# INTERNATIONAL STANDARD

**ISO**

**3746**

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# Acoustics — Determination of sound power levels and sound energy levels of noise sources using sound pressure — Survey method using an enveloping measurement surface over a reflecting plane

*Acoustique — Détermination des niveaux de puissance acoustique et des niveaux d'énergie acoustique émis par les sources de bruit à partir de la pression acoustique — Méthode de contrôle employant une surface de mesure enveloppante au-dessus d'un plan réfléchissant*

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# Foreword

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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 3746 was prepared by Technical Committee ISO/TC 43, *Acoustics*, Subcommittee SC 1, *Noise*.

This third edition cancels and replaces the second edition (ISO 3746:1995), which has been technically revised. It also incorporates the Technical Corrigendum ISO 3746:1995/Cor.1:1995.

# Introduction

This International Standard is one of the series ISO 3741[2] to ISO 3747[6], which specify methods for determining the sound power levels and sound energy levels of noise sources including machinery, equipment and their sub-assemblies. Guidelines to select one of those methods 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 test code for the individual noise source in order to select the appropriate sound measurement surface and microphone array from among those allowed in each of the ISO 3740[1] to ISO 3747[6] series, and to give requirements for 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 machine event is calculated from this sound power and the time over which it existed.

This International Standard specifies methods giving results of ISO 12001:1996, accuracy grade 3 (survey grade) when measurements are performed 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.

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

For applications where greater accuracy is required, reference can be made to ISO 3744, ISO 3745[5] or an appropriate part of ISO 9614[14]-[16]. If the relevant criteria for the measurement environment specified in this International Standard are not met, it might be possible to refer to another of the ISO 3741[2] to ISO 3747[6] series, or to an appropriate part of ISO 9614[14]-[16].

# Acoustics — Determination of sound power levels and sound energy levels of noise sources using sound pressure — Survey method using an enveloping measurement surface over a reflecting plane

## 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 a noise source (machinery or equipment) in a test environment for which requirements are given. The sound power level (or, in the case of noise bursts or transient noise emission, the sound energy level) produced by the noise source with frequency 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 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      The conditions for measurements given in this International Standard can be impracticable for very tall or very long sources such as chimneys, ducts, conveyors, and multi-source industrial plants. A 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.

### 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 with frequency A-weighting applied. The uncertainty conforms with that of ISO 12001:1996, accuracy grade 3 (survey 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 3744, *Acoustics — Determination of sound power levels and sound energy levels of noise sources using sound pressure — Engineering methods for an essentially free field over a reflecting plane*

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

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

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

IEC 60942:2003, *Electroacoustics — Sound calibrators*

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

## 3   Terms and definitions

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

**3.1**
**sound pressure**
$p$
difference between instantaneous pressure and static pressure

NOTE 1     Adapted from ISO 80000-8:2007[23], 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 $\mu$Pa

[ISO/TR 25417:2007[22], 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. $L_{pA}$ denotes the A-weighted sound pressure level.

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

**3.3**
**time-averaged sound pressure level**

$L_{p,T}$

ten times the logarithm to the base 10 of the ratio of the time average of the square of the sound pressure, $p$, during a stated time interval of duration, $T$ (starting at $t_1$ and ending at $t_2$), to the square of a reference value, $p_0$, expressed in decibels

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

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 $L_{pA,T}$, which is usually abbreviated to $L_{pA}$.

NOTE 3    Adapted from ISO/TR 25417:2007[22], 2.3.

**3.4**
**single event time-integrated sound pressure level**

$L_E$

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

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

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

NOTE 1    This quantity can be obtained by $L_{p,T} + 10 \lg \left[ \dfrac{T}{T_0} \right] \text{dB}$, 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[22]).

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

**3.7**
**frequency range of interest**
frequency range of octave bands with nominal mid-band frequencies from 125 Hz to 8 000 Hz

**3.8**
**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, the ISO 11201[18] to ISO 11204[21] series.

**3.9**
**characteristic source dimension**
$d_0$
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.

**3.10**
**measurement distance**
$d$
distance from the reference box to a parallelepiped measurement surface

NOTE        Measurement distance is expressed in metres.

**3.11**
**measurement radius**
$r$
radius of a hemispherical, half-hemispherical or quarter-hemispherical measurement surface

NOTE        Measurement radius is expressed in metres.

**3.12**
**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

**3.13**
**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.

**3.14**
**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-weighting is denoted $K_{1A}$.

**3.15**
**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-weighting is denoted $K_{2A}$.

NOTE 3    In general, the environmental correction depends on the area of the measurement surface and usually $K_{2A}$ increases with $S$.

**3.16**
**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.

**3.17**
**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.

**3.18**
**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[23], 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.

**3.19**
**sound power level**
$L_W$
ten times the logarithm to the base 10 of the ratio of the sound power of a source, $P$, to a reference value, $P_0$, expressed in decibels

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

where the reference value, $P_0$, is 1 pW

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

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

[ISO/TR 25417:2007[22], 2.9]

**3.20**
**sound energy**
$J$

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

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

NOTE 1    Sound energy is expressed in joules.

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

[ISO/TR 25417:2007[22], 2.10]

**3.21**
**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

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

where the reference value, $J_0$, is 1 pJ

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

[ISO/TR 25417:2007[22], 2.11]


# 4   Test environment

## 4.1   General

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

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 manufacturers 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 the sound generation over the frequency range of interest or on the background noise during the course of the measurements.

At altitudes above 1 500 m, sound power levels and sound energy levels shall be corrected to reference meteorological conditions in accordance with ISO 3744.

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 Criterion for background noise

The A-weighted sound pressure levels due to background noise averaged over the microphone positions, or traverses, on the measurement surface shall be at least 3 dB below the mean sound pressure level due to the noise source under test in operation when measured in the presence of this background noise (see 8.3.2).

## 4.3 Criterion for acoustic adequacy of test environment

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

NOTE 1    If the environmental correction $K_{2A}$ exceeds 7 dB, ISO 3747[6], ISO 9614-1[14] or ISO 9614-2[15] can be used.

NOTE 2    In some specific cases, the horizontal testing plane is only partially 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 source is mounted and indicates the possible consequences on the measurement uncertainty.

# 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 2.

Class 2 instrumentation is acceptable for steady noise but generally it is recommended to use class 1 instrumentation.

## 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 this series of measurements shall be discarded.

The calibration of the sound calibrator, and the compliance of the instrumentation system with the requirements of IEC 61672-1 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 and the compliance of the instrumentation system with the requirements of IEC 61672-1 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 practicable, 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 minimize any sound radiated into the test environment from such equipment. The noise source under test shall be taken to include all significant sources of sound emission, including auxiliary equipment which cannot either be removed or adequately quietened, and the reference box (see 7.1) shall be extended appropriately.

## 6.3 Noise source location

The noise source to be tested shall be installed with respect to 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. Resilient mountings 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 on the source are both minimized. In this case, the mounting base should be rigid (i.e. have a sufficiently high mechanical impedance) to prevent it from vibrating excessively and radiating sound. 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  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, $d_0$, used to determine the dimensions of the measurement surface, is shown in Figure 1 for reference boxes on 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 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.

NOTE    Other microphone arrangements and measurement surfaces, as given, for example, in ISO 3744, which provide improved accuracy can also be used.

For a noise source located in a suitable flat outdoor area (see Clause 4) a greater measurement distance is usually selected and a hemispherical measurement surface is preferred. For a noise source located in a room or space having unfavourable acoustical conditions (e.g. containing sound-reflecting objects or being subject to high levels of background noise), the selection of a small measurement distance is appropriate and this dictates the selection of a parallelepiped measurement surface.

For measurements on a series of similar 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.

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.
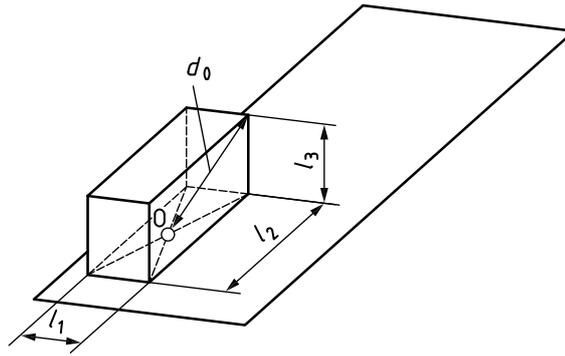
a) **Reference box on one reflecting plane,** $d_0 = \sqrt{(l_1/2)^2 + (l_2/2)^2 + l_3^2}$
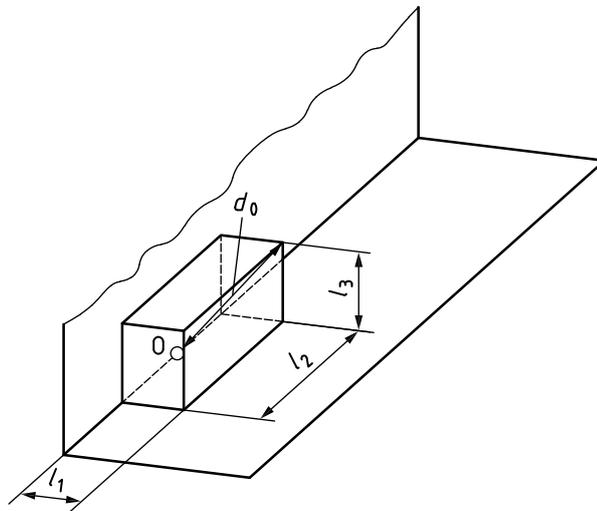
b) **Reference box on two reflecting planes,** $d_0 = \sqrt{l_1^2 + (l_2/2)^2 + l_3^2}$
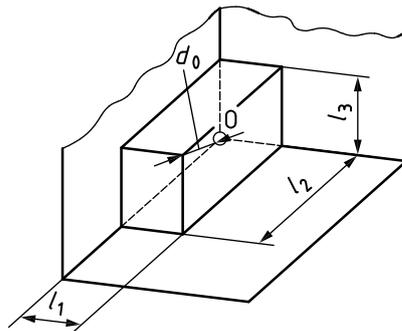
c) **Reference box on three reflecting planes,** $d_0 = \sqrt{l_1^2 + l_2^2 + l_3^2}$

**Key**

$d_0$   characteristic source dimension

$l_1$   reference box length

$l_2$   reference box width

$l_3$   reference box height

O   origin

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

### 7.2.3 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 greater than or equal to twice the characteristic source dimension, $d_0$, not less than 1 m and not greater than 16 m.

For small products, the measurement radius may be less than 1 m, but shall not be less than 0,5 m.

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 or a combination of forms.

If there is only one reflecting plane, the measurement surface is a full hemisphere and its area (see 8.3.5 and 8.4.4) $S = 2\pi r^2$. 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 0,15 m, but preferably 1 m or more.

If there is only one reflecting plane (see Figures C.2 to C.6), the area $S$ of the measurement surface is given by Equation (7):

$$S = 4(ab + bc + ca) \tag{7}$$

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.7), the measurement surface area is given by

$$S = 2(2ab + bc + 2ca) \tag{8}$$

where

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

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

$$c = l_3 + d$$

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.8), the measurement surface area is given by

$$S = 2(2ab + bc + ca) \tag{9}$$

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.

# 8 Determination of sound power levels and sound energy levels

## 8.1 Determination of environmental correction

The environmental correction, $K_{2A}$, shall first be determined using Annex A.

## 8.2 Microphone positions on the measurement surface

### 8.2.1 Hemispherical measurement surface

For a noise source tested adjacent to one reflecting plane, the microphones shall be located at the four positions numbered 4, 5, 6, and 10, the co-ordinates of which are given in Table B.1 and illustrated in Figures B.1 and B.2.

For a noise source tested adjacent to two reflecting planes, the microphones shall be located at the three positions numbered 14, 15, and 18, the co-ordinates 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 positions numbered 14, 21, and 22, the co-ordinates of which are given in Table B.2 and illustrated in Figure B.4.

Additional microphone positions shall be used to make further measurements if the range of A-weighted sound pressure levels (i.e. the difference in decibels between the highest and lowest levels) measured in accordance with 8.3.1 exceeds twice the number of measurement positions.

The additional microphone positions shall be those numbered 14, 15, 16, and 20 in Table B.1 and Figure B.2. Optionally, the required additional positions on the full hemisphere may be obtained with another measurement at the original microphone positions with the noise source under test rotated through 60°.

If the source under test radiates noise predominantly in one direction or if the noise from a large source is emitted only from a small portion of the source, the usage of extra localized microphone positions on the measurement surface in the region of high radiation should be considered. In this case, follow the procedures specified in ISO 3744.

### 8.2.2 Parallelepiped measurement surface

The number and locations of the microphone positions or traverses depend upon the dimensions of the measurement surface and the measurement distance, 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 the range of A-weighted sound pressure levels (i.e. the difference in decibels between the highest and lowest levels) measured in accordance with 8.3.1 exceeds twice the number of measurement positions.

The number of measurement positions shall be increased as shown in Figure C.1, by increasing the number of equally sized rectangular partial areas.

If the source under test radiates noise predominantly in one direction or if the noise from a large source is emitted only from a small portion of the source, the usage of extra localized microphone positions on the measurement surface in the region of high radiation should be considered. In this case follow the procedures of ISO 3744.

### 8.2.3 Reduction in the number of microphone positions

The number of microphone positions can be reduced if preliminary investigations for a particular family of noise sources show that by using the reduced number of microphone positions, the determined surface sound pressure levels do not deviate by more than 1 dB from those determined from measurements over the complete set of microphone positions in accordance with 8.2.1 and 8.2.2. An example is when the radiation pattern is shown to be symmetrical.

NOTE    The overhead position(s) can be omitted for safety reasons, if so stated in the relevant noise test code.

## 8.3   Determination of sound power levels

### 8.3.1   Measurement of sound pressure levels

A-weighted time-averaged sound pressure levels from the noise source under test, $L'_{pAi(ST)}$, shall be obtained at each microphone position ($i = 1, 2 \ldots n$) over a typical period of operation of the source, for each mode of operation selected (see 6.5). 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 shall be at least 10 s unless otherwise stated in the noise test code for the specific family of noise sources.

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

### 8.3.2   Calculation of mean time-averaged sound pressure levels

The mean values of the measured sound pressure levels from the noise source under test and the background noise shall be determined as described below.

Refer to 4.2 for the criterion for background noise and for determining whether or not the measurements meet the requirements of this International Standard.

For a measurement surface having microphone positions associated with equal segment areas, the mean A-weighted 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, $\overline{L'_{pA(ST)}}$, shall be calculated using Equation (10):

$$\overline{L'_{pA(ST)}} = 10 \lg \left[ \frac{1}{N_M} \sum_{i=1}^{N_M} 10^{0,1 L'_{pA i(ST)}} \right] \text{dB} \qquad (10)$$

where

$L'_{p\mathrm{A}i(\mathrm{ST})}$    is the A-weighted time-averaged sound pressure level of the noise source under test (ST) from the $i$th microphone position or traverse, in decibels;

$N_\mathrm{M}$    is the number of microphone positions or individual microphone traverses.

The mean A-weighted time-averaged sound pressure level of the background noise, $\overline{L_{p\mathrm{A(B)}}}$, shall be calculated using Equation (11):

$$\overline{L_{p\mathrm{A(B)}}} = 10\,\lg\left[\frac{1}{N_\mathrm{M}}\sum_{i=1}^{n}10^{0,1L_{p\mathrm{A}\,i(\mathrm{B})}}\right]\mathrm{dB} \tag{11}$$

where

$L_{p\mathrm{A}i(\mathrm{B})}$    is the A-weighted time-averaged background (B) noise level from the $i$th microphone position or $i$th microphone traverse, in decibels;

$N_\mathrm{M}$    is the number of microphone positions.

If extra localized microphone positions on the measurement surface are added in accordance with 8.2.1 or 8.2.2, follow the surface-averaging procedure in ISO 3744.

### 8.3.3 Corrections for background noise

The background noise corrections, $K_{1\mathrm{A}}$, shall be calculated using Equation (12):

$$K_{1\mathrm{A}} = -10\,\lg\left(1-10^{-0,1\Delta L_{p\mathrm{A}}}\right)\mathrm{dB} \tag{12}$$

where

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

in which

$\overline{L'_{p\,\mathrm{A(ST)}}}$    is the 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,

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

If $\Delta L_{p\mathrm{A}} > 10$ dB, $K_{1\mathrm{A}}$ is assumed equal to zero.

For $3$ dB $\leqslant \Delta L_{p\mathrm{A}} \leqslant 10$ dB, corrections shall be calculated in accordance with Equation (12).

If $\Delta L_{p\mathrm{A}} < 3$ dB, the accuracy of the result(s) is reduced and the value of $K_{1\mathrm{A}}$ to be applied in this case is 3 dB (the value for $\Delta L_{p\mathrm{A}} = 3$ dB). In this case, it shall be clearly stated in the text of the report, as well as in graphs and tables of results, that the data from the test represent an upper boundary to the sound power level of the noise source under test.

### 8.3.4 Calculation of surface time-averaged sound pressure level

The surface time-averaged sound pressure level, $\overline{L_{p\mathrm{A}}}$, shall be calculated by correcting the mean time-averaged sound pressure level, $\overline{L'_{p\mathrm{A(ST)}}}$, for background noise ($K_{1\mathrm{A}}$, see 8.3.3) and the test environment [$K_{2\mathrm{A}}$, see Equation (A.1)] respectively, using Equation (13):

$$\overline{L_{p\mathrm{A}}} = \overline{L'_{p\mathrm{A(ST)}}} - K_{1\mathrm{A}} - K_{2\mathrm{A}} \tag{13}$$

### 8.3.5 Calculation of sound power levels

The sound power level, $L_{W\mathrm{A}}$, for the meteorological conditions at the time and place of the test shall be calculated using Equation (14):

$$L_{W\mathrm{A}} = \overline{L_{p\mathrm{A}}} + 10 \lg \frac{S}{S_0} \text{ dB} \tag{14}$$

where

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

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

## 8.4 Determination of sound energy levels

### 8.4.1 Measurement of single event time-integrated sound pressure levels

A-weighted single event time-integrated sound pressure levels from the noise source under test, $L'_{E\mathrm{A}i\mathrm{(ST)}}$, shall be obtained at each microphone position ($i = 1, 2 \dots N_\mathrm{M}$) either for one single sound emission event at a time (in which case the process shall be repeated $N_\mathrm{e}$ times, where $N_\mathrm{e}$ is at least five) or from several successive ($N_\mathrm{e}$) sound emission events (where again $N_\mathrm{e}$ 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.

In addition, 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, $L_{p\mathrm{A}i\mathrm{(B)}}$, shall be obtained at each microphone position over the same integration time used for the measurement of the noise source under test.

### 8.4.2 Corrections for background noise

The background noise correction, $K_{1\mathrm{A}}$, shall be calculated using Equation (15):

$$K_{1\mathrm{A}} = -10 \lg \left( 1 - 10^{-0,1\Delta L_{E\mathrm{A}}} \right) \text{ dB} \tag{15}$$

where

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

in which

$\overline{L'_{E\text{A(ST)}}}$      is 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;

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

The integration time, $T$, shall be the same for the measurement of the noise source under test and of the background noise.

If $\Delta L_{E\text{A}} > 10$ dB, $K_{1\text{A}}$ is assumed equal to zero.

For 3 dB $\leqslant \Delta L_{E\text{A}} \leqslant$ 10 dB, corrections shall be calculated according to Equation (15).

If $\Delta L_{E\text{A}} < 3$ dB, the accuracy of the result(s) is reduced and the value of $K_{1\text{A}}$ to be applied in this case is 3 dB (the value for $\Delta L_{E\text{A}} = 3$ dB). In this case, it shall be clearly stated in the text of the report, as well as in graphs and tables of results, that the data from the test represent an upper boundary to the sound energy level of the noise source under test.

### 8.4.3 Calculation of surface single event time-integrated sound pressure levels

If $N_\text{e}$ single event time-integrated sound pressure levels have been measured one at a time at the $i$th microphone position, the mean single event time-integrated sound pressure level at that position, $L'_{E\text{A}i\text{(ST)}}$, shall be calculated using Equation (16):

$$L'_{E\text{A}i\text{(ST)}} = 10 \lg \left[ \frac{1}{N_\text{e}} \sum_{q=1}^{N_\text{e}} 10^{0,1 L'_{E\text{A}i,q\text{(ST)}}} \right] \text{dB} \tag{16}$$

where

$L'_{E\text{A}i,q\text{(ST)}}$      is the A-weighted single event time-integrated sound pressure level at the $i$th microphone position for the $q$th sound emission event ($q = 1, 2 \ldots N_\text{e}$) of the noise source under test in operation, in decibels;

$N_\text{e}$      is the number of measurements of single sound emission events.

If a continuous measurement at the $i$th microphone position encompasses $N_\text{e}$ sound emission events, the mean single event time-integrated sound pressure level for one event at that position, $L'_{E\text{A}i\text{(ST)}}$, shall be calculated using Equation (17):

$$L'_{E\text{A}i\text{(ST)}} = L'_{E\text{A}i,N_\text{e}\text{(ST)}} - 10 \lg N \text{ dB} \tag{17}$$

where

$L'_{E\text{A}i,N_\text{e}\text{(ST)}}$      is the A-weighted time-integrated sound pressure level at the $i$th microphone position, encompassing $N_\text{e}$ successive sound emission events of the noise source under test in operation, in decibels;

$N_\text{e}$      is the number of sound emission events encompassed by one measurement of the single event time-integrated sound pressure level.

The mean single event time-integrated sound pressure level over the measurement surface, $\overline{L'_{E\text{A(ST)}}}$ shall be calculated using the mean single event time-integrated sound pressure levels at the individual microphone positions, $L'_{E\text{A}i\text{(ST)}}$, in the same way as for the time-averaged sound pressure levels specified in 8.3.2.

The surface single event time-integrated sound pressure level, $\overline{L_{EA}}$, shall then be calculated by correcting the mean single event time-integrated sound pressure level over the measurement surface, $\overline{L'_{EA(ST)}}$, for background noise ($K_{1A}$, see 8.3.3) and the test environment [$K_{2A}$, see Equation (A.1)] respectively, using Equation (18):

$$\overline{L_{EA}} = \overline{L'_{EA(ST)}} - K_{1A} - K_{2A} \tag{18}$$

### 8.4.4 Calculation of sound energy levels

The sound energy level, $L_{JA}$, for the meteorological conditions at the time and place of the test shall be calculated using Equation (19):

$$L_{JA} = \overline{L_{EA}} + 10 \lg \frac{S}{S_0} \text{ dB} \tag{19}$$

where

$\overline{L_{EA}}$   is the A-weighted 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$^2$.

## 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, $\sigma_{tot}$, in decibels:

$$u\left(L_W\right) \approx u\left(L_J\right) \approx \sigma_{tot} \tag{20}$$

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, $\sigma_{R0}$, in decibels, and the standard deviation, $\sigma_{omc}$, in decibels, describing the uncertainty due to the instability of the operating and mounting conditions of the source under test in accordance with:

$$\sigma_{tot} = \sqrt{\sigma_{R0}^2 + \sigma_{omc}^2} \tag{21}$$

Equation (21) shows that variations of operating and mounting conditions expressed by $\sigma_{omc}$ should be taken into account before a measurement procedure with a certain grade of accuracy (characterized by $\sigma_{R0}$) is selected for a specific machine family (see 9.5 and D.3).

NOTE    If different measurement procedures offered by the ISO 3741[2] to ISO 3747[6] series are used, systematic numerical deviations (biases) can additionally occur.

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

$$U = k\,\sigma_{tot} \tag{22}$$

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 may 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 $\sigma_{omc}$

The standard deviation $\sigma_{omc}$ [see Equation (D.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 $\sigma_{omc}$, repeated sound pressure levels are measured either at the microphone position associated with the highest sound pressure level, $L'_{pi(ST)}$, or measured and averaged over the entire measurement surface, $\overline{L}'_{p(ST)}$. Measurements are then corrected for background noise. For each of these repeated measurements, the mounting of the machine and its operating conditions shall be readjusted. The symbol $\sigma_{omc}$ is modified to $\sigma'_{omc}$ for the individual sound source under test. It is possible that a noise test code provides a value of $\sigma_{omc}$ representative of 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 $\sigma_{omc}$ 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 unforeseeable manner, a value of 2 dB is appropriate. However, in extreme cases, e.g. strongly varying noise generated by the processed material (stone-breaking machines, metal-cutting machines, and presses operating under load), a value of 4 dB results.

## 9.3 Determination of $\sigma_{R0}$

### 9.3.1 General

The standard deviation $\sigma_{R0}$ 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 $\sigma_{omc}$.

The values of $\sigma_{R0}$ given in Table 1 reflect knowledge current at the time of publication. 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 D).

### 9.3.2 Round robin test

The round robin test for determining $\sigma_{R0}$ 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 $\sigma'_{tot}$ 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, $\sigma'_{tot}$, in decibels, of all results obtained with a round robin test includes the standard deviation $\sigma'_{omc}$ and allows $\sigma'_{R0}$ to be determined by using

$$\sigma'_{R0} = \sqrt{\sigma'^{2}_{tot} - \sigma'^{2}_{omc}} \tag{23}$$

If $\sigma'_{R0}$ 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 $\sigma_{R0}$. Whenever available, such a value should be given in the noise test code specific to the machine family concerned (together with $\sigma_{omc}$) 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 $\sigma_{R0}$.

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 local environmental correction $K_3$, or if the noise emission of a machine is rechecked at the same location. Results of such delimited tests should be denoted by $\sigma_{R0,DL}$, and this designation should also be used for tests on large machines being not movable in space.

Values for $\sigma_{R0,DL}$ can be expected to be lower than those given in Table 1.

The determination of $\sigma_{R0}$ using Equation (23) is imprecise if $\sigma_{tot}$ is only slightly higher than $\sigma_{omc}$. In this case, Equation (23) provides a small value of $\sigma_{R0}$, but with a low accuracy. To limit this inaccuracy, $\sigma_{omc}$ should not exceed $\sigma_{tot}/\sqrt{2}$.

### 9.3.3 Modelling approach for $\sigma_{R0}$

Generally $\sigma_{R0}$, 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, $\sigma_{R0}$ can be described by the modelling approach presented in ISO/IEC Guide 98-3, as follows:

$$\sigma_{R0} \approx \sqrt{\left(c_1 u_1\right)^2 + \left(c_2 u_2\right)^2 + ..... + \left(c_n u_n\right)^2} \tag{24}$$

In Equation (24), the uncertainty components due to the instability of the sound emission of the source are not included. These components are covered by $\sigma_{omc}$. Annex D discusses each component of the uncertainty $\sigma_{R0}$ in accordance with knowledge existing at the time of publication.

NOTE  If the uncertainty components in the modelling approach are correlated, Equation (24) does not apply. Furthermore, the modelling approach requires detailed knowledge to determine the individual terms in Equation (24).

By contrast, the estimation of $\sigma_{R0}$ based on a round robin test does not require assumptions about possible correlations between the individual terms of Equation (24). At the time of publication, a round robin test is more realistic than determining possible correlations between the individual terms of Equation (24) and their dependency 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 $\sigma_{R0}$

Table 1 shows typical upper bound values of the standard deviation $\sigma_{R0}$ for accuracy grade 3 that may cover most of the applications of this International Standard (References [27][28]). 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 $\sigma_{R0}$ for a given family of machines are smaller than those given in Table 1, a round robin test is recommended to obtain machine-specific values of $\sigma_{R0}$.

**Table 1 — Typical upper bound values of the standard deviation of reproducibility of the method, $\sigma_{R0}$, for A-weighted sound power levels and sound energy levels determined in accordance with this International Standard**

| Application | Standard deviation of reproducibility, $\sigma_{R0}$ dB |
|---|---|
| For a noise source which emits sound without significant tones | 3 |
| For a noise source which emits sound that contains predominant discrete tones | 4 |

## 9.5 Total standard deviation $\sigma_{tot}$ and expanded measurement uncertainty $U$

The total standard deviation and the expanded measurement uncertainty shall be determined using Equation (21) and Equation (22), respectively. For the purpose of this International Standard, a normal distribution is assumed. Thus a coverage factor of $k = 2$ shall be used corresponding to a coverage probability of 95 %. The coverage factor and coverage probability shall be reported together with the expanded measurement uncertainty.

EXAMPLE Accuracy grade 3; $\sigma_{omc} = 2,0$ dB; coverage factor $k = 2$; determined $L_{WA} = 82$ dB. Machine-specific determinations of $\sigma_{R0}$ have not been undertaken, thus the value is taken from Table 1 ($\sigma_{R0} = 3$ dB). Using Equations (22) and (21) it follows

$$U = 2 \times \sqrt{3^2 + 2^2} \text{ dB} = 7,2 \text{ dB}$$

Additional examples of calculated values for $\sigma_{tot}$ are given in D.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.

## 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 compliance of the instrumentation system, 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, the shape of the measurement surface and the measurement radius or distance;

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, in decibels, whether time-averaged or single event, in the test environment from the noise source under test;

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

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

f)   the A-weighted surface time-averaged sound pressure levels or A-weighted surface single event time-integrated sound pressure levels, in decibels;

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

NOTE        ISO 9296[13] requires that the declared A-weighted sound power levels, $L_{W\mathrm{Ad}}$, of computers and business equipment are expressed in bels, using the identity 1 B = 10 dB.

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

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

## 11  Test report

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

## Determination of the environmental correction

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

NOTE    The value of the environmental correction can also be determined in accordance with the procedures of ISO 3744.

The environmental correction, $K_{2A}$, shall be calculated from Equation (A.1):

$$K_{2A} = 10 \lg \left[ 1 + 4 \frac{S}{A} \right] \text{dB} \qquad\qquad (A.1)$$

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.

In order to ascertain the acoustic characteristics of the test environment, $K_{2A}$ shall be determined from Equation (A.1) using the value of $A$ given by Equation (A.2):

$$A = \alpha S_V \qquad\qquad (A.2)$$

where

$\alpha$    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, $\alpha$**

| Mean sound absorption coefficient, $\alpha$ | 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 Key microphone positions and additional microphone positions

Four key microphone positions associated with equal areas of the measurement surface are numbered 4, 5, 6 and 10 in Figures B.1 and B.2, and their co-ordinates according to the co-ordinate system defined in 7.1 are listed in Table B.1. Four additional microphone positions are numbered 14, 15, 16 and 20 in Figure B.2 and their co-ordinates are also listed in Table B.1.

**Table B.1 — Microphone positions for a noise source over a reflecting plane**
(key microphone positions: 4,5,6,10; additional microphone positions: 14,15,16,20;
$r$ is the radius of the measurement hemisphere)

| Position number | $x/r$ | $y/r$ | $z/r$ |
|---|---|---|---|
| 4 | −0,45 | 0,77 | 0,45 |
| 5 | −0,45 | −0,77 | 0,45 |
| 6 | 0,89 | 0 | 0,45 |
| 10 | 0 | 0 | 1 |
| 14 | 0,45 | −0,77 | 0,45 |
| 15 | 0,45 | 0,77 | 0,45 |
| 16 | −0,89 | 0 | 0,45 |
| 20 | 0 | 0 | 1 |
| NOTE        The overhead positions 10 and 20 coincide and it is permissible to omit these if so indicated in the relevant noise test code. | | | |

NOTE      The microphone positions are a subset of those used in ISO 3744 for a broadband noise source; the same position numbers are used in both this International Standard and in ISO 3744.

## 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 co-ordinates of the microphone positions are shown in Figure B.3 and are numbered 14, 15 and 18 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 are shown in Figure B.4 and numbered 14, 21 and 22 in Table B.2.

**Table B.2 — Microphone positions for a source adjacent to two or three reflecting planes**

| Position number | $x/r$ | $y/r$ | $z/r$ |
|---|---|---|---|
| 14 | 0,45 | −0,77 | 0,45 |
| 15 | 0,45 | 0,77 | 0,45 |
| 18 | 0,66 | 0 | 0,75 |
| 21 | 0,77 | −0,45 | 0,45 |
| 22 | 0,47 | −0,47 | 0,75 |



**Key**
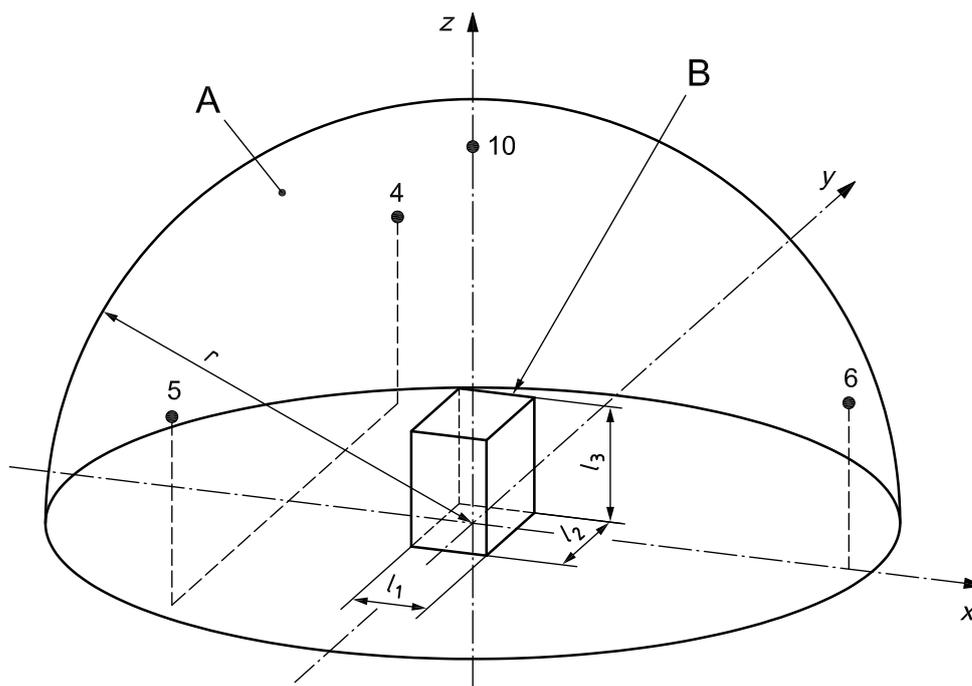
●   key microphone positions (4, 5, 6, 10)
A   measurement surface
B   reference box
$l_1$   reference box length
$l_2$   reference box width
$l_3$   reference box height
$r$   radius of measurement surface

**Figure B.1 — Key microphone positions on the hemispherical measurement surface**

**Key**
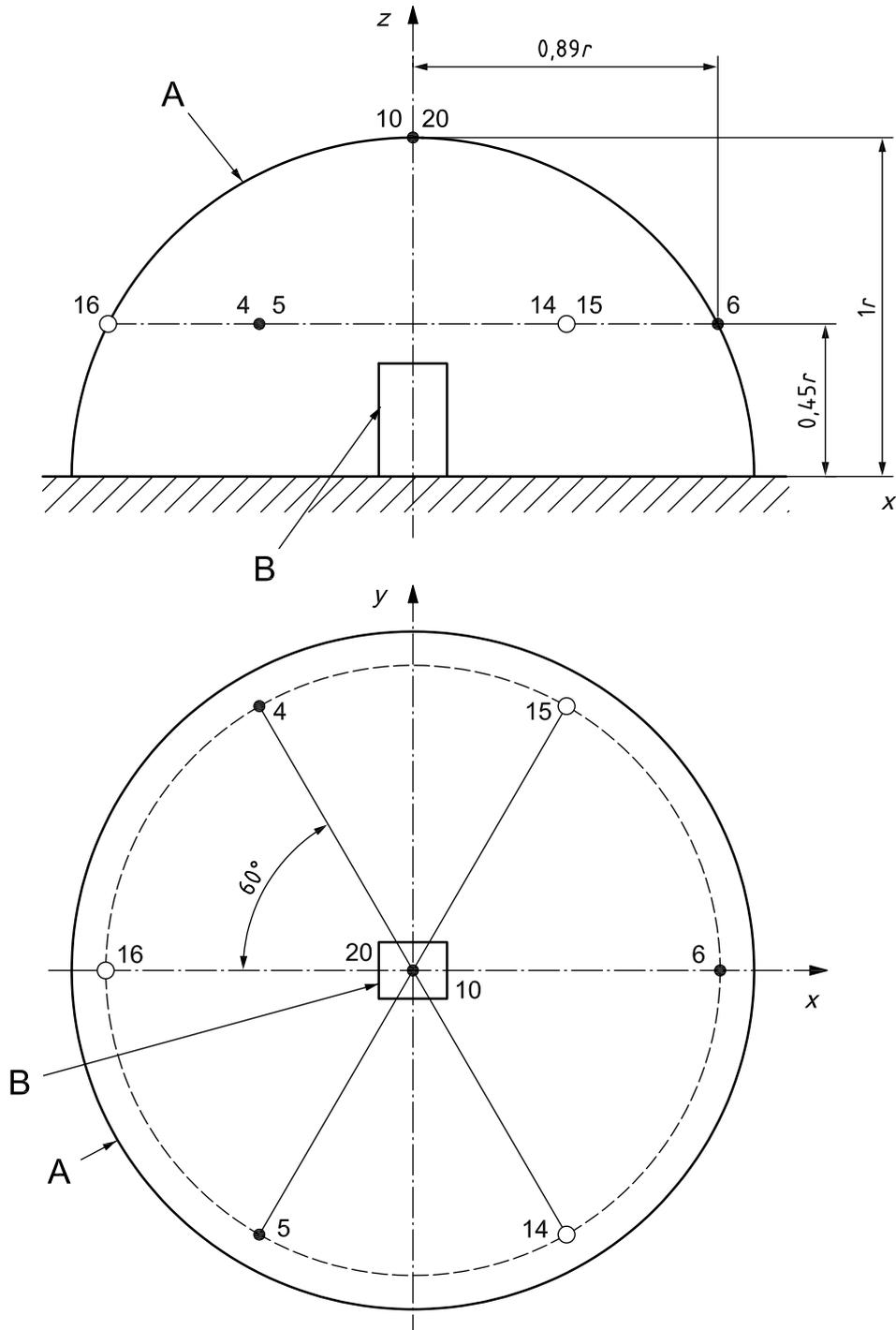
●   key microphone positions (4, 5, 6, 10)

○   additional microphone positions (14, 15, 16, 20)

A   measurement surface

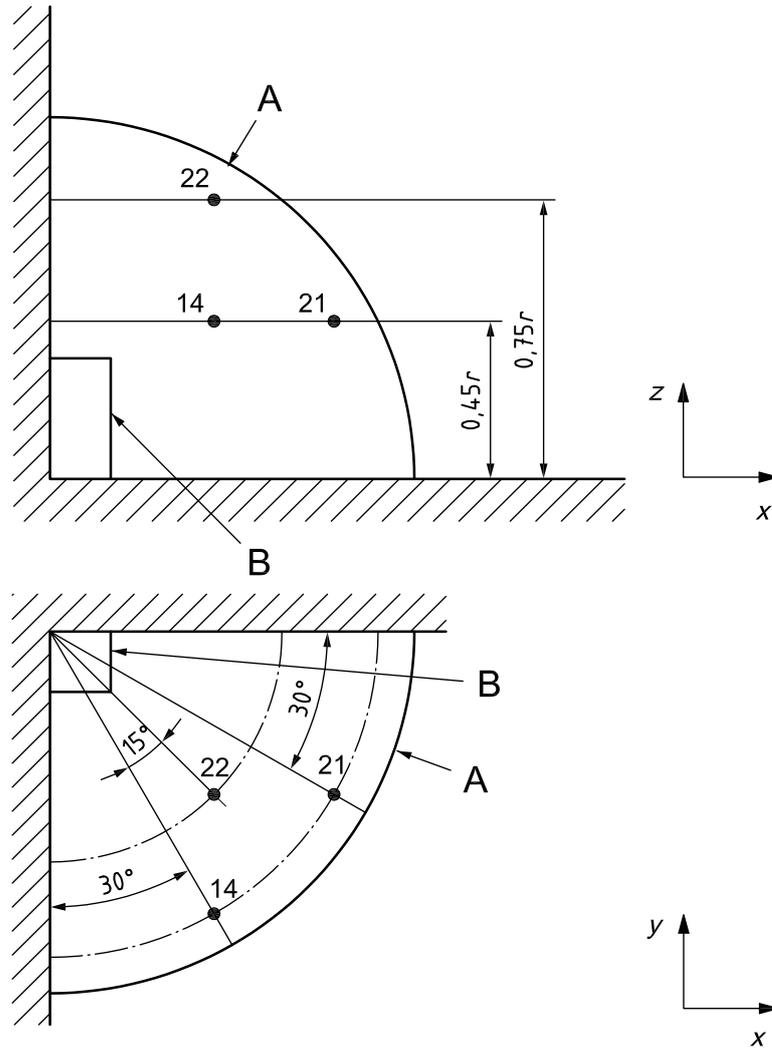B   reference box

$r$   radius of measurement surface

**Figure B.2 — Microphone positions on the hemispherical measurement surface**

**Key**
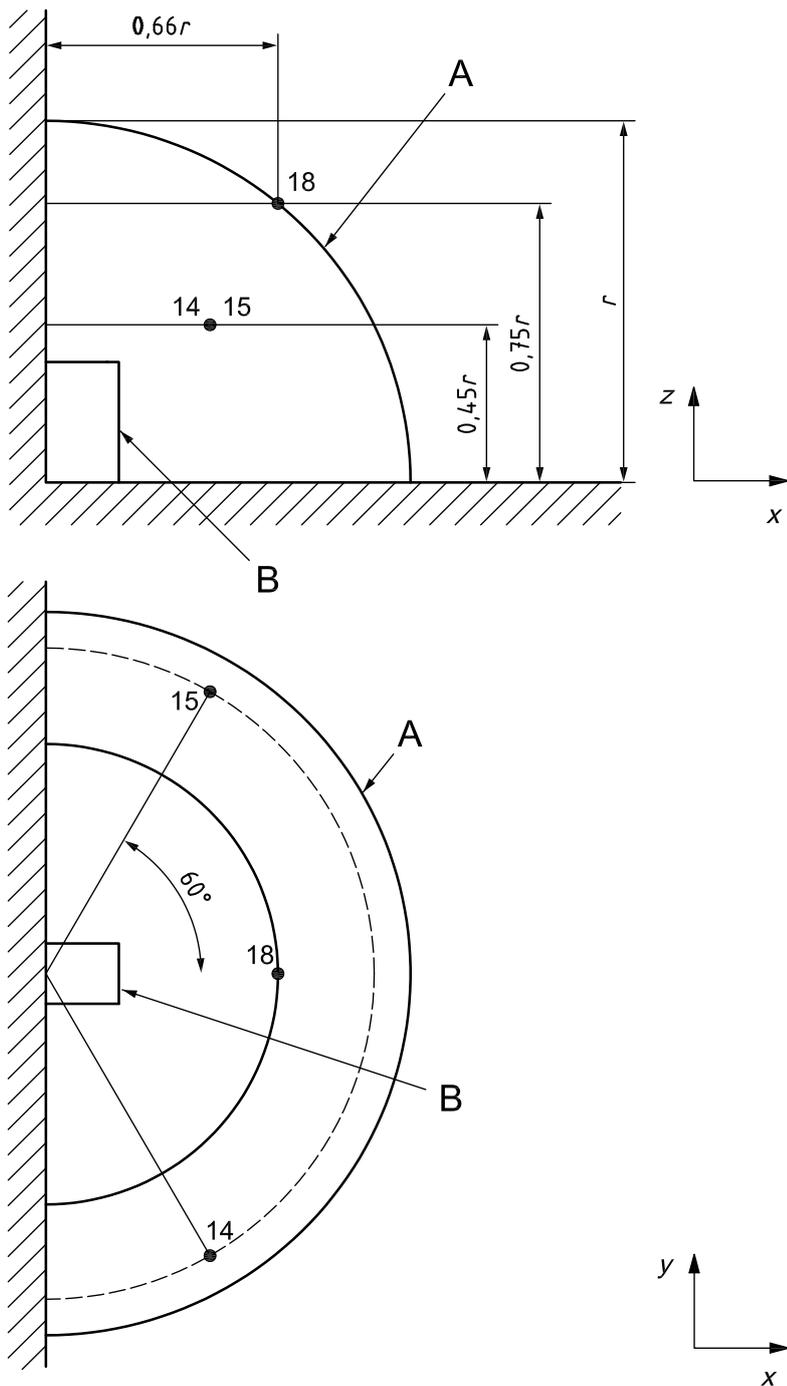
●   microphone positions (14, 15, 18)

A   measurement surface

B   reference box

$r$   radius of measurement surface

**Figure B.3 — Microphone positions on a half-hemispherical measurement surface adjacent to two reflecting planes**

**Key**

● microphone positions (14, 21, 22)

A measurement surface

B reference box

*r* radius of measurement surface

**Figure B.4 — Microphone positions on a quarter-hemispherical measurement surface adjacent to three reflecting planes**

# Annex C
## (normative)

# Microphone arrays on a parallelepiped measurement surface

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

Each plane of the measurement surface shall be considered on its own and so subdivided that the result is the smallest possible number of equal-sized rectangular partial areas with a maximum length of side equal to $3d$, where $d$ is the measurement distance (3.10) (see Figure C.1). The microphone positions are in the centre of each partial area. In this way the microphone positions for Figures C.2 to C.6 are obtained.

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

For a source to be tested adjacent to more than one reflecting plane, reference shall be made to Figures C.7 and C.8.
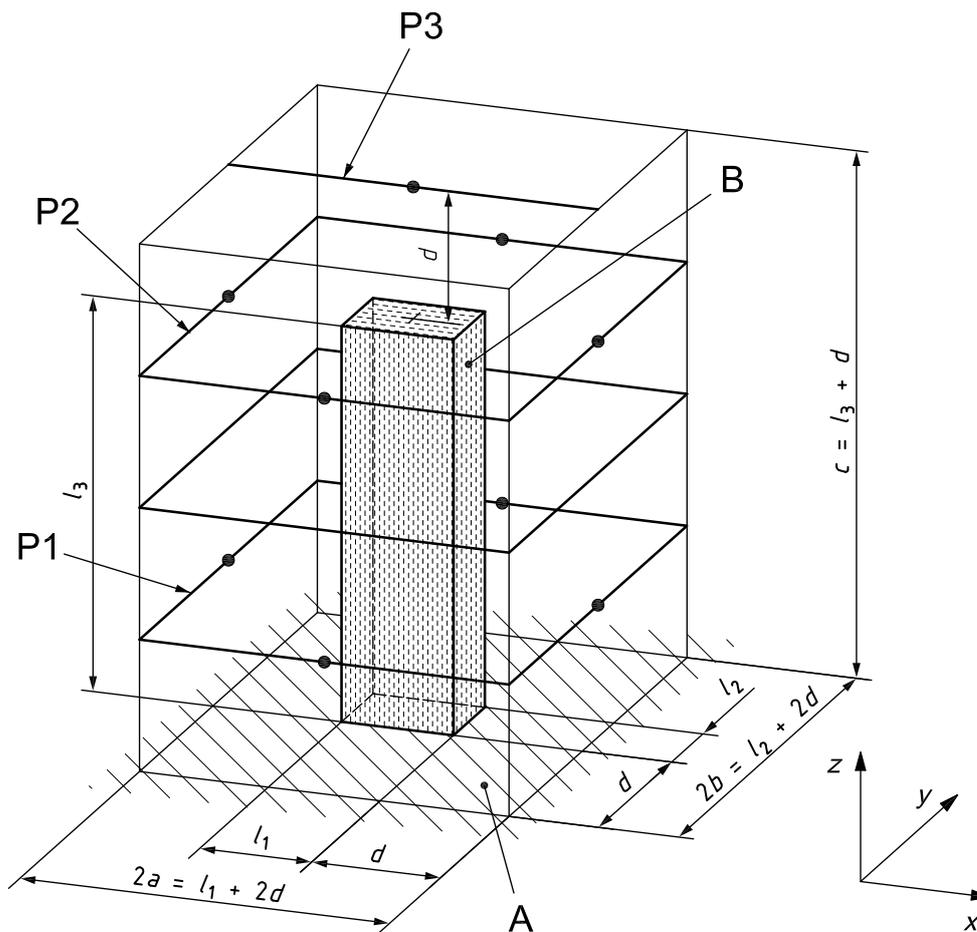


**Key**

●   microphone positions

$d$   measurement distance
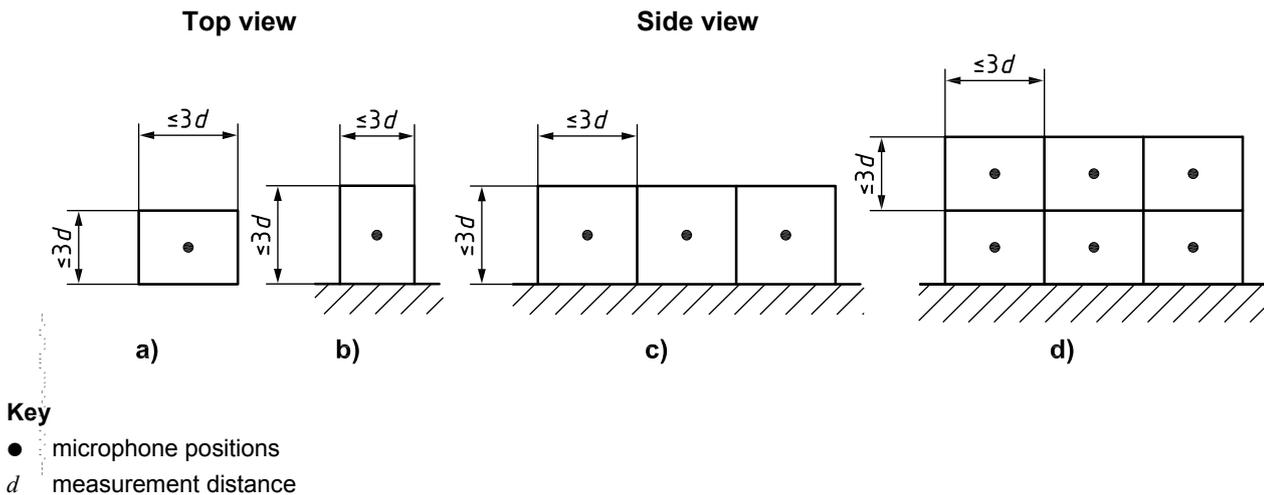
**Figure C.1 — Microphone positions on a parallelepiped measurement surface**
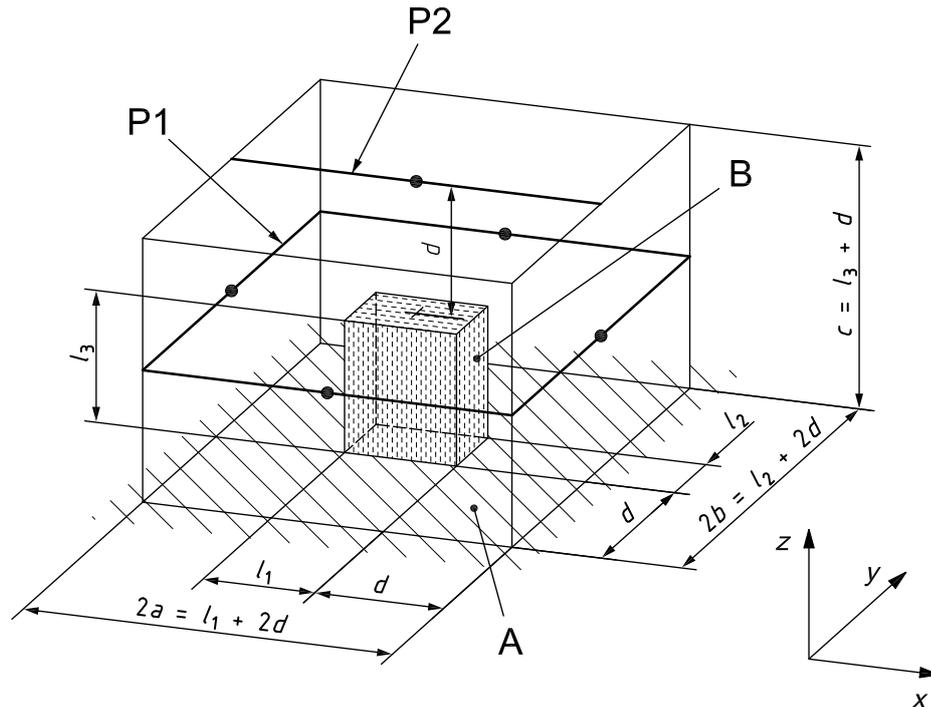
**Key**

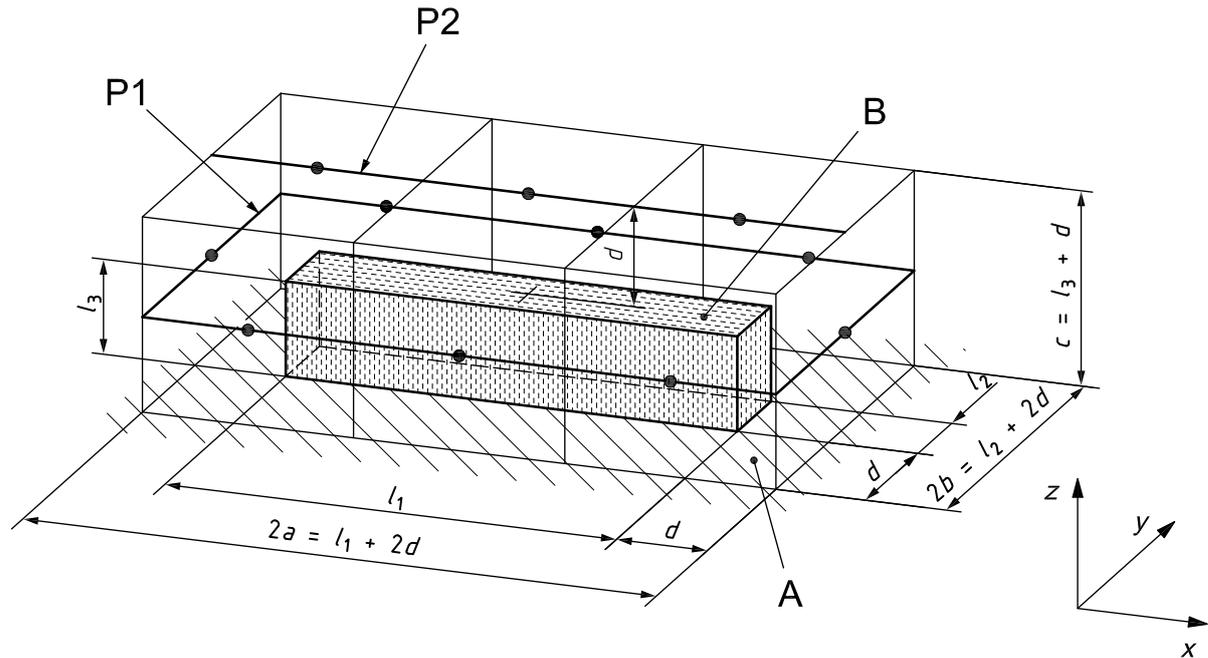| | |
|---|---|
| ● | microphone positions |
| A | reflecting plane |
| B | reference box |
| $2a$ | measurement surface length |
| $2b$ | measurement surface width |
| $c$ | measurement surface height |
| $d$ | measurement distance |
| $l_1$ | reference box length |
| $l_2$ | reference box width |
| $l_3$ | reference box height |
| P1, P2 | path 1, path 2 |

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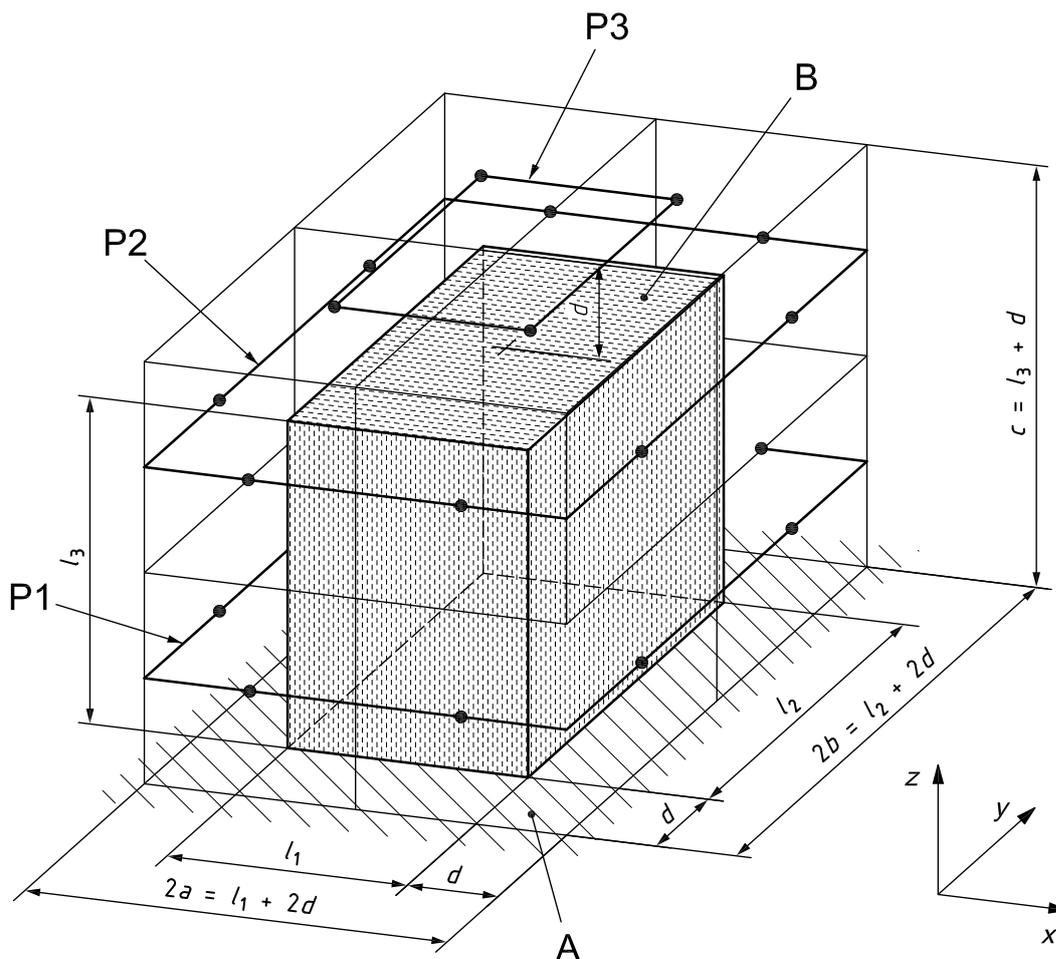
Key

| ● | | 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, P2, P3 | | path 1, path 2, path 3 |

**Figure C.3 — Example of a measurement surface and 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**

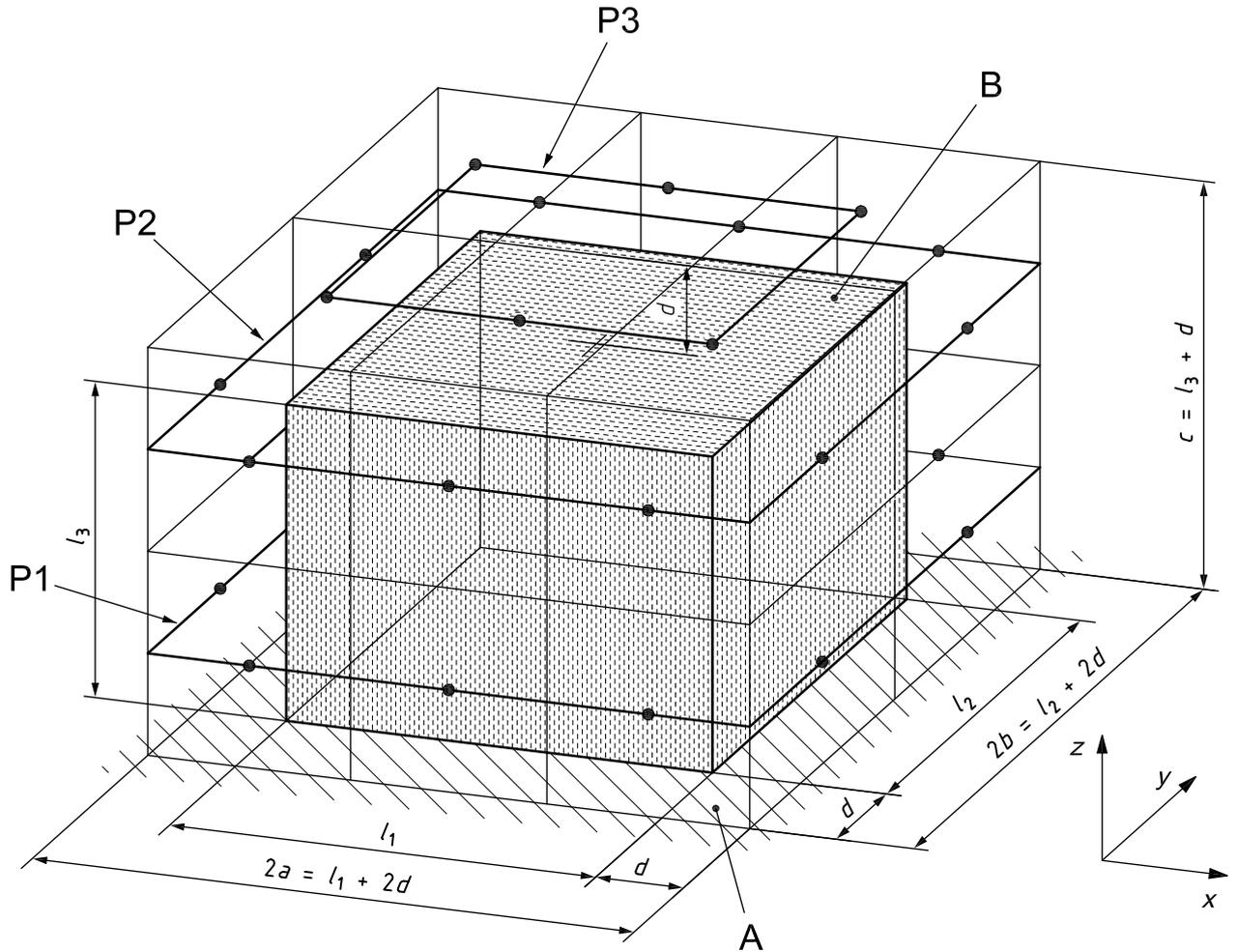| | |
|---|---|
| ● | microphone positions |
| A | reflecting plane |
| B | reference box |
| $2a$ | measurement surface length |
| $2b$ | measurement surface width |
| $c$ | measurement surface height |
| $d$ | measurement distance |
| $l_1$ | reference box length |
| $l_2$ | reference box width |
| $l_3$ | reference box height |
| P1, P2 | path 1, path 2 |

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

**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, P2, P3 | path 1, path 2, path 3 |

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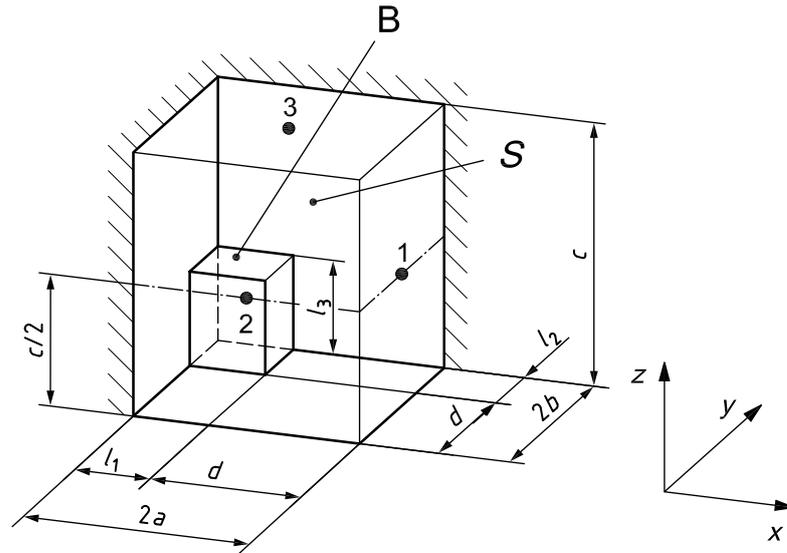
**Key**

| | |
|---|---|
| ● | 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, P2, P3 | path 1, path 2, path 3 |

**Figure C.6 — Example of a measurement surface and 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**

| | |
|---|---|
| ● | microphone positions (1, 2, 3, 4) |
| 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.7 — Parallelepiped measurement surface with four microphone positions for floor-standing noise sources adjacent to two reflecting planes**

**Key**

| | |
|---|---|
| ● | microphone positions (1, 2, 3) |
| 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.8 — Parallelepiped measurement surface with three microphone positions for floor-standing noise sources adjacent to three reflecting planes**

# Annex D
(informative)

# Guidelines on the development of information on measurement uncertainty

## D.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.

## D.2 Considerations on the total standard deviation $\sigma_{\text{tot}}$

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 $\sigma_{\text{tot}}$ [see Equation (22)], with $\sigma_{\text{tot}}$ being the approximation of the relevant $u(L_{W\text{A}})$ as defined in ISO/IEC Guide 98-3.

This total standard deviation $\sigma_{\text{tot}}$ results from the two components $\sigma_{R0}$ and $\sigma_{\text{omc}}$ [see Equation (21)], which are significantly different in nature.

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

The machinery specific standard deviation $\sigma_{\text{omc}}$ cannot be calculated and has to be determined by repeated measurements as described in D.3. Information on the standard deviation $\sigma_{R0}$ is given in D.4.

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.

## D.3 Considerations on $\sigma_{\text{omc}}$

The standard deviation $\sigma_{\text{omc}}$, described in 9.2, is calculated from

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

where

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

$L_{p\mathrm{av}}$     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 $L_{p\mathrm{av}}$ are replaced in Equation (D.1) by $\overline{L_{p,j}}$, and $\overline{L_{p\mathrm{av}}}$, 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 $\sigma_{\mathrm{omc}}$ are given in the following.

The test conditions shall represent normal usage and conform to manufacturers' and users' recommended practice. However, even in normal use, 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 $\sigma_{\mathrm{omc}}$ 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, $\sigma_{\mathrm{tot}}$, investigations on $\sigma_{\mathrm{omc}}$ have a higher priority compared to those on the other uncertainty components leading to $\sigma_{R0}$ [see Equation (21)]. This is because $\sigma_{\mathrm{omc}}$ may be significantly larger in practice than, for example, $\sigma_{R0} = 3$ dB for accuracy grade 3 measurements as given in Table 1.

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

These examples show that it may be superfluous to extend the measuring effort to ensure a measurement of accuracy grade 2 if the uncertainty associated with the mounting and operating conditions is large.

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

**Table D.1 — Examples of calculated total standard deviations $\sigma_{tot}$ for three different cases**

| Standard deviation of reproducibility of the method, $\sigma_{R0}$, dB | Operating and mounting conditions | | |
|---|---|---|---|
| | stable | unstable | very unstable |
| | Standard deviation $\sigma_{omc}$, dB | | |
| | 0,5 | 2 | 4 |
| | Total standard deviation $\sigma_{tot}$, 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 |

## D.4 Considerations on $\sigma_{R0}$

### D.4.1 General

Upper bound values of $\sigma_{R0}$ are given in Table 1. Additionally in 9.3, the investigation of values of $\sigma_{R0}$ 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 (24) which requires more detailed information.

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

The budget approach, however, implies that both $c_i$ and $u_i$ are statistically independent components. Crucially, it also implies 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.

### D.4.2 Contributions to the uncertainty $\sigma_{R0}$

#### D.4.2.1 General

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

$$L_{WA} = \delta_{method} + \delta_{omc} + \overline{L'_{pA(ST)}} + 10 \lg \frac{S}{S_0} \, dB - K_{1A} - K_{2A} + \delta_{met} + \delta_{slm} + \delta_{mic} + \delta_{angle} + \delta_{tone} \tag{D.2}$$

where

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

$\delta_{omc}$ is an input quantity to allow for any uncertainty due to operating and mounting conditions — this quantity is not included in the calculation of $\sigma_{R0}$ [see Equation (21)];

$\overline{L'_{pA(ST)}}$ is the mean A-weighted 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$^2$;

$K_{1A}$ is the background noise correction, in decibels, see Equation (12);

$K_{2A}$ is the environmental correction, in decibels, see Annex A;

$\delta_{met}$ is an input quantity to account for the different decibel reference quantities used in sound pressure level and in sound power level, as well as the changes in sound power with temperature and pressure, in decibels;

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

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

$\delta_{angle}$ 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;

$\delta_{tone}$ is an input quantity to allow for any uncertainty due to spectral shape and the presence of tones.

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

NOTE 2    The quantities included in Equation (D.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 $\sigma_{omc}$ whereas $\sigma_{R0}$ includes the rest of the uncertainty components.

Table D.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.

The calculation of $\sigma_{R0}$ 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 D.2 are given in D.4.2.2 to D.4.2.11. Equations to calculate uncertainties are given with examples to show the expected range of measurement uncertainties.

**Table D.2 — Uncertainty budget for determinations of $\sigma_{R0}$ for sound power level and sound energy level, valid for A-weighted measurements of a source with a relatively flat frequency spectrum**

| Quantity | | Estimate[a] dB | Standard uncertainty[a], $u_i$ | Probability distribution | Sensitivity coefficient[a], $c_i$ |
|---|---|---|---|---|---|
| $\delta_{method}$ | method | 0 | 0,6 | Normal | 1 |
| $\overline{L'_{pA(ST)}}$ | mean time-averaged sound pressure level | $\overline{L'_{pA(ST)}}$ | $s$, repeatability standard deviation | Normal | $1 + \dfrac{1}{10^{0,1\Delta L_{pA}} - 1}$ |
| $S$ | measurement surface area | $10 \lg \dfrac{S}{S_0}$ | $\Delta r / \sqrt{3}$ | Rectangular | $8,7/r$ |
| $K_{1A}$ | background noise correction | $K_{1A}$ | $s$, repeatability standard deviation | Normal | $\dfrac{1}{10^{0,1\Delta L_{pA}} - 1}$ |
| $K_{2A}$ | environmental correction | $K_{2A}$ | $K_{2A}/4$ | Normal | 1 |
| $\delta_{met}$ | meteorological corrections | $H_a/1\,000$ | 0,3 | Triangular | 1 |
| $\delta_{slm}$ | sound level meter | 0 | Class 1: 0,5 Class 2: 1,0 | Normal | 1 |
| $\delta_{mic}$ | sampling | 0 | $\dfrac{s}{\sqrt{N_M}}$ | Normal | 1 |
| $\delta_{angle}$ | angle | 0 | Box: 1,2 Hemisphere: 0,25 | Rectangular | $10^{-K_{2A}/10}$ |
| $\delta_{tone}$ | spectral shape | 0 | Audible tones: 3 Otherwise: 0 | Normal | 1 |
| [a] Quantities are described in the numerical example following this table. | | | | | |

### D.4.2.2 Measurement method

Different measurement methods may lead to different results. 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, $\sigma_{R0}$. 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, the assumed value of this parameter due to residual uncertainties $u_{method} = 0,6$ dB. With a sensitivity coefficient of $c_{method} = 1$, this results in an uncertainty contribution of 0,6 dB.

### D.4.2.3 Sound pressure measurement repeatability

The mean time-averaged sound pressure level of the source under test is usually determined only once. This result is considered to be a suitable estimate of the quantity. Its standard uncertainty, indicating the repeatability of this value, has to be determined separately by a number of (at least six) successive measurements carried out at a single microphone position under identical conditions (i.e. same measurement procedure, same observer, same measuring instrument, same location, but with the measuring instrument

removed and installed again between trials). The standard deviation of the values of these measurements may be taken as the standard uncertainty of $\overline{L'_{p\text{A(ST)}}}$.

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

where $L'_{p\text{av}}$ is the arithmetic average of the measured $L'_{p,j}$ values.

The sensitivity coefficient is the partial derivative of $L_{W\text{A}}$ [Equation (D.2)], with respect to $\overline{L'_{p\text{A(ST)}}}$ and is given, after substitution for $K_{1\text{A}}$ according to its definition, by:

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

Measurement repeatability can be strongly influenced by averaging time. Using the same extreme scenario as for $c_{K_{1\text{A}}}$ results in $c_{L_{p\text{A(ST)}}} = 2$. In this extreme scenario, the high assumed background noise level causes $u_{L'_{p\text{A(ST)}}}$ to be at least 1,5 dB due solely to the fluctuations in background noise. The resulting uncertainty contribution $u_{L_{p\text{A(ST)}}} c_{L_{p\text{A(ST)}}} = 3$ dB. If the averaging time does not cover a sufficient number of machinery cycles, the total uncertainty may be unacceptably large for a survey 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, $u_{L_{p\text{A(ST)}}}$, 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 less than 1,5 dB.

### D.4.2.4 Measurement surface area

For a hemispherical measurement surface, the estimate for $S = 2\pi r^2$ is calculated for a given value of the radius $r$ of the hemisphere. The standard uncertainty depends on the uncertainty of the realization of the defined microphone positions on this surface. If the uncertainty in the measurement surface dimensions is assumed to have a rectangular distribution with a range of $\pm \Delta r$, the standard deviation results in

$$u_S = \frac{\Delta r}{\sqrt{3}}$$

Similar results apply for a box surface. If the uncertainty in the measurement surface dimensions is assumed to have a rectangular distribution with a range of $\pm \Delta d$, the standard deviation is

$$u_S = \frac{\Delta d}{\sqrt{3}}$$

The sensitivity coefficient is obtained from the derivative of $L_{W\text{A}}$ with respect to $r$. After substitution for the surface area $S = 2\pi r^2$, the sensitivity coefficient is $c = 8,7/r$ for a hemisphere or $c = 8,7/d_0$ for a box surface. Typically an uncertainty contribution of 0,1 dB is achievable with very careful microphone positioning.

### D.4.2.5 Background noise correction

An estimate of $K_1$ is derived from measurements of the mean time-averaged sound pressure levels of the source under test and of background noise according to its definition. The standard uncertainty of the background noise correction may be obtained from the standard deviations of the results of repeated

measurements (at least six) of the background level difference $\Delta L_{p,}$ at a single microphone position on the measurement surface.

Since the relationship between $L_{WA}$ and $\overline{L'_{pA(ST)}}$ is already covered by D.4.2.3, the sensitivity coefficient of the background noise correction is obtained as the partial derivative of the sound power level, $L_{WA}$, with respect to the background noise level $L_{p(B)}$ and is given by

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

In this example, the background noise is assumed to have a standard deviation of 3 dB, and if the extreme case is taken where $L'_{pA(ST)} - L_{pA(B)}$ is 3 dB, this results in a sensitivity coefficient, $c_{K_{1A}} = 1$. In this worst case, the total contribution to uncertainty is 3,0 dB. Typically (assuming better control of background noise), this uncertainty contribution should be less than 1,5 dB. This uncertainty could be reduced by lowering fluctuations in background noise. The uncertainty, $u_{K_{1A}}$, 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 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.

### D.4.2.6    Environmental reflections

An estimate of the correction for acoustical environment has to be determined by the procedures specified in Annex A. Practical experience suggests that the standard uncertainty is approximately given by $u_{K_{2A}} \approx K_{2A}/4$, leading to a value of $u_{K_{2A}} = 1,8$ dB for an environmental correction of $K_{2A} = 7$ dB.

The sensitivity coefficient is equal to 1. For the extreme scenario, the total uncertainty contribution is 1,8 dB. More typically, $K_{2A}$ is smaller and the uncertainty contribution is 1,2 dB. A smaller uncertainty contribution can be obtained by reducing the measurement distance, or reduction of $K_{2A}$ by changing rooms, adding absorption in the room, or opening large doors and windows. This uncertainty component could be made negligible in an outdoor measurement. Consideration should be given to use of a higher grade measurement if $K_{2A}$ values can be reduced below 4 dB.

### D.4.2.7    Meteorological corrections

Measurements at high altitude cause an underestimate of the sound power level when compared to measurements at sea level. The magnitude of the underestimate of $\delta_{met}$ is approximately $H_a/1\,000$ (where $H_a$ is the altitude in metres). For altitudes below 1 500 m, no meteorological correction is required, and the associated uncertainty is typically small (assuming a triangular distribution for this uncertainty, the standard deviation is 0,6 dB). At altitudes above 1 500 m it is recommended that meteorological corrections such as those given in ISO 3744 be considered.

### D.4.2.8    Sound level meter

The estimate of $\delta_{slm}$ is zero and the corresponding sensitivity coefficient is 1. The standard uncertainty $u_{slm}$ due to performance deviations of the measuring instrumentation from nominal performance depends on the class of instrumentation in accordance with IEC 61672-1:2002 and on frequency and other characteristics of the noise to be measured. For a well-calibrated sound level meter at medium frequencies, and for a broadband and approximately stationary noise character, $u_{slm}$ may be assumed to be typically 0,5 dB for a class 1 instrument and 1 dB for a class 2 instrument. For different measurement conditions, reference is made to IEC 61672-1.

### D.4.2.9 Sampling

The standard uncertainty due to sampling is given by:

$$u_{\text{mic}} = \frac{s}{\sqrt{N_{\text{M}}}} = \frac{1}{\sqrt{N_{\text{M}}}} \sqrt{\frac{1}{(N_{\text{M}}-1)} \sum_{i=1}^{N_{\text{M}}} (L'_{pi(\text{ST})} - L'_{p\text{av}})^2}$$

where

$N_{\text{M}}$     is the number of microphone positions;

$L'_{p\text{av}}$     is the arithmetic average of the measured $L'_{pi(\text{ST})}$ values.

The worst case occurs when the range of measured levels is 10 dB, for a source with a directivity index of 5 dB or more measured in an outdoor environment, resulting in $u_{\text{mic}} = 2{,}5$ dB. However, in a reverberant environment, the range of levels is smaller and a more typical value of $u_{\text{mic}} = 1{,}4$ dB results.

The sensitivity coefficient $c_{\text{mic}} = 1$. The uncertainty contribution can be reduced by increasing the number of measurement positions, or increasing the measurement distance.

### D.4.2.10 Angle

The use of sound pressure to approximate the sound intensity basically leads to an overestimate of the sound power. The magnitude of this overestimation depends on the sound source, its directional characteristics and the measurement distance. No generally valid relationships either for an approximate estimate or for its standard uncertainty can be given. The derivation of a value for a reasonable standard uncertainty experimentally by investigating different sound sources using different methods (i.e. sound pressure versus sound intensity measurements) is recommended.

For a hemispherical measurement surface in a free field above a reflecting plane, typically the standard deviation is $u_{\text{angle}} = 0{,}25$ dB. For a box-shaped measurement surface, the standard deviation is $u_{\text{angle}} = 1{,}25$ dB.

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

The angle error only affects the direct sound field from the source, thus the sensitivity coefficient $c_{\text{angle}} = 10^{-K_2/10}$. The worst case scenario would occur with a box measurement surface used outdoors, with a corresponding uncertainty contribution of 1,2 dB. Typically with $K_{2\text{A}} = 5$ dB, the sensitivity coefficient, $c_{\text{angle}} = 0{,}3$ dB, and the total contribution to uncertainty $u_{\text{angle}} c_{\text{angle}} = 0{,}4$ dB. For a given measurement surface, the uncertainty contribution, $u_{\text{angle}} c_{\text{angle}}$, is reduced for a larger $K_{2\text{A}}$. 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.

### D.4.2.11 Spectral shape

When the source produces audible tones, the small number of microphone positions can increase uncertainty related to interference effects. In such a case, experience suggests that $u_{\text{tone}} = 3$ dB. Typically, in cases where there are no audible tones, or when measurements are made with enough microphones so that microphones are at three or more unique heights, assume $u_{\text{tone}} = 0$ dB. The sensitivity coefficient $u_{\text{mic}} = 1$. When tones are present, the uncertainty contribution can be reduced by increasing the number of measurement positions.

### D.4.2.12 Typical value for $\sigma_{R0}$

Using the typical values from D.4.2.2 to D.4.2.11, $\sigma_{R0}$ based on Equation (D.2) is

$$\sigma_{R0} = \sqrt{0,6^2 + 1,5^2 + 0,1^2 + 1,5^2 + 1,2^2 + 0,6^2 + 1,0^2 + 1,4^2 + 0,4^2 + 0} \text{ dB}$$
$$= 3,1 \text{ dB}$$

## D.5 Combined standard uncertainty

In the case of negligible correlation between the input quantities, the combined standard uncertainty of the determination of the A-weighted sound power level, $u(L_W)$, in decibels, is given by Equation (D.3):

$$u(L_W) \approx \sigma_{\text{tot}} = \sqrt{\sigma_{R0}^2 + \sigma_{\text{omc}}^2} = \sqrt{\sum_i (c_i u_i)^2 + \sigma_{\text{omc}}^2} \tag{D.3}$$

## D.6 Measurement uncertainty based on reproducibility data

In the absence of data for uncertainty contributions and possible correlations between input quantities, values for the standard deviation of reproducibility as given in Clause 9 may be used as an estimate of the combined standard uncertainty of determinations of sound power levels, $u(L_{WA})$. A value may then be selected for the coverage factor, $k$, and the product, $k \cdot \sigma_{\text{tot}}$, 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 two. To avoid misinterpretation, the coverage probability should be stated in test reports, together with the expanded measurement uncertainty.

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