with respect to $\overline{L_{p(\mathrm{B})}}$ using Equations (H.1) and (16). In this example, the sign of the sensitivity coefficient is unimportant, and reduces to

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

For $\Delta L_p \leqslant 10$ dB this may be further simplified to $\left|c_{K_1}\right| \approx 3{,}6/\Delta L_p - 0{,}24$. In this example, the background noise is assumed to have a standard deviation of 3 dB and, if the extreme case is taken where $\overline{L'_{p(\mathrm{ST})}} - \overline{L_{p(\mathrm{B})}}$ is 6 dB, this results in a sensitivity coefficient, $c_{K_1} = 0{,}3$. In this worst case, the total contribution to uncertainty is 1,0 dB. Typically (assuming better control of background noise), this uncertainty contribution should be closer to 0,3 dB. This uncertainty could be reduced by lowering fluctuations in background noise. The uncertainty, u_{K_1}, is typically halved each time the averaging time is increased by a factor of four. Reductions in the sensitivity coefficient are obtained by reducing background noise by systematically tracking down and blocking and/or absorbing noise from unwanted sources (through proper grounding, lead wrapping, vibration isolation, adding mass, adding absorptive materials, etc., as appropriate). Relative to the source, background noise is reduced by 3 dB when the measurement surface area is reduced by a factor of two.

H.4.2.6 Environmental reflections

Practical experience suggests that the uncertainty due to the environmental correction, u_{K_2}, is given by $u_{K_2} = K_2/4$ where K_2 is the environmental correction; with $K_2 = 4$ dB, the value of $u_{K_2} = 1{,}0$ dB.

The corresponding sensitivity coefficient is given by $c_{K_2} = 1$.

For the extreme scenario, the environmental correction is 4 dB, resulting in u_{K_2} = 1,0 dB, and a total uncertainty contribution of 1,0 dB. A smaller uncertainty contribution could be obtained by reducing the measurement distance, or reduction of K_2 by changing rooms, adding absorption in the room, or opening large doors and windows, or making measurements outdoors. Typically $c_{K_2}\, u_{K_2}$ = 0,5 dB.

H.4.2.7 Meteorological and radiation impedance corrections

The uncertainty in determining the meteorological and radiation impedance corrections (see Annex G) is denoted $u_{C_1+C_2}$. If applied, this parameter is given by $u_{C_1+C_2}$ = 0,2 dB.

For altitudes less than 500 m, no meteorological or radiation impedance correction is required. At 120 m altitude and 23 °C the correction is zero and at 500 m altitude the correction is 0,6 dB. Assuming a triangular distribution for this uncertainty, the standard deviation is $s_{\text{met}} = 0{,}6/\sqrt{6} = 0{,}3\,\text{dB}$.

The corresponding sensitivity coefficient is given by $c_{C_1+C_2}$ = 1.

Assuming the altitude is less than 500 m and the meteorological and radiation impedance corrections are not applied, the standard deviation is 0,3 dB with corresponding uncertainty contribution of 0,3 dB. A lower uncertainty contribution can be obtained by measuring in a different location, or by applying the meteorological and radiation impedance corrections.

H.4.2.8 Sound level meter

The uncertainty in the measuring instrumentation is denoted u_{slm}. For a class 1 instrument, the value of this parameter is u_{slm} = 0,5 dB.

The sensitivity coefficient for the sound level meter is given by c_{slm} = 1.

Uncertainties in the sound level meter directly affect measured levels, so that c_{slm} = 1, and the total uncertainty contribution is 0,5 dB. Additional details regarding parameters affecting the uncertainty of sound level meters can be found in IEC 61672-1. A lower sensitivity coefficient, c_{slm}, is possible if K_2 is estimated using the absolute comparison test in A.2, this also requires a separate accounting for the uncertainties due to the reference sound source.

H.4.2.9 Sampling

The uncertainty due to the finite number of microphone positions, u_{mic}, is given by:

$$u_{\text{mic}} = \frac{u_{L'_{p(\text{ST})}}}{\sqrt{N_{\text{M}}}} = \frac{V_{\text{I}}^*}{\sqrt{N_{\text{M}}}} = \frac{1}{\sqrt{N_{\text{M}}}} \sqrt{\frac{1}{(N_{\text{M}}-1)} \sum_{i=1}^{N_{\text{M}}} \left[L'_{pi(\text{ST})} - L'_{p\text{av}} \right]^2}$$

where

V_{I}^* is the apparent surface sound pressure level non uniformity index (see 3.25);

N_{M} is the number of microphone positions.

The corresponding sensitivity coefficient is given by c_{mic} = 1.

Typically the range of measured values is less than 5 dB, and assuming the minimum nine measurement positions, a typical value of u_{mic} = 0,7 dB. In an extreme scenario, if the range of measured values was 10 dB, and the number of measurement positions was only increased to 10, then u_{mic} = 1,8 dB. The uncertainty u_{mic} is reduced by half each time the number of measurement positions is quadrupled. Increasing the measurement distance may also reduce the uncertainty if the microphones are close to localized sources. Changing the source position may also help. When measurements are influenced by the diffuse field in the room, increasing the reverberation time and adding diffusers may reduce this component of uncertainty (additional details can be found in ISO 3741[2]).

H.4.2.10 Angle

The uncertainty due to the incident angle of the sound energy is denoted u_{angle}. The use of sound pressure to approximate the sound intensity leads to an overestimate of the sound power. For a box shaped measurement surface this overestimate ranges between 0 dB and 1,2 lg(S/d^2) dB, depending on the angle and impedance of the incident sound, (i.e. the intensity and coherence of sound produced by different parts of the source). The magnitude of the correction depends on the source and shall be specified in a noise test code. The largest overestimate occurs when sound is produced from a localized position near the centre of the bottom edge of the measurement surface, an example would be a reference sound source positioned near a very large machine. For a given box shaped measurement surface, the standard uncertainty is approximately (see Reference [27])

$$u_{\text{angle}} = 0{,}05\,\text{dB} + 0{,}6\,\lg\left(\frac{S}{d^2}\right)\text{dB}$$

where

d is the distance to the measurement surface;

S is the measurement surface area.

For a hemispherical measurement surface in a free field above a reflecting plane the standard uncertainty is

$$u_{\text{angle}} = 0{,}25\ \text{dB}\ .$$

NOTE At high frequencies the microphone directivity may compensate for the angle error.

The corresponding sensitivity coefficient is given by $c_{\text{angle}} = 10^{-K_2/10}$. The angle error only affects the direct sound field from the source. The sensitivity coefficient c_{angle} is obtained from the derivative of $\partial\overline{L_p}\big/\partial\overline{L_{\text{direct}}}$ using

$$\overline{L_p} = 10\,\lg\left(10^{0{,}1\overline{L_{\text{direct}}}} + 10^{0{,}1\overline{L_{\text{reverb}}}}\right)$$

where

$\overline{L_{\text{direct}}}$ is the sound pressure level from the direct field of the source;

$\overline{L_{\text{reverb}}}$ is the level of the sound pressure contribution from the reverberant sound field.

The derivative is simplified by assuming $K_2 \approx \overline{L_p} - \overline{L_{\text{direct}}}$ as in A.2. For a worst case scenario, assume a cubic measurement surface located very close to a large noise source under test. For example, a source with typical height width and depth of 8 m, with a measurement distance of 1 m would have u_{angle} = 1,6 dB (Annex C also indicates that at such a close measurement distance over 100 measurement points would be required). The sensitivity coefficient has a maximum value c_{angle} = 1 when K_2 = 0 dB (i.e. outdoors). More typically, a measurement surface with nine points, would reduce u_{angle} to 1,0 dB, with K_2 = 2 dB, the sensitivity coefficient c_{angle} = 0,6 dB, and the total contribution to uncertainty $u_{\text{angle}}\ c_{\text{angle}}$ = 0,6 dB. For a given measurement surface the uncertainty contribution, $u_{\text{angle}}\ c_{\text{angle}}$, is reduced for a larger K_2. The uncertainty contribution could be reduced by increasing the measurement distance. For large measurement distances, a hemispherical measurement surface can reduce this uncertainty contribution below 0,25 dB.

H.4.2.11 Temperature

The uncertainty due to changes in temperature is denoted u_θ. Changes in temperature affect the environmental correction K_2 by changing the absorption of the air in the room. Assuming that the temperature, θ, falls within a range, $\pm\Delta\theta$ °C, with a rectangular distribution, the uncertainty is given by

$$u_\theta = \Delta\theta / \sqrt{3}$$

The sensitivity coefficient due to the temperature, c_θ, is a rough approximation of the derivative of $L_{W\text{ref,atm}}$ with respect to temperature. The basic equation for c_θ was obtained from ISO 3741[2], omitting the C_2 term and including a term to account for K_2. The derivation of the K_2 term is given in the discussion of c_{angle}.

$$c_\theta = \frac{-0{,}57 + 0{,}25\ \lg\left(2{,}6\,f\right)}{1 + 0{,}0011H + 0{,}007\theta}\left(1 - 10^{-K_2/10}\right)$$

where

H is the relative humidity, expressed as a percentage;

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

The highest value for this parameter occurs for large K_2, at high frequencies, in a dry room, at low temperature. A typical worst case would occur when the source under test changes the room temperature by say 10 °C, so that $u_\theta = 2{,}9$ °C. In the worst case for a high frequency source at 10 kHz, with $K_2 = 4$ dB, at 10 °C and $H = 10$ %, the sensitivity coefficient is approximately 0,3 so that $u_\theta c_\theta = 0{,}8$ dB. Better control of temperature, allowing the room to come to temperature equilibrium before testing, or shorter measurement times can reduce this uncertainty. The sensitivity coefficient can be reduced if K_2 is lowered by adding absorption in the room, or opening large doors and windows. 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 % relative humidity below 20 °C when $H \leqslant 30$ %, to a maximum of ±5 °C and ± 10 % relative humidity above 20 °C when $H > 50$ %. Typically when the source has little effect on room temperature and produces predominantly low frequency noise, this component is negligible, say $u_\theta c_\theta = 0{,}04$ dB.

H.4.2.12 Humidity

The uncertainty due to changes in relative humidity, u_H, assumes that the relative humidity, H, falls within a range, $\pm\Delta H$ %, with a rectangular distribution, the uncertainty is given by

$$u_H = \Delta H / \sqrt{3}$$

The sensitivity coefficient due to the relative humidity, c_H, is obtained from a rough approximation of the derivative of L_W with respect to relative humidity in a similar manner to that used for c_θ.

$$c_H = \frac{-2{,}6 + 1{,}6\ \lg\left(0{,}7\,f\right)}{1 + 0{,}5H}\left(1 - 10^{-K_2/10}\right) \quad \text{if} \quad H > 10\ \%$$

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

The highest value for this parameter occurs at 10 kHz in a dry room. In the worst case for a high frequency source at 10 kHz, with $K_2 = 4$ dB, at $H = 10$ %, the sensitivity coefficient is approximately 0,3. If the tolerance on relative humidity is ±5 %, then the total uncertainty contribution, $u_H c_H = 1{,}0$ dB. Better control of humidity, allowing the room to come to equilibrium before testing, or shorter measurement times can reduce this uncertainty. The sensitivity coefficient can be reduced if K_2 is lowered by adding absorption in the room, or opening large doors and windows. Higher humidity is typically associated with a lower sensitivity coefficient per degree change in temperature. The recommended humidity ranges given in ISO 3741[2] are ±3 %, if $H < 30$ %, to a maximum of ±10 %, if $H > 50$ %. Typically room temperature is better controlled, and most sources produce low frequency noise, so that this component is negligible, say $u_H\, c_H = 0{,}1$ dB.

H.4.2.13 Typical value for σ_{R0}

Using the typical values from above, σ_{R0} based on Equation (H.2) is

$$\begin{aligned}\sigma_{R0} &= \sqrt{0{,}4^2 + 0{,}3^2 + 0{,}3^2 + 0{,}3^2 + 0{,}5^2 + 0{,}3^2 + 0{,}5^2 + 0{,}7^2 + 0{,}6^2 + 0{,}04^2 + 0{,}1^2}\\ &= 1{,}4\,\text{dB}\end{aligned}$$

H.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 (H.3):

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

H.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 for 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 measurement 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 measurement uncertainty.

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