BRITISH STANDARD

BS EN ISO
9614-3:2009

# Acoustics — Determination of sound power levels of noise sources using sound intensity

## Part 3: Precision method for measurement by scanning (ISO 9614-3:2002)

ICS 17.140.01

British Standards

# National foreword

This British Standard is the UK implementation of EN ISO 9614-3:2009. It is identical to ISO 9614-3:2002. It supersedes BS EN ISO 9614-3:2002 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee EH/1/4, Machinery noise.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

**Compliance with a British Standard cannot confer immunity from legal obligations.**

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EUROPEAN STANDARD
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# EN ISO 9614-3

August 2009

ICS 17.140.01

Supersedes EN ISO 9614-3:2002

English Version

# Acoustics - Determination of sound power levels of noise sources using sound intensity - Part 3: Precision method for measurement by scanning (ISO 9614-3:2002)

Acoustique - Détermination par intensimétrie des niveaux de puissance acoustique émis par les sources de bruit - Partie 3: Méthode de précision pour mesurage par balayage (ISO 9614-3:2002)

Akustik - Bestimmung der Schallleistungspegel von Geräuschquellen aus Schallintensitätsmessungen - Teil 3: Scanning-Verfahren der Genauigkeitsklasse 1 (ISO 9614-3:2002)

This European Standard was approved by CEN on 20 July 2009.

CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the CEN Management Centre or to any CEN member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the CEN Management Centre has the same status as the official versions.

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# Foreword

The text of ISO 9614-3:2002 has been prepared by Technical Committee ISO/TC 43 “Acoustics” of the International Organization for Standardization (ISO) and has been taken over as EN ISO 9614-3:2009 by Technical Committee CEN/TC 211 “Acoustics” the secretariat of which is held by DS.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by February 2010, and conflicting national standards shall be withdrawn at the latest by February 2010.

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

This document supersedes EN ISO 9614-3:2002.

This document has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association, and supports essential requirements of EC Directives.

For relationship with EC Directives, see informative Annexes ZA and ZB, which are integral parts of this document.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and the United Kingdom.

## Endorsement notice

The text of ISO 9614-3:2002 has been approved by CEN as a EN ISO 9614-3:2009 without any modification.

# Annex ZA
(informative)

## Relationship between this European Standard and the Essential Requirements of EU Directive 98/37/EC

This European Standard has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association to provide a means of conforming to Essential Requirements of the New Approach Directive 98/37/EC, amended by 98/79/EC on machinery.

Once this standard is cited in the Official Journal of the European Communities under that Directive and has been implemented as a national standard in at least one Member State, compliance with the normative clauses of this standard confers, within the limits of the scope of this standard, a presumption of conformity with the relevant Essential Requirements of that Directive and associated EFTA regulations.

**WARNING -** Other requirements and other EU Directives may be applicable to the product(s) falling within the scope of this standard.

# Annex ZB
(informative)

## Relationship between this European Standard and the Essential Requirements of EU Directive 2006/42/EC

This European Standard has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association to provide a means of conforming to Essential Requirements of the New Approach Directive 2006/42/EC on machinery.

Once this standard is cited in the Official Journal of the European Communities under that Directive and has been implemented as a national standard in at least one Member State, compliance with the normative clauses of this standard confers, within the limits of the scope of this standard, a presumption of conformity with the relevant Essential Requirements of that Directive and associated EFTA regulations.

**WARNING —** Other requirements and other EU Directives may be applicable to the product(s) falling within the scope of this standard.

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# Foreword

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

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

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 part of ISO 9614 may be the subject of patent rights other than those identified above. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 9614-3 was prepared by Technical Committee ISO/TC 43, *Acoustics*, Subcommittee SC 1, *Noise*.

ISO 9614 consists of the following parts, under the general title *Acoustics — Determination of sound power levels of noise sources using sound intensity*:

— *Part 1: Measurement at discrete points*

— *Part 2: Measurement by scanning*

— *Part 3: Precision method for measurement by scanning*

Annexes B and C form a normative part of this part of ISO 9614. Annexes A, D, E, F, G, H and I are for information only.

# Introduction

**0.1** The sound power radiated by a source is equal in value to the integral of the scalar product of the sound intensity vector and the associated elemental area vector over any surface totally enclosing the source. Other International Standards which describe methods of determination of the sound power levels of noise sources, principally ISO 3740 to ISO 3747, without exception specify sound pressure level as the primary acoustic quantity to be measured. The relationship between sound intensity level and sound pressure level at any point depends on the characteristics of the source, the characteristics of the measurement environment, and the disposition of the measurement positions with respect to the source.

The procedures specified in ISO 3740 to ISO 3747 are not always applicable, for the following reasons.

a) Specific facilities are necessary if high precision is required. It is frequently not possible to install, and operate, large pieces of equipment in such facilities.

b) They cannot be used in the presence of high levels of extraneous noise generated by sources other than that under investigation.

**0.2** This part of ISO 9614 specifies methods of determining the sound power levels of sources, within specific ranges of uncertainty, under test conditions which are less restricted than those required by ISO 3740 to ISO 3747.

It is recommended that personnel performing sound intensity measurements according to this part of ISO 9614 are appropriately trained and experienced.

**0.3** This part of ISO 9614 complements ISO 9614-1, ISO 9614-2 and the ISO 3740 to ISO 3747 series, which specify various methods for the determination of sound power levels of machines and equipment. It differs from the ISO 3740 to ISO 3747 series principally in three aspects.

a) Measurements are made of sound intensity as well as of sound pressure.

b) The uncertainty of the sound power level determined by the method specified in this part of ISO 9614 is classified according to the results of specified ancillary tests and calculations performed in association with the test measurements.

c) Current limitations of intensity measurement equipment which conforms to IEC 61043 restrict measurements to the one-third octave range 50 Hz to 6,3 kHz. Octave band and band-limited A-weighted values are determined from the constituent one-third-octave band values.

**0.4** The integral over any surface totally enclosing the source of the scalar product of the sound intensity vector and the associated elemental area vector provides a measure of the sound power radiated directly into the air by all sources located within the enclosing surface and excludes sound radiated by sources located outside this surface. In practice, this exclusion is effective only if the source under test and other sources of extraneous intensity on the measurement surface are stationary over time. In the presence of sound sources operating outside the measurement surface, any system lying within the surface can absorb a proportion of energy incident upon it. The total sound power absorbed within the measurement surface will appear as a negative contribution to source power, and can produce an error in the sound power determination. In order to minimize the associated error, it is therefore necessary to remove any sound-absorbing material lying within the measurement surface which is not normally present during the operation of the source under test.

This method is based on sampling of the intensity normal to the measurement surface by moving an intensity probe continuously along specified paths. The resulting sampling error is a function of the spatial variation of the normal intensity component over the measurement surface, which depends on the directivity of the source, the chosen measurement surface, the pattern and speed of the probe scanning, and the proximity of extraneous sources outside the measurement surface.

The accuracy of measurement of the normal component of sound intensity at a position is sensitive to the difference between the local sound pressure level and the local normal sound intensity level. A large difference can occur when the intensity vector at a measurement position is directed at a large angle (approaching 90°) to the local normal to the measurement surface. Alternatively, the local sound pressure level can contain strong contributions from sources outside the measurement surface, but can be associated with little net sound energy flow, as in a reverberant field in an enclosure; or the field can be strongly reactive because of the presence of the near field and/or standing waves.

The accuracy of determination of sound power level is adversely affected by a flow of sound energy into the volume enclosed by the measurement surface through a portion of that surface, even though it is, in principle, compensated by increased flow of the volume out through the remaining portion of the surface. This condition is caused by the presence of a strong extraneous source outside the measurement surface. This part of ISO 9614 limits such situations by giving relevant criteria.

# Acoustics — Determination of sound power levels of noise sources using sound intensity —

## Part 3:
## Precision method for measurement by scanning

## 1 Scope

**1.1** This part of ISO 9614 specifies a method for measuring the component of sound intensity normal to a measurement surface which is chosen so as to enclose the sound source(s) of which the sound power level is to be determined.

Surface integration of the intensity component normal to the measurement surface is approximated by subdividing the measurement surface into contiguous partial surfaces, and scanning the intensity probe over each partial surface along a continuous path which covers the extent of the partial surface. The measurement instrument determines the averaged normal intensity component and averaged squared sound pressure over the duration of each scan. The scanning operation can be performed either manually or by means of a mechanical system.

The octave band or band-limited weighted sound power level is calculated from the measured one-third-octave-band values. The method is applicable to any source for which a physically stationary measurement surface can be defined, and on which the sound generated by the source under test and by other significant extraneous sources are stationary in time. The source is defined by the choice of measurement surface. The method is applicable in specific test environments fulfilling all relevant requirements of this part of ISO 9614.

This part of ISO 9614 specifies certain ancillary procedures, described in annex C, to be followed in conjunction with the sound power determination. The results are used to indicate the quality of the determination, and hence the grade of accuracy. If the quality of the determination does not meet the requirements of this part of ISO 9614, the test procedure shall be modified in the manner indicated.

This part of ISO 9614 is not applicable to any frequency band in which the sound power of the source is found to be negative on measurement.

**1.2** This part of ISO 9614 is applicable to sources situated in any environment which is neither so variable over time as to reduce the accuracy of the measurement of sound intensity to an unacceptable degree, nor subjects the intensity measurement probe to gas flows of unacceptable speed or unsteadiness (see 5.2.2, 5.3 and 5.4).

In some cases it will be found that the test conditions are too adverse to allow the requirements of this part of ISO 9614 to be met. For example, extraneous noise levels can exceed the dynamic capability of the measuring instrument or can vary to an excessive degree during the test. In such cases the method given in this part of ISO 9614 is not suitable for the determination of the sound power level of the source.

## 2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of ISO 9614. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this part of ISO 9614 are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

IEC 60651, *Sound level meters*

IEC 60942:1998, *Electroacoustics — Sound calibrators*

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

IEC 61043:1993, *Electroacoustics — Instruments for the measurement of sound intensity — Measurements with pairs of pressure sensing microphones*

GUM:1993, *Guide to the expression of uncertainty in measurement.* BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML.

## 3 Terms and definitions

For the purposes of this part of ISO 9614, the following terms and definitions apply.

NOTE Symbols used in this part of ISO 9614 are listed in annex A. Definitions of field indicators are given in annex B.

### 3.1
### sound pressure level

$L_p$

ten times the logarithm to the base 10 of the ratio of the mean-square sound pressure to the square of the reference sound pressure

NOTE 1 The reference sound pressure is 20 μPa.

NOTE 2 Sound pressure level is expressed in decibels.

### 3.2
### instantaneous sound intensity

$\vec{I}(t)$

instantaneous flow of sound energy per unit of area and per unit time in the direction of the local instantaneous acoustic particle velocity

NOTE This is a vectorial quantity which is equal to the product of the instantaneous sound pressure at a point and the associated particle velocity

$$\vec{I}(t) = p(t) \cdot \vec{u}(t) \tag{1}$$

where

$p(t)$ is the instantaneous sound pressure at a point;

$\vec{u}(t)$ is the associated instantaneous particle velocity at the same point;

$t$ is time.

### 3.3
### sound intensity

$\vec{I}$

time-averaged value of $\vec{I}(t)$ in a temporally stationary sound field

$$\vec{I} = \lim_{T\to\infty} \frac{1}{T}\int_0^T \vec{I}(t)\mathrm{d}t \tag{2}$$

where

$T$ is the integration period

NOTE Also

$I$ is the signed magnitude of $\vec{I}$ ; in this part of ISO 9614, the sign is chosen so that the energy flow going out of the sound source through the measurement surface is measured positive;

$|I|$ is the unsigned magnitude of $\vec{I}$ .

### 3.4
### normal sound intensity

$I_\mathrm{n}$

component of sound intensity in the direction normal to a measurement surface defined by the unit normal vector $\vec{n}$

$$I_\mathrm{n} = \vec{I} \cdot \vec{n} \tag{3}$$

where $\vec{n}$ is the unit normal vector directed out of the volume enclosed by the measurement surface

### 3.5
### normal sound intensity level

$L_{I_\mathrm{n}}$

logarithmic measure of the unsigned value of the normal sound intensity, $|I_\mathrm{n}|$, given by

$$L_{I_\mathrm{n}} = 10\lg\frac{|I_\mathrm{n}|}{I_0}\ \mathrm{dB} \tag{4}$$

where $I_0$ is the reference sound intensity ($=10^{-12}$ W·m$^{-2}$)

NOTE 1 It is expressed in decibels.

NOTE 2 When $I_\mathrm{n}$ is negative, the level is expressed as (–) $XX$ dB, except when used in the evaluation of $\delta_{pI_0}$ (see 3.10).

## 3.6 Sound powers

### 3.6.1
### partial sound power

$P_i$

time-averaged flow of sound energy per unit of time through a partial surface of a measurement surface, given by

$$P_i = \overline{I_{\mathrm{n}i}} \cdot S_i \tag{5}$$

where

$\overline{I_{\mathrm{n}i}}$ is the signed magnitude of the partial surface average normal sound intensity measured on the partial surface $i$ of the measurement surface;

$S_i$ is the area of the partial surface $i$.

NOTE 1 When the averaged normal sound intensity level $\overline{L}_{I_{\text{n}}}$ for a partial surface $i$ is expressed as $XX$ dB, the value of $\overline{I_{\text{n}i}}$ is calculated from the equation.

$$\overline{I_{\text{n}i}} = I_0 10^{XX/10} \tag{6}$$

NOTE 2 When the averaged normal sound intensity level $\overline{L}_{I_{\text{n}}}$ for a partial surface $i$ is expressed as (–) $XX$ dB, the value of $\overline{I_{\text{n}i}}$ is calculated from the equation.

$$\overline{I_{\text{n}i}} = -I_0 10^{XX/10} \tag{7}$$

### 3.6.2
### sound power

$P$

total sound power generated by a source, as determined using the method given in this part of ISO 9614, given by

$$P = \sum_{i=1}^{N} P_i \tag{8}$$

where $N$ is the total number of partial surfaces of the measurement surface

### 3.6.3
### sound power level

$L_W$

logarithmic measure of the sound power generated by a source, as determined using this part of ISO 9614, given by

$$L_W = 10 \lg \frac{|P|}{P_0} \text{ dB} \tag{9}$$

where $P_0$ is the reference sound power (= $10^{-12}$ W)

NOTE 1 It is expressed in decibels.

NOTE 2 When $P$ is negative, the level is expressed as (–) $XX$ dB for record purposes only.

### 3.6.4
### normalized sound power level

$L_{W0}$

sound power level under the reference meteorological condition (temperature $\theta_0 = 23$ °C, barometric pressure $B_0 = 101\,325$ Pa), given by

$$L_{W0} = L_W - 15 \lg \left[ \frac{B}{101\,325} \times \frac{296{,}15}{273{,}15 + \theta} \right] \text{dB} \tag{10}$$

where

$\theta$ is the air temperature, in degrees Celsius, during the actual measurement;

$B$ is the barometric pressure, in pascals, during the actual measurement.

NOTE See annex H.

## 3.7 Surfaces

### 3.7.1
**measurement surface**
hypothetical surface on which intensity measurements are made, and which either completely encloses the sound source under test or, in conjunction with an acoustically rigid continuous surface, encloses the sound source under tests

NOTE In cases where the hypothetical surface is penetrated by bodies possessing solid surfaces, the measurement surface terminates at the lines of intersection between the bodies and the surface.

### 3.7.2
**partial surface**
one of a set of smaller surfaces into which a measurement surface is divided and over which a partial sound power is obtained

See Figure 1.

### 3.7.3
**segment**
one of a set of smaller surfaces into which a partial surface is divided

See Figure 2.

NOTE The idea of “segment” is introduced so that the scanning path and time are determined on a partial surface.

### 3.8
**extraneous intensity**
contribution to the sound intensity which arises from the operation of sources external to the measurement surface (source mechanisms operating outside the volume enclosed by the measurement surface)

### 3.9
**probe**
that part of the intensity measurement system which incorporates the sensors

### 3.10
**pressure-residual intensity index**
$\delta_{pI_0}$
difference between the indicated $L_p$ and indicated $L_{I\delta}$ when the intensity probe is placed and oriented in a sound field such that the sound intensity is zero

$$\delta_{pI_0} = L_p - L_{I\delta} \tag{11}$$

where $L_{I\delta}$ is the level of residual intensity $I_\delta$ given by

$$L_{I\delta} = 10 \lg \frac{|I_\delta|}{I_0} \text{ dB} \tag{12}$$

NOTE 1 It is expressed in decibels.

NOTE 2 Details for determining $\delta_{pI_0}$ are given in IEC 61043.

### 3.11
**dynamic capability index**
$L_{\mathrm{d}}$
index given by

$$L_\mathrm{d} = \delta_{pI_0} - K \qquad (13)$$

NOTE 1 It is expressed in decibels.

NOTE 2 The value of the bias error factor $K$ is 10 dB for the measurement according to this part of ISO 9614. $\delta_{pI_0}$ is the relevant value of the microphone separation used in the actual measurement.

### 3.12
**stationary signal**
signal whose time-averaged properties during a measurement on one partial surface of the measurement surface are equal to those obtained on the same partial surface when the averaging period is extended over the total time taken to measure on all partial surfaces

## 3.13 Scanning

### 3.13.1
**scan**
continuous movement of an intensity probe along a specified path on a partial surface of a measurement surface

### 3.13.2
**scan-line density**
inverse of the average separation of adjacent scanning lines

### 3.13.3
**scanning time**
$T_\mathrm{s}$
time spent for one scan of a path defined on a partial surface

## 3.14 Instrumentation and data acquisition

### 3.14.1
**instantaneous mode**
real-time mode of a measuring instrument that continuously measures time-series of intensity and squared sound pressure and stores one-third-octave band intensity and squared sound pressure components

### 3.14.2
**measurement interval**
$\Delta t$
time interval of a continuous series of short-time averaged intensity and pressure measurements

NOTE The time interval is limited by the speed of the data processing and storage.

### 3.14.3
**time-series of intensity $I_{\mathrm{n}q}$ and squared pressure $p_q^2$**
sequence of short-time averaged intensity and squared pressure values, sampled at discrete times $q\Delta t$, where $q$ = 1, 2, 3,..$Q$

See Figure 3.

### 3.14.4
**time-averaged sound intensity $\overline{I_{\mathrm{n}m}}$ and squared pressure $\overline{p_m^2}$**
averaged sound intensity and squared pressure over the period [$(m - 1)T$, $mT$], $m$ = 1, 2, 3,... $M$, which are given, respectively, by

$$\overline{I_{\mathrm{n}m}} = \frac{1}{Q} \sum_{q=(m-1)Q+1}^{mQ} I_{\mathrm{n}q} \tag{14}$$

and

$$\overline{p_m^2} = \frac{1}{Q} \sum_{q=(m-1)Q+1}^{mQ} p_q^2 \tag{15}$$

where $Q$ is the number of values of $I_{\mathrm{n}q}$ and $p_q^2$ that fall within the period $[(m-1)T, mT]$

See Figure 3.

NOTE When evaluating $F_{\mathrm{T}}$, the averaging intervals with period $T$ may be separated from each other.

## 4 General requirements

### 4.1 Size of sound source under test

The size of the sound source under test is unrestricted provided that all criteria specified in annex C are satisfied. The extent of the source is defined by the choice of the measurement surface.

### 4.2 Character of sound radiated by the source

The signal shall be stationary over time, as defined in 3.12. Actions should be taken to avoid measurement during times of operation of non-stationary extraneous noise sources of which the occurrences are predictable (see Table C.1).

### 4.3 Measurement uncertainty

The value of the sound power level of a sound source determined by a single application of the procedures of this part of ISO 9614 is likely to differ from the true value. The actual difference cannot be evaluated accurately, but the confidence that the value of sound power level determined lies within a certain range around the true value can be stated, on the assumption that the values determined by numerous applications of the procedure are normally distributed about the true value. Where repeated applications are made to a source located at a given test site under nominally identical test conditions, using the same test procedures and instrumentation, the values so determined constitute the data set which statistically describes the repeatability of the determination. Where the values are determined from tests conforming to this part of ISO 9614 made on the given source at different test sites using physically different instruments, the data set so obtained statistically describes the reproducibility of the determination. Reproducibility is affected by variations in experimental technique and in environmental conditions at the test sites. The standard deviations do not account for variations of sound power output caused by changes in operating conditions of a source (e.g. rotational speed, line voltage) or mounting conditions.

Estimated upper values of the standard deviations of reproducibility of sound power levels determined in accordance with this part of ISO 9614 are given in Table 1. The figures take into account random deviations associated with the measurement procedure as well as tolerances in the instrument performance specified in IEC 61043 but exclude the effects of variation in source installation, mounting and operating conditions. Unless more specific knowledge of relevant sources of uncertainty is available, the expanded measurement uncertainty for a coverage probability of 95 % as defined in the GUM shall be stated to be two times the standard deviation of reproducibility given in Table 1.

The uncertainty in determination of the sound power level of a sound source is related to the nature of the sound field of the source, the nature of the extraneous sound field, the absorption of the source under test, and the form of the intensity field sampling and measurement procedure employed. For this reason this part of ISO 9614 specifies initial procedures for the evaluation of indicators of the nature of the sound field which exists in the region of the proposed measurement surface (see annex B). The results of this initial test are used to select an appropriate course of action according to Table C.1.

Below 50 Hz there are insufficient data on which to base uncertainty values. For the purposes of this part of ISO 9614, the normal range for A-weighted data is covered by the one-third-octave bands from 50 Hz to 6,3 kHz. The A-weighted value which is computed from one-third-octave band levels in the range 50 Hz to 6,3 kHz is correct if there are no significantly high levels in the bands 31 Hz to 40 Hz and 8 kHz to 10 kHz. For the purposes of this assessment, significant levels are band levels which after A-weighting are no more than 6 dB below the A-weighted value computed. If A-weighted measurements and associated sound power level determinations are made in a more restricted frequency range, this range shall be stated in accordance with 10 b). If only an A-weighted determination is required, any single A-weighted band level of 10 dB or more below the highest A-weighted band level may be neglected. If two or more band levels appear insignificant, they may be neglected if the level of the sum of the A-weighted sound powers in these bands is 10 dB or more below the highest A-weighted band level. If only an A-weighted overall sound power level is required, the uncertainty of determination of the sound power level in any band in which it is 10 dB or more below the overall weighted level, is irrelevant.

**Table 1 — Estimated upper values of the standard deviations of reproducibility of sound power levels determined in accordance with this part of ISO 9614**

| **One-third-octave band centre frequencies** Hz | **Upper values of standard deviation of reproducibility** dB |
|---|---|
| 50 to 160 | 2,0 |
| 200 to 315 | 1,5 |
| 400 to 5 000 | 1,0 |
| 6 300 | 2,0 |
| A-weighted [a] | 1,0 [b] |

[a] Calculated from one-third-octave bands from 50 Hz to 6,3 kHz.

[b] Applicable to a source which emits sound with a relatively “flat” spectrum in the frequency range 50 Hz to 6,3 kHz in the one-third-octave band.

NOTE 1 If certain operatives use similar facilities and instrumentation, the results of sound power determinations on a given source at a given site are likely to exhibit smaller standard deviations than those indicated in Table 1.

NOTE 2 For a particular family of sound sources of similar size with similar sound power spectra operating in similar environmental conditions, and measured according to a specific test code, the standard deviations of reproducibility are likely to be less than those indicated in Table 1. Statistical methods for the characterization of batches of machines are described in ISO 7574-4.

NOTE 3 The procedures of this part of ISO 9614 and the standard deviations stated in Table 1 are applicable to measurements on a given source. Characterization of the sound power levels of a batch of sources of the same family or type involves the use of random sampling techniques in which confidence intervals are specified, and the results are expressed in terms of statistical upper limits. In applying these techniques, the total standard deviation is either known or estimated, including the standard deviation of production, which is a measure of the variation in sound power output between individual machines within the batch, as defined in ISO 7574-1.

# 5 Acoustic environment

## 5.1 Criteria for adequacy of the test environment

The test environment shall be such that the principle upon which sound intensity measured by the particular instrument employed, as given in IEC 61043, is validated. In addition, it shall satisfy the requirements stated in 5.2 to 5.5.

## 5.2 Extraneous intensity

### 5.2.1 Level of extraneous intensity

The level of extraneous intensity shall be minimized so that it does not unacceptably reduce measurement accuracy (see C.1.4).

NOTE If substantial quantities of absorbing material are part of the source under test, high levels of extraneous intensity can lead to an underestimate of the sound power. Annex E gives indications of how to evaluate the resulting error in the special case where the source under test can be switched off.

### 5.2.2 Variability of extraneous intensity

The variability of the extraneous intensity during the measurement period shall be avoided by appropriate actions prior to the test (e.g. disabling automatically switched sources of extraneous noise which are not essential to source operation; making plant operators aware of the problem) and by the selection of appropriate periods of measurement.

## 5.3 Wind and gas flows

A probe windscreen may be used in cases where fluid flow is present on the measurement surface. Do not make measurements when wind or gas flow conditions in the vicinity of the intensity probe contravene the limits for satisfactory performance of the measurement system, as specified by the manufacturer. If there is a wind flow, the maximum speed relative to the probe shall not exceed 1 m/s.

Annex D describes the adverse effects of flow and turbulence on sound intensity measurement.

## 5.4 Temperature

The probe shall not be placed closer than 20 mm to bodies having a temperature different from that of the ambient air.

NOTE The exposure of the probe to temperature gradients along the probe axis can produce time-dependent, differential modifications to the responses of the two microphones which introduce bias errors into the intensity estimates.

## 5.5 Configuration of the surroundings

The configuration of the test surroundings shall remain unchanged during the performance of a test with the exception of the location of the person holding the probe; this is particularly important if the source emits sound of a tonal nature. Cases where variation in the test surroundings during a test is unavoidable shall be reported. Ensure, as far as possible, that the operator does not stand in a position on, or close to, the axis of the probe during the period of measurement on any surface. If practicable, any extraneous objects shall be removed from the vicinity of the source.

## 5.6 Atmospheric conditions

Air pressure and temperature affect air density and speed of sound. Effects of these quantities on instrument calibration shall be ascertained and appropriate corrections shall be made to indicated intensities (see IEC 61043).

## 6 Instrumentation

### 6.1 General

A class 1 sound intensity measurement instrument and probe that meet the requirements of the IEC 61043:1993 shall be used. Adjust the intensity measurement instrument to allow for ambient air pressure and temperature in accordance with IEC 61043. Record the pressure-residual intensity index of the instrument used for measurements, as defined by IEC 61043, for each frequency band of measurement.

The instrument shall have the capability of capturing time-series of intensity and squared pressure and time-averaged intensity and squared pressure (see 3.14, 6.3 and Figure 3).

### 6.2 Calibration and field check

#### 6.2.1 Complete instrumentation

Verify the compliance of the instrument including the probe with IEC 61043 either at least once a year in a laboratory making calibrations in accordance with appropriate standards, or at least every 2 years if an intensity calibrator is used before each sound power determination. Report the results in accordance with 10 d).

To check the instrumentation for proper operation prior to each series of measurements, either apply the field-check procedure specified by the manufacturer, or, if no field check is specified, apply the procedure in 6.2.2 and 6.2.3 to indicate anomalies within the measuring system that may have occurred during transportation, etc.

#### 6.2.2 Sound pressure level

Determine the pressure sensitivity of each microphone of the intensity probe using a class 0 or 1 or 0L or 1L calibrator in accordance with IEC 60942:1998.

#### 6.2.3 Intensity

Place the intensity probe on the measurement surface, with the axis oriented normal to the surface, at a position where the overall linear intensity is higher than the surface average. Measure the normal sound intensity level in all frequency bands in which the determination is to be made. Rotate the intensity probe through 180° about an axis normal to the measurement axis and place it with its acoustic centre in the same position as the first measurement. Measure the intensity again. Mount the intensity probe on a stand to retain the same position upon rotation of the probe. For the maximum band level measured in one-third-octave bands, the two values of $I_\mathrm{n}$ shall have opposite signs and the difference between the two sound intensity levels shall be less than 1,0 dB in all bands for the measuring equipment to be acceptable.

### 6.3 Time-series of sound intensity and sound pressure

The instrument shall be able to capture time-series of sound intensity and squared sound pressure data continuously at least for more than the required scanning time $T_\mathrm{s}$ and the required time period in order to determine the temporal variability indicator $F_\mathrm{T}$ according to 8.3.2. The measurement interval $\Delta t$ shall be equal to or less than 0,5 s. If an FFT type analyser is used as an instrument, it shall be able to capture the data with the Hanning window and with at least 30 % overlap (see Figure 3 and annex G).

## 7 Installation and operation of the source

### 7.1 General

Mount the source, or place it as stated in a noise test code for the particular type of machinery or equipment or, if no such noise test code exists, in a proper way representative of normal use. Ensure that possible sources of variability in the source/extraneous source/test environment are identified.

### 7.2 Operating conditions of the source under test

Use the operating conditions specified in the appropriate noise test code. If there is no such code, select the appropriate conditions from the following:

a) device under specified load and operating conditions;

b) device under full load (if different from above);

c) device under no load (idling);

d) device under operating conditions corresponding to maximum sound representative of normal use;

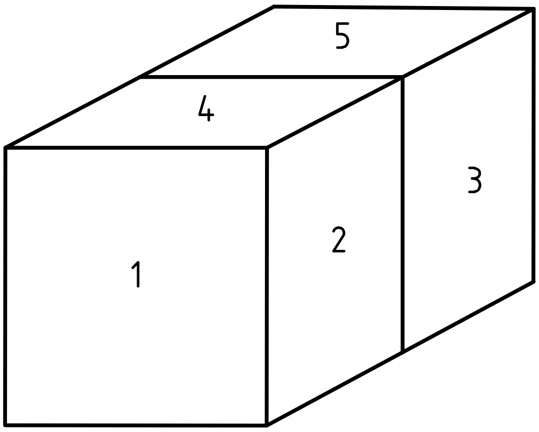
e) device with simulated load operating under carefully defined conditions;

f) device operating condition with characteristic work cycle.

## 8 Measurement of normal sound intensity component levels

### 8.1 Determination of measurement surface

The measurement surface shall be defined around the source under test. When the scanning is performed manually, the measurement surface should preferably be a parallelepiped and each partial surface shall be rectangular (see Figure 1). The minimum distance between the partial surface and the surface of the source under test shall be greater than or equal to 0,25 m unless that surface is on a component which can be shown, by test, to radiate an insignificant proportion of the sound power of the source under test. The chosen surface may incorporate areas which are non-absorbent (diffuse-field sound absorption coefficient less than 0,06), such as a concrete floor or masonry wall, where convenient. Intensity measurements shall not be made on such surfaces and the areas of such non-absorbent surfaces shall not be included in the evaluation of source sound power according to equation (5) (see 3.6.1).



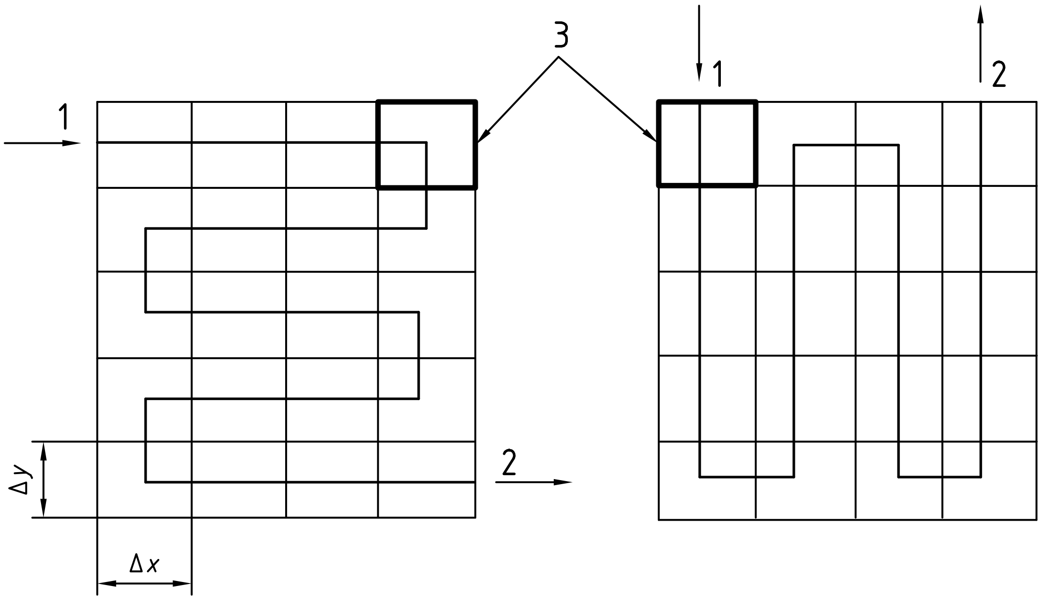
**Key**

1 - 5 Partial surface number

**Figure 1 — Example of measurement surface (parallelepiped) and partial surfaces (rectangular)**

### 8.2 Determination of scanning paths and segments

The basic element of a scanning path is a single straight line. The scanning path shall be such that it provides uniform coverage of each partial surface at a uniform speed. Carry out the scan either manually or by means of a mechanized traversing system. The extraneous intensity generated by this mechanism as measured by the probe shall be demonstrably at least 20 dB lower than that emitted by the source under test on the measurement surface. Move the intensity probe continuously along specified paths on each partial surface. Perform the scanning operation in such a manner that the axis of the probe is maintained perpendicular to the measurement surface at all times, and that the speed of movement of the probe is uniform. Certain areas such as cracks or openings can be highly significant in terms of the sound radiated, and shall be treated with special care in selecting the partial measurement surfaces to be used.



**Key**

1, 2 Scanning paths

3 Segments

NOTE In this case, the number of segments $N_s$ is 20.

**Figure 2 — Examples of two orthogonal scanning paths on a rectangular partial surface**

This part of ISO 9614 employs a method that uses one of two orthogonal scanning paths on each partial surface. Before determining a scanning path, divide the partial surface into segments such as shown in Figure 2. The ratio of $\Delta x$ and $\Delta y$ shall satisfy $0{,}83 \leq \Delta x/\Delta y \leq 1{,}2$. The larger one of the two sides of the segment shall be less than half of the minimum distance between the partial surface and the surface of the source under test. For the entire measurement surface, the area ratio of the largest segment to the smallest one shall be smaller than or equal to 1,5. The starting and finishing points of the scanning path are shown by numbers 1 and 2, respectively (1 and 2 may be reversed). At the corners of the scanning pattern, the lines may be curved slightly in order to make it easy to keep the scanning speed as constant as possible.

## 8.3 Measurements

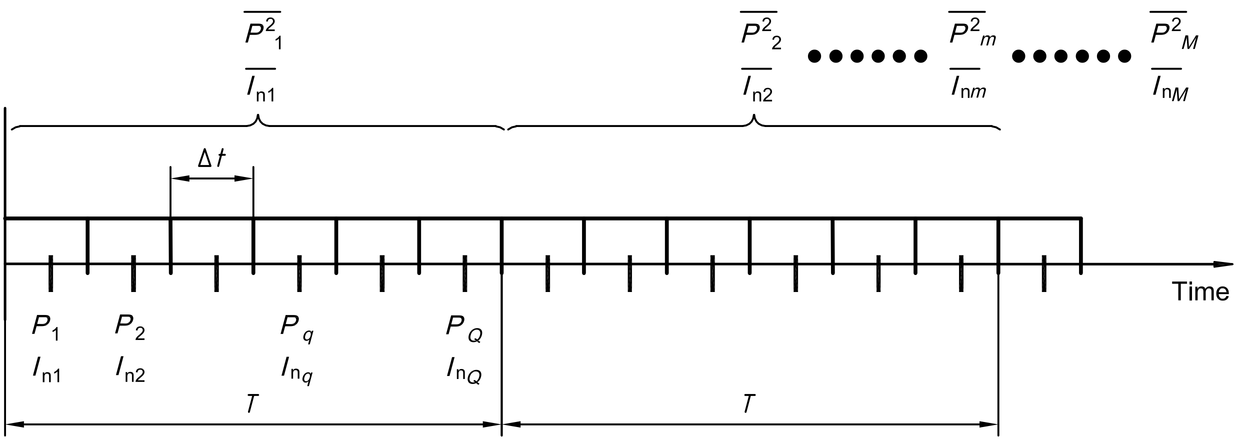
### 8.3.1 General procedure

The procedure for achieving the desired grade of accuracy is presented in annex C and the summary of this procedure is shown in Figure C.1. One of the two orthogonal paths shown in Figure 2 for each partial surface is used in this part of ISO 9614. For a chosen scanning path on a partial surface, the scan is performed twice. Two normal intensity levels averaged over the scanning time $T_s$ for each partial surface are compared and if the difference is within a tolerance (criterion 1), those two intensity levels are temporarily adopted as the average normal intensity level for that partial surface. After finishing measurements for all partial surfaces, criteria 2 to 5 are checked for the measurement surface and, if they are satisfied, intensity levels obtained for each partial surface are used to determine the sound power of the source.

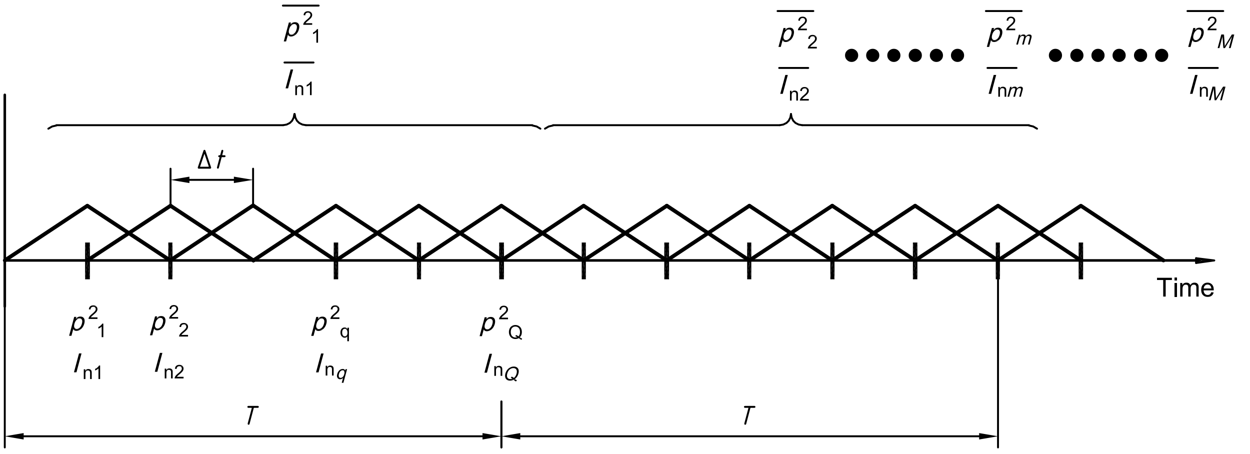
In the case of the determination of A-weighted sound power level, it is not necessary for criteria 1 to 5 to be satisfied if the level of the sum of the A-weighted sound powers in those bands is 10 dB or more below the highest A-weighted band level [see 4.3 and 10f) 2)].

### 8.3.2 Test of the temporal variability of the sound field and the determination of the scanning time

Choose an appropriate measurement position with a high intensity level on the measurement surface for assessment of whether the sound field is stationary or not. Set the measuring instrumentation to "instantaneous mode" and record the time-series of sound intensity $I_{\mathrm{n}q}$ for more than 100 s. Calculate time-averaged sound intensities $\overline{I_{\mathrm{n}m}}$, $m = 1, 2, 3, .... M$ over the period $T$ (see Figure 3). The value of $T$ shall be equal to or greater than 1,0 s and $M$ will normally take a value of 10. The averaging periods may be separated from each other. Then, calculate the temporal variability indicator for various values of $T$ with an increment of 0,5 s or smaller using equation (B.1), and find the averaging time $T_{F_{\mathrm{T}} < 0{,}6}$ that satisfies $F_{\mathrm{T}} < 0{,}6$ for each one-third-octave band.



**a) Direct method**



**b) FFT method**

**Figure 3 — Calculation of time-averaged sound intensity $\overline{I_{\mathrm{n}m}}$ and squared sound pressure $\overline{p_m^2}$, $m = 1, 2, 3,$ ... $M$ with the averaging period $T$ from the measurement of time-series of sound intensity $I_{\mathrm{n}Q}$ and squared sound pressure $p_Q^2$**

The scanning time $T_\mathrm{S}$ for each scan shall be equal to or greater than the maximum value among those of $N_\mathrm{S} \cdot T_{F_\mathrm{T}<0,6}$ for individual one-third-octave bands, where $N_\mathrm{S}$ is the number of segments on a partial surface. If $T_\mathrm{S}$ determined as above is not practicable as the minimum value for the scanning time, then take action as given in Table C.1.

The scanning speed shall not exceed 0,5 m/s for a manual scanning (see 5.3). For an automated scanning by a traversing system, the scanning speed may be arbitrary provided that the requirements for the scanning time and the noise level generated by the traversing system are satisfied.

### 8.3.3 Measurement of intensities and pressures on a partial surface and check of repeatability of the scan

Make two separate scans on the same scanning path with scanning time $T_\mathrm{S}$ and record time-series of intensities and squared sound pressures twice. The actual scanning time $T_\mathrm{S}'$ shall be within ± 20 % of the desired scanning time $T_\mathrm{S}$. If not, discard the data and make another measurement. For each scan, obtain intensity levels $\overline{L}_{I_\mathrm{n}(1)}$ and $\overline{L}_{I_\mathrm{n}(2)}$ averaged over the scanning time $T_\mathrm{S}'$. Evaluate $\left|\overline{L}_{I_\mathrm{n}(1)} - \overline{L}_{I_\mathrm{n}(2)}\right|$ for all frequency bands of measurement and introduce values into criterion 1 given in C.1.2.

If this criterion is satisfied for the two scans, record the averaged normal intensity levels for all frequency bands of measurement:

$$\overline{L}_{I_\mathrm{n}} = 10\,\mathrm{lg}\left[\frac{1}{2}\left(10^{\overline{L}_{I_\mathrm{n}(1)}/10} + 10^{\overline{L}_{I_\mathrm{n}(2)}/10}\right)\right]\ \mathrm{dB} \qquad (16)$$

Also, if criterion 1 is satisfied, obtain time-averaged intensities and squared sound pressures that correspond to each segment on the partial surface. At first, obtain time-averaged intensities and squared sound pressures for each segment and for each scan following the procedure described in annex G. Then take averages for each segment for the two scans. These data will be used for the calculation of the field non-uniformity indicator $F_\mathrm{S}$.

In cases where criterion 1 is not satisfied, attempt to identify the causes of the difference and suppress them by taking action as given in Table C.1.

### 8.3.4 Evaluation of the instrument capability

Evaluate the signed pressure-intensity indicator $F_{pI_\mathrm{n}}$ for the whole measurement surface for all frequency bands of measurement according to equation (B.6) and introduce the value into criterion 2 given in C.1.4. If this criterion is not satisfied, take action as given in Table C.1.

### 8.3.5 Evaluation of the presence of strong extraneous noise

Evaluate the unsigned pressure-intensity indicator $F_{p|I_\mathrm{n}|}$ for the whole measurement surface for all frequency bands of measurement according to equation (B.3) and introduce the value together with $F_{pI_\mathrm{n}}$ into criterion 3 as given in C.1.5. If this criterion is not satisfied, take action as given in Table C.1.

### 8.3.6 Evaluation of the effect of field non-uniformity

Evaluate field non-uniformity indicator $F_\mathrm{S}$ over the whole measurement surface for all frequency bands of measurement according to equation (B.8) and introduce into criterion 4 as given in C.1.6.1. If this criterion is not satisfied, take action as given in Table C.1.

## 8.4 Further actions

If criteria 1 to 4 are satisfied in each frequency band for the measurement surface, the initial sound power determination is qualified as a final result according to the following section. Otherwise, take appropriate actions according to C.2 and measure the normal sound intensity component levels and associated sound pressure levels using the modified measurement configuration. Recalculate indicators $F_\mathrm{T}$, $F_{p|I_\mathrm{n}|}$, $F_{pI_\mathrm{n}}$, and $F_\mathrm{S}$ and assess according to C.1. Take actions according to C.2. Repeat this procedure until the criteria according to C.1 are fulfilled.

There are cases where criteria 1 to 3 are satisfied but criterion 4 is not. In these cases, the scanning density should be increased by a factor of 2 or more. If the ratio of the field non-uniformity indicators of the previous measurement to the present measurement satisfies criterion 5 (see C.1.6.2), it is considered that the present scanning density is adequate and the measured average intensity levels for each partial surface may be used to calculate the radiated power.

If the ratio of the field non-uniformity indicators of the previous measurement $F_{\mathrm{S}(1)}$ to the present measurement $F_{\mathrm{S}(2)}$ does not satisfy criterion 5, the scanning density should be increased more.

In cases where repeated actions including the increase of scanning density fail to satisfy the specified criteria, record a null test result and state the associated reasons, or use ISO 9614-2 and obtain radiated power with the grade of engineering or survey.

## 9 Determination of sound power level

### 9.1 Calculation of partial sound powers for each partial surface of the measurement surface

Calculate a partial sound power in each frequency band for each partial surface of the measurement surface by equation (5).

### 9.2 Calculation of normalized sound power level

Calculate the sound power level of the sound source under test, $L_W$, in each frequency band according to equations (8) and (9). Then calculate the normalized sound power level according to equation (10).

If the sound power $P$ is negative in any frequency band, the method given in this part of ISO 9614 is not applicable to that band.

Where the A-weighted sound power level is to be determined, the averaged normal sound intensity levels $\overline{L}_{I_\mathrm{n}}$ are the values of the measured one-third-octave band levels with applied frequency weighting according to IEC 60651. The weighting factors of IEC 60651 shall be applied at normal centre frequencies according to IEC 61260.

## 10 Information to be recorded

The following information, if applicable, shall be compiled and reported for all measurements that are made according to this part of ISO 9614.

**a) Test**

1) date and location of test.

**b) Sound source under test**

1) type;
2) technical data;
3) dimensions;
4) manufacturer;
5) machine serial number;
6) year of manufacture;
7) description of the source under test (including its major dimensions and surface texture);
8) qualitative description of the character of the source under test, including tonal or cyclic character and variability;
9) mounting conditions;
10) operating conditions.

**c) Acoustic environment**

1) description of the test environment:
   - if indoors, a description of the geometry and nature of the enclosure surfaces,
   - if outdoors, a sketch showing the surrounding terrain, including physical description of the test environment;
2) air temperature in degrees Celsius, barometric pressure in pascals, and relative humidity;
3) mean wind speed and direction, where relevant;
4) any source of variability in the test environment; description of any devices/procedures taken to minimize the effect of extraneous intensity and/or excessive reverberation;
5) qualitative description of any gas/air flows and unsteadiness.

**d) Instrumentation**

1) equipment used for measurements, including names, types, serial numbers and manufacturers and probe configuration;
2) method(s) used for checking calibration and field performance;
3) places and dates of calibration and verification of test equipment;
4) form of windscreen used;
5) the pressure-residual intensity index in accordance with IEC 61043.

**e) Measurement procedure**

1) description of the mounting, or support system, of the scanning mechanism, and of the intensity probe;
2) description of the scan including geometry and speed;
3) quantitative description of the measurement surface, partial surfaces and their segment numbers; a drawing of the scanning paths shall be presented;
4) scanning time on each partial surface;
5) description of any steps found necessary to improve measurement accuracy.

**f) Acoustical data**

1) tabulation of the field indicators $F_\mathrm{T}$, $F_{p|I_\mathrm{n}|}$, $F_{pI_\mathrm{n}}$, and $F_\mathrm{S}$ in each frequency band of sound power determination, calculated from each set of measurements on each partial surface used;
2) tabular presentation of the calculated value of normalized sound power level of the sound source under test in all frequency bands used; where an A-weighted sound power level determination is to be made, the contribution of frequency bands in which criteria 1 to 4 or criteria 1 to 3 and 5 are not satisfied shall be omitted from the determination and a statement to this effect shall be made, unless their contributions may be neglected according to 4.3;
3) presentation of the results of the probe-reversal field checks specified in 6.2.3, if appropriate;
4) measurement uncertainty.

# Annex A
(informative)

# List of symbols used in this part of ISO 9614

| Symbol | Term | Unit | Cited in |
|---|---|---|---|
| $p(t)$ | instantaneous sound pressure | Pa | 3.2 |
| $\vec{u}(t)$ | instantaneous particle velocity | m/s | 3.2 |
| $\rho$ | density of the air | kg/m$^3$ | Annex H |
| $c$ | speed of sound | m/s | Annex H |
| $\rho c$ | characteristic impedance of air | Pa·s/m | Annex H |
| $\theta$ | air temperature | °C | 3.6.4, annex H |
| $B$ | barometric pressure | Pa | 3.6.4, annex H |
| $t$ | time | s | 3.2 |
| $\Delta t$ | measurement interval | s | 3.14.2 |
| $T_\mathrm{s}$ | scanning time | s | 3.13.3, 6.3 |
| $\vec{n}$ | unit normal vector directed out of the volume enclosed by the measurement surface | — | 3.4 |
| $S_i$ | area of the partial surface $i$ | m$^2$ | 3.6.1 |
| $N_\mathrm{s}$ | number of segments on a partial surface | — | 8.3.2 |
| $N$ | total number of segments on the measurement surface | — | B.2.2 |
| $p_q^2$ | time-series of squared pressure, where $q = 1, 2, 3, ...Q$ | Pa$^2$ | 3.14.3 |
| $\overline{p_m^2}$ | time-averaged squared pressure, where $m = 1, 2, 3, ...M$ | Pa$^2$ | 3.14.4 |
| $\overline{p_j^2}$ | time-averaged squared pressure measured on each segment | Pa$^2$ | B.2.2 |
| $p_0$ | reference sound pressure (= 20 μPa) | Pa | B.2.2 |
| $\vec{I}(t)$ | instantaneous sound intensity | W/m$^2$ | 3.2 |
| $\vec{I}$ | sound intensity | W/m$^2$ | 3.3 |
| $I$ | signed magnitude of $\vec{I}$ | W/m$^2$ | 3.3 |
| $\lvert I \rvert$ | unsigned magnitude of $\vec{I}$ | W/m$^2$ | 3.3 |
| $I_\mathrm{n}$ | normal sound intensity | W/m$^2$ | 3.4 |
| $I_0$ | reference sound intensity (=$10^{-12}$ W·m$^{-2}$) | W/m$^2$ | 3.5 |
| $\overline{I}_{\mathrm{n}i}$ | signed magnitude of the partial surface average normal sound intensity measured on the partial surface $i$ of the measurement surface | W/m$^2$ | 3.6.1 |
| $I_{\mathrm{n}q}$ | time-series of intensity, where $q = 1, 2, 3, ...Q$ | W/m$^2$ | 3.14.3 |

| Symbol | Term | Unit | Cited in |
|---|---|---|---|
| $\overline{I}_{\mathrm{n}m}$ | time-averaged sound intensity, where $m = 1, 2, 3, \ldots M$ | W/m$^2$ | 3.14.4 |
| $\left\lvert\overline{I}_{\mathrm{n}}\right\rvert_j$ | time-averaged unsigned normal sound intensity measured on each segment | W/m$^2$ | B.2.2 |
| $\overline{I}_{\mathrm{n}j}$ | time-averaged signed normal sound intensity measured on each segment | W/m$^2$ | B.2.3 |
| $L_p$ | sound pressure level | dB | 3.1 |
| $\overline{L}_p$ | averaged sound pressure level | dB | B.2.2 |
| $L_{I_\mathrm{n}}$ | normal sound intensity level | dB | 3.5 |
| $\overline{L}_{I_\mathrm{n}}$ | averaged signed normal sound intensity level | dB | 3.6.1, B.2.3 |
| $L_{I\delta}$ | level of residual intensity $I_\delta$ | dB | 3.10 |
| $P_i$ | partial sound power | W | 3.6.1 |
| $P$ | sound power | W | 3.6.2 |
| $P_0$ | reference sound power ($=10^{-12}$ W) | W | 3.6.3 |
| $L_W$ | sound power level | dB | 3.6.3 |
| $L_{W0}$ | normalized sound power level | dB | 3.6.4 |
| $\delta_{pI_0}$ | pressure-residual intensity index | dB | 3.10 |
| $L_\mathrm{d}$ | dynamic capability index | dB | 3.11 |
| $K$ | bias error factor | dB | 3.11 |
| $F_\mathrm{T}$ | temporal variability indicator | - | B.2.1 |
| $F_{p\lvert I_\mathrm{n}\rvert}$ | unsigned pressure-intensity indicator | dB | B.2.2 |
| $F_{pI_\mathrm{n}}$ | signed pressure-intensity indicator | dB | B.2.3 |
| $F_\mathrm{S}$ | field non-uniformity indicator | - | B.2.4 |

# Annex B
(normative)

# Calculation of field indicators

## B.1 General

Evaluate the field indicator $F_{\mathrm{T}}$ at a point on the measurement surface and the indicators $F_{p|I_{\mathrm{n}}|}$, $F_{pI_{\mathrm{n}}}$ and $F_{\mathrm{S}}$ over the measurement surface according to equations (B.1) to (B.9) in each frequency band used for the determination of sound power level. These indicators are obtained from time-series of data by setting the measurement instrument in the instantaneous mode (see 3.14.1).

## B.2 Definition of field indicators

### B.2.1 Temporal variability indicator, $F_{\mathrm{T}}$

Evaluate a value of the temporal variability indicator, $F_{\mathrm{T}}$, of the sound field at an appropriate position selected on the measurement surface. Record the time-series of intensity data $I_{\mathrm{n}q}$ and obtain time-averaged intensities $\overline{I_{\mathrm{n}m}}$ over the period $T$ (see 8.3). Then, calculate $F_{\mathrm{T}}$ from equation (B.1):

$$F_{\mathrm{T}} = \frac{1}{\overline{I_{\mathrm{n}}}} \sqrt{\frac{1}{M-1} \sum_{m=1}^{M} \left(\overline{I_{\mathrm{n}m}} - \overline{I_{\mathrm{n}}}\right)^2} \tag{B.1}$$

where $\overline{I_{\mathrm{n}}}$ is the average value of $\overline{I_{\mathrm{n}m}}$, $m = 1, 2, 3, \ldots M$ calculated from equation (B.2):

$$\overline{I_{\mathrm{n}}} = \frac{1}{M} \sum_{m=1}^{M} \overline{I_{\mathrm{n}m}} \tag{B.2}$$

By varying the averaging period $T$, a time that satisfies $F_{\mathrm{T}} < 0{,}6$ is obtained. This value, $T_{F_{\mathrm{T}} < 0{,}6}$, will be used to determine the minimum value of the scanning time $T_{\mathrm{S}}$ ($T_{\mathrm{S}} \geq N_{\mathrm{S}} \cdot T_{F_{\mathrm{T}} < 0{,}6}$) for a partial surface, where $N_{\mathrm{S}}$ is the number of segments of the partial surface. $M$ will normally take a value of 10. For the evaluation of $F_{\mathrm{T}}$, two consecutive intervals with period $T$ for $\overline{I_{\mathrm{n}m}}$ and $\overline{I_{\mathrm{n}(m+1)}}$ shall have no overlap and may be separated.

NOTE The symbol $F_1$ is used for $F_{\mathrm{T}}$ in ISO 9614-1 (see annex I).

### B.2.2 Unsigned pressure-intensity indicator, $F_{p|I_{\mathrm{n}}|}$

Calculate the unsigned pressure-intensity indicator, $F_{p|I_{\mathrm{n}}|}$, for the measurement surface from equation (B.3):

$$F_{p|I_{\mathrm{n}}|} = \overline{L}_p - \overline{L}_{|I_{\mathrm{n}}|} \tag{B.3}$$

where $\overline{L}_p$ is the averaged sound pressure level, in decibels, calculated from equation (B.4):

$$\overline{L}_p = 10\lg\left(\frac{1}{N}\sum_{j=1}^{N}\overline{p_j^2}/p_0^2\right)\ \text{dB} \tag{B.4}$$

where

$\overline{p_j^2}$ is the time-averaged squared pressure measured on each segment;

$p_0$ is the reference sound pressure (= 20 μPa);

$N$ is the total number of segments on the measurement surface.

$\overline{L}_{|I_\text{n}|}$ is the average unsigned normal sound intensity level, in decibels, calculated from equation (B.5):

$$\overline{L}_{|I_\text{n}|} = 10\lg\left(\frac{1}{N}\sum_{j=1}^{N}\left|\overline{I_\text{n}}\right|_j / I_0\right)\ \text{dB} \tag{B.5}$$

where $\left|\overline{I_\text{n}}\right|_j$ is the time-averaged unsigned normal sound intensity measured on each segment.

NOTE 1 The unsigned pressure-intensity indicator, $F_{p|I_\text{n}|}$, is called the surface pressure-intensity indicator, $F_2$, in ISO 9614-1 (see annex I).

NOTE 2 Although areas of segments for each partial surface can differ by at most 50 % (see 8.2), the effect of this difference is neglected in applying equations (B.3), (B.4) and (B.5). The same idea is also applied in B.2.3 and B.2.4.

NOTE 3 In applying equations (B.3), (B.4) and (B.5), the total number of segments is considered to be $2N$ because of the repetition of scan on each partial surface.

### B.2.3 Signed pressure-intensity indicator, $F_{pI_\text{n}}$

Calculate the signed pressure-intensity indicator, $F_{pI_\text{n}}$, for the measurement surface from equation (B.6):

$$F_{pI_\text{n}} = \overline{L}_p - \overline{L}_{I_\text{n}} \tag{B.6}$$

where

$\overline{L}_p$ is the averaged sound pressure level, in decibels, calculated from equation (B.4);

$\overline{L}_{I_\text{n}}$ is the averaged signed normal sound intensity level, in decibels, calculated from equation (B.7):

$$\overline{L}_{I_\text{n}} = 10\lg\left|\frac{1}{N}\sum_{j=1}^{N}\overline{I_{\text{n}j}} / I_0\right|\ \text{dB} \tag{B.7}$$

where $\overline{I_{\text{n}j}}$ is the time-averaged signed normal sound intensity measured on each segment.

NOTE 1 The signed pressure-intensity indicator $F_{pI_\text{n}}$ is called the negative partial power indicator $F_3$ in ISO 9614-1. This indicator is equivalent to the sound field pressure-intensity indicator $F_{pI}$ specified in ISO 9614-2 in the special case of uniform segment area.

NOTE 2 $F_{pI_\mathrm{n}} - F_{p|I_\mathrm{n}|}$ is equivalent to the negative partial power indicator $F_{+/-}$ specified in ISO 9614-2 in the special case of uniform segment area.

### B.2.4 Field non-uniformity indicator, $F_\mathrm{S}$

Calculate the field non-uniformity indicator, $F_\mathrm{S}$, for the measurement surface from equation (B.8):

$$F_\mathrm{S} = \frac{1}{\overline{I_\mathrm{n}}} \sqrt{\frac{1}{N-1} \sum_{j=1}^{N} (\overline{I_{\mathrm{n}j}} - \overline{I_\mathrm{n}})^2} \qquad \text{(B.8)}$$

where

$$\overline{I_\mathrm{n}} = \frac{1}{N} \sum_{j=1}^{N} \overline{I_{\mathrm{n}j}} \qquad \text{(B.9)}$$

NOTE The symbol $F_4$ is used for $F_\mathrm{S}$ in ISO 9614-1.

# Annex C
(normative)

# Procedure for achieving the desired accuracy

## C.1 Qualification requirements

### C.1.1 General

In the application of this part of ISO 9614, the sound field conditions at measurement positions on the initial measurement surface can vary widely. In order to guarantee upper limits for uncertainties of the sound power levels determined, it is necessary to check the adequacy of the instrumentation and of the chosen measurement parameters (e.g. measurement surface, distance, path) in relation to the sound field/environmental conditions particular to the specific measurement.

The general procedure is summarized in Figure C.1.

### C.1.2 Check for the adequacy of the averaging time

An averaging time $T$ that satisfies $F_\mathrm{T} < 0{,}6$ (expressed as $T_{F_\mathrm{T} < 0{,}6}$) is used to determine the scanning time $T_\mathrm{s}$. The value of $T_\mathrm{s}$ shall be equal to or greater than $N_\mathrm{s} \cdot T_{F_\mathrm{T} < 0{,}6}$. If this condition is not practicable, take action as given in Table C.1.

### C.1.3 Check for the repeatability of the scan on a partial surface

The scan is repeated on each partial surface using the same scanning path and the averaged intensity levels in each frequency band of measurement shall be within the allowed tolerance:

**Criterion 1**

$$\left| \overline{L}_{I_\mathrm{n}(1)} - \overline{L}_{I_\mathrm{n}(2)} \right| \le \frac{s}{2} \tag{C.1}$$

where $\overline{L}_{I_\mathrm{n}(1)}$ and $\overline{L}_{I_\mathrm{n}(2)}$ are the normal intensity levels obtained by two scans, and $s$ is the uncertainty given in Table 1. If this criterion is not satisfied, take action as given in Table C.1 (see Figure C.1).

### C.1.4 Check for the adequacy of the measurement equipment

The dynamic capability index $L_\mathrm{d}$ of the measurement instrumentation shall be greater than the indicator, $F_{pI_\mathrm{n}}$, determined in accordance with annex B in each frequency band of measurement:

**Criterion 2**

$$L_\mathrm{d} \ge F_{pI_\mathrm{n}} \tag{C.2}$$

If a chosen measurement surface does not satisfy criterion 2, take action as given in Table C.1 (see Figure C.1).

### C.1.5 Check for the presence of strong extraneous noise

Compare $F_{p|I_\mathrm{n}|}$ and $F_{pI_\mathrm{n}}$, and check if the following condition is satisfied for each frequency band of measurement:

**Criterion 3**

$$F_{pI_\mathrm{n}} - F_{p|I_\mathrm{n}|} \text{ u } 3 \tag{C.3}$$

If this criterion is not satisfied, take action as given in Table C.1 to reduce the effect of the extraneous noise (see Figure C.1).

### C.1.6 Check for the field non-uniformity

#### C.1.6.1 Initial check for the field non-uniformity

Calculate the field non-uniformity indicator $F_\mathrm{S}$ for the measurement surface, and check if the following condition is satisfied in each frequency band of measurement:

**Criterion 4**

$$F_\mathrm{S} \text{ u } 2 \tag{C.4}$$

If all previous criteria are satisfied and if this criterion is not satisfied, take action as given in Table C.1 to reduce the effect of the field non-uniformity (see Figure C.1).

#### C.1.6.2 Check for the adequacy of the scan-line density

If the scan density is increased by a factor of 2 or more on the same partial surface, compare the present and previous field indicators and check if the following condition is satisfied in each frequency band of measurement:

**Criterion 5**

$$0{,}83 \text{ u } F_{\mathrm{S}(1)} / F_{\mathrm{S}(2)} \text{ u } 1{,}2 \tag{C.5}$$

If criterion 5 is satisfied, the result is qualified as the final result even if $F_{\mathrm{S}(2)}$ W 2.

## C.2 Action to be taken to increase the grade of accuracy of determination

In case where criteria 1 to 5 are not satisfied, take actions as given in Table C.1 for each condition to increase the accuracy of determination of sound power level under test (see Figure C.1).

**Table C.1 — Actions to be taken to increase accuracy of determination of sound power level**

| Condition | Action code | Action |
|---|---|---|
| If $T_s$ is not practicable | **A** | Increase the scanning time, and/or reduce the temporal variability of extraneous intensity, or measure during periods of less variability. |
| **Criterion 1**<br>If $\left\lvert \overline{L}_{I_n(1)} - \overline{L}_{I_n(2)} \right\rvert > s/2$ | **B**<br>and/or<br>**C** | Modify the scanning speed, time, and/or path.<br>Modify partial surfaces and/or measurement surface. |
| **Criterion 2**<br>If $L_d < F_{pI_n}$ | **D**<br>or<br>**E** | In the presence of significant extraneous noise and/or strong reverberation, reduce the average distance of the measurement surface from the source to a minimum average value of 0,25 m. In the absence of significant extraneous noise and/or strong reverberation, increase the average distance to a maximum of 1 m.<br>Shield the measurement surface from extraneous noise source or take action to reduce sound reflections to the source. |
| **Criterion 3**<br>If $F_{pI_n} - F_{p\lvert I_n \rvert} > 3$ | **D**<br>or<br>**E** | Same actions as for criterion 2). |
| **Criterion 4**<br>If $F_S > 2$ | **F**<br>or<br>**G** | Increase the average distance of the partial surface from the source.<br>Increase the scanning density. |
| **Criterion 5**<br>If $F_{S(1)} / F_{S(2)} < 0,83$<br>or $F_{S(1)} / F_{S(2)} > 1,2$ | **G** | Increase the scanning density. |

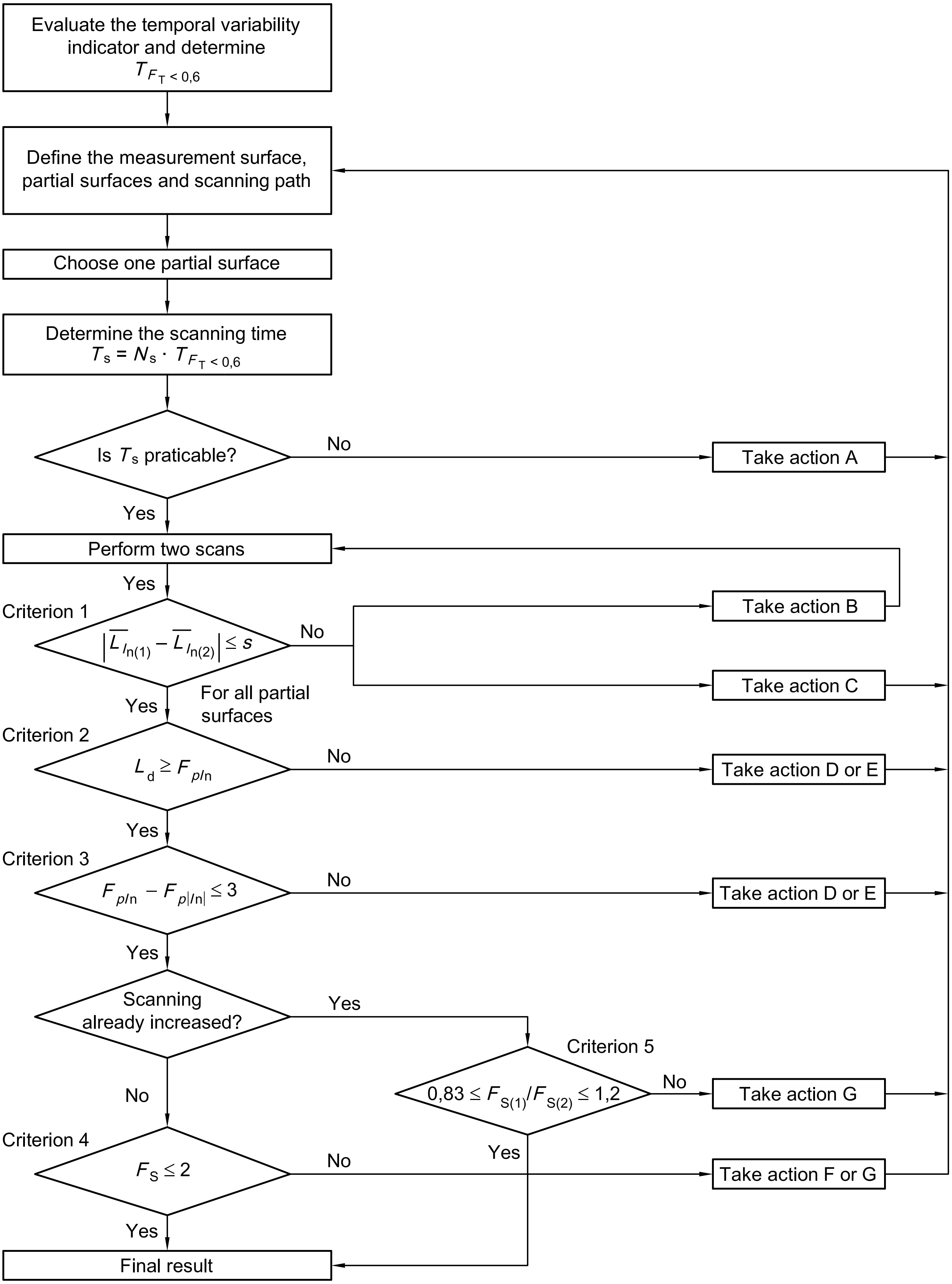


**Figure C.1 — Scheme for achieving the desired accuracy**

# Annex D
(informative)

## Effects of airflow on measurement of sound intensity

Sound intensity probes are sometimes exposed to airflow during the process of measurement, for example in windy outdoor conditions, or near flows generated by cooling fans. In principle, the theoretical basis of intensity measurement is invalid in the presence of steady fluid flow, however, the errors are negligible in low Mach number flow ($Ma < 0{,}05$), except in highly reactive fields. More serious errors are likely to be caused by the effects of unsteady airflow (turbulence).

Turbulence may exist in the flow impinging on a probe, and it may also be caused by the presence of the probe itself. The fluid momentum fluctuations inherent in turbulence are associated with fluctuating pressures; these are non-acoustic and are not normally correlated to the pressure fluctuations due to any sound field present. They are, however, registered by any pressure-sensitive transducer exposed to the flow, and the resulting signals cannot be distinguished from those caused by acoustic pressures. Turbulence is convected at a speed close to that of the mean (time-average) flow, and contains eddies (regions of correlated motion), which are generally much smaller than typical audio-frequency wavelengths, with the result that spatial pressure gradients in turbulence can greatly exceed those in sound waves. Hence the associated particle velocities can considerably exceed those in typical sound fields. The result is that strong pseudo-intensity signals can be generated. Turbulence caused by the presence of the intensity probe may be effectively suppressed by the careful use of a suitable windscreen. However, turbulent eddies (not caused by the probe) can exist in wind flows and in the flow generated by cooling fans and blowers. The mean (or time averaged) flow produced by a fan can be effectively reduced to zero by throttling, but this may by no means suppress turbulent pressure fluctuation which will still be measured on a measurement surface near to the fan or blower which may be extremely difficult or impossible to suppress using a probe windscreen. Extreme care should be taken in making sound power measurement of fans and blowers. Use of windscreens will be essential and careful experiments are very desirable to ensure that sound intensity is being measured with the intensity probe rather than pseudo-sound or turbulent pressure fluctuations.

The function of a probe windscreen is to divert the flow from the immediate vicinity of the pressure transducers. Because of the low convection speed of the turbulence, the turbulent pressure and velocity fluctuations acting on the outer surface of the windscreen cannot effectively propagate to the central region of a windscreen where the pressure transducers are situated, while sound waves are much less attenuated. This is the principle of discrimination effected by a windscreen.

It should be realized, however, that there is a limit to the effectiveness of this discrimination. Very intense turbulent fluctuations will not be completely excluded, and low-frequency, large-scale turbulence is less well attenuated than small-scale, high-frequency turbulence. Since the frequency spectrum of wind- and fan-generated turbulence tends to fall rapidly with frequency, it is the low-frequency (typically $< 200$ Hz) intensity measurements which are likely to be the most affected.

The scale and frequency of turbulence depend very much on the nature of the generation process, and therefore it is impossible to legislate specifically for every unsteady/flow situation which can be encountered during the application of intensity measurement in field situations. Since the r.m.s. value of turbulent pressure fluctuations increases as the square of mean flow speed, a conservative “blanket” limitation is placed on the mean flow speed.

As a general guide, it should be noted that a tendency for one-third-octave intensity and/or particle velocity levels to remain high, or even to rise at low frequencies ($< 100$ Hz), is a danger sign unless there is evidence that sound pressure levels do likewise, and that the measured source can be subjectively judged to radiate strongly in the low-frequency range. Another qualitative indication of the contamination of sound intensity values by turbulent pseudo-intensity is a high degree of unsteadiness in the indicated intensity and particle velocity levels. Inter-microphone coherence is not necessarily a good indicator of contamination by turbulence, because low-frequency, large-scale turbulent pressure fluctuations can be highly correlated over distances typical of intensity microphone separations.

# Annex E
(informative)

## Effect of sound absorption within the measurement surface

If the source shows obvious significant sound absorption (e.g. relevant material for heat insulation and/or sound absorbers), and if the measurement of the indicator $F_{pI_\mathrm{n}}$ yields a value of more than 3 dB, the influence of the absorbed sound power on the total sound power measured should be checked. This is possible only if the source under test can be switched off. Then, if the remaining extraneous noise is unchanged, the absorbed sound power level $L_{W,\mathrm{abs}}$ can be directly determined from the measurements of the sound intensity on the surface enclosing the switched-off source under test by applying the method given in this part of ISO 9614 and determining $L_{W,\mathrm{abs}}$ from equation (9). If the extraneous noise cannot be maintained when switching off the source under test, a rough estimate of the absorbed sound power can be determined by help of a suitable artificial extraneous sound source producing similar levels on the measurement surface as the original extraneous sound source.

The effects of absorption may be neglected if the following condition is satisfied:

$$L_W - L_{W,\mathrm{abs}} \geqslant 10\ \mathrm{dB} \qquad \text{(E.1)}$$

where

$L_W$ is the level of the total sound power with the source running [according to equations (8) and (9)];

$L_{W,\mathrm{abs}}$ is the level of the absorbed sound power with the source switched off.

Otherwise, actions should be taken in order to reduce the level of the extraneous intensity or to shield the measurement surface from the extraneous noise sources.

# Annex F
(informative)

## Measurement surface and scanning procedure

The basic principle of sound power determination using the intensity measurement technique is to measure the intensity component normal to the measurement surface which totally encloses the source under test. The main uncertainties in the results obtained by this technique are associated with instrumentation and signal analysis errors and with a non-ideal field sampling (scanning) process. This annex presents guidelines for performing the field sampling procedure. By following these guidelines and using the scanning parameters specified in this part of ISO 9614, the uncertainties may be minimized, and the grades of accuracy stated in Table 1 may be achieved.

The measurement surface should be so defined that it is easily scanned, and should be of such a form that the effects of extraneous intensity and the source near field are minimized. The scan lines are thus kept straight, and the orientation of the probe remains unchanged during each straight-line section of the path.

The measurement surface, the partial surfaces and the scan pattern should be selected to suit the source geometry and its environment according to 8.1 and 8.2 (see Figure F.1).

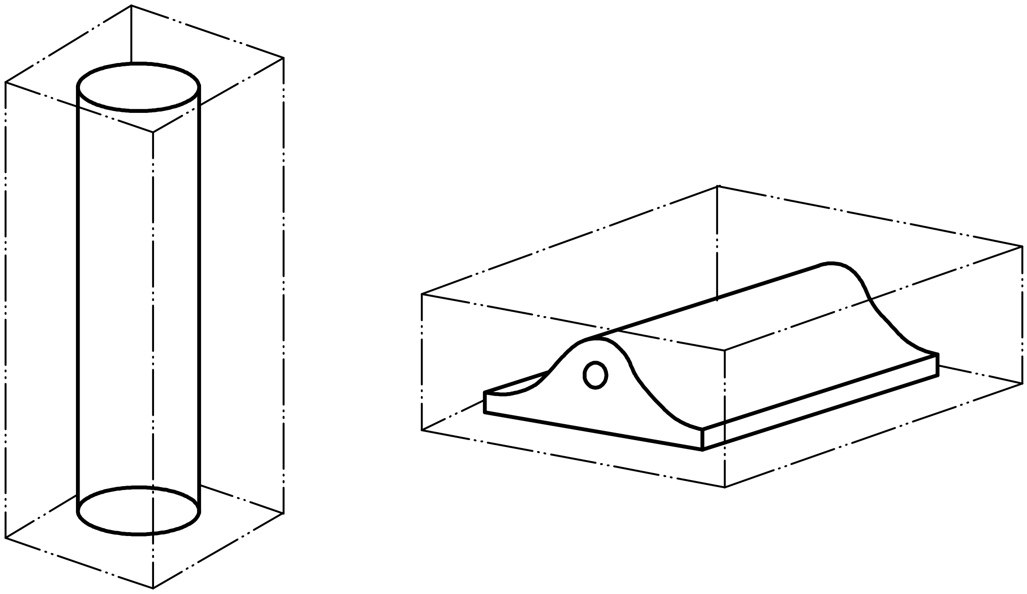


**Figure F.1 — Recommended measurement surfaces for curved sound sources**

Each partial surface should be so defined that it is easily and comfortably scanned at constant speed with a uniform line density, while maintaining the axis of the probe perpendicular to the local surface. The turn at the end of a scanning line can produce an error in the surface-averaging process, overestimating the contribution from the edge. Every effort should be made to maintain a constant scanning speed over the whole of the scan path.

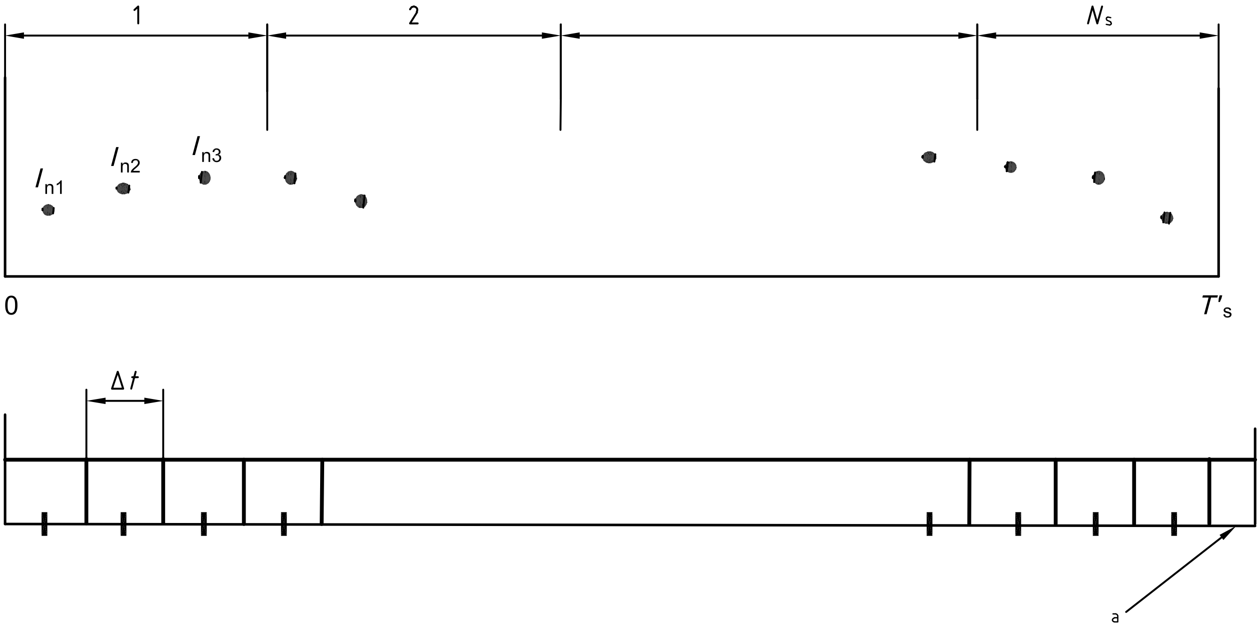
In cases when the processor operation time is predetermined in discrete steps, every effort should be made to minimize the interval between finishing the scan over any one partial surface and stopping the operation.

Equal attention should be paid to following the selected scan path and to maintaining the uniformity of the scanning speed, uniformity of the line density and probe axis orientation. Excessive concentration on any one of these tasks can adversely affect the accuracy of the measurement.

# Annex G
(informative)

## Procedure for obtaining time-averaged intensities and squared pressures from a sequence of short-time averaged intensities and squared pressures

Let the number of short-time averaged intensities and squared pressures obtained in one scan be $N_x$. Then the scanning time is obtained by $T_s' = \Delta t \cdot N_x$. In this process, as Figure G.1 shows, the last sampling data may be interrupted and discarded. However, since $\Delta t << T_s'$ is normally satisfied, this effect is negligible. Divide the period $T_s'$ into $N_s$ sections and find out how many short-time averaged intensities and squared pressures are included in each section. Then, the time-averaged intensities and squared pressures are simply calculated by taking the averages of those intensities and squared pressures included in each section.



a) **Direct method**

b) **FFT method**

a The last sampling may be discarded.

**Figure G.1 — Process for obtaining the time-averaged intensities and squared pressures from the series of short time averaged intensities and squared pressures**

# Annex H
(informative)

# Normalization of sound power level

## H.1 General

If the sensitivity of the microphones used for the sound intensity probe is calibrated under the actual meteorological conditions, the measured sound pressure $p$ (in Pa) is correct for the actual measurement condition. The associated particle velocity $u$ (in m/s) is given by

$$u = -\frac{1}{\rho}\int \frac{\partial p}{\partial n}\,\mathrm{d}\tau \tag{H.1}$$

where $\rho$ is the density of the air (in kg/m$^3$).

If the density of air for the actual measurement condition is used, the measured particle velocity and, therefore, the sound intensity $I$ (in W/m$^2$) are also true for the actual measurement conditions.

$$I = \overline{pu} \tag{H.2}$$

This part of ISO 9614 requires that a Class 1 instrument as specified in IEC 61043:1993 be used. In 6.13 of IEC 61043:1993, it is stated that Class 1 processors shall have provision for entering values of ambient atmospheric pressure and temperature or correction factors derived from these quantities for use in the calculation of sound intensity. Therefore, the intensity measurement following this part of ISO 9614 always gives a true intensity for the actual meteorological condition.

## H.2 Calculation of normalized sound power level

The sound power $P$ (in W) radiated from a source depends significantly on the density of air $\rho$ and the speed of sound in air $c$ (in m/s) [17], [18].

As the first approach, the following can be assumed [19], [20]

$$P \propto \rho c^{n} \tag{H.3}$$

Here, $n = 1$for sound radiation due to structural vibration at higher frequencies, $n = -1$ for monopole radiation, $n = -3$ for dipole radiation and $n = -5$ for quadrupole radiation [20].

By assuming $n = -1$ as the average of the $n$ value for most of structural and aerodynamic sound sources, the following equation is obtained as the first step correction for normalized sound power level:

$$C^{*} = -10\,\lg\left[\left(\frac{\rho}{\rho_0}\right)\left(\frac{c}{c_0}\right)^{-1}\right]\ \mathrm{dB} \tag{H.4}$$

Here, we have

$$\rho = \frac{B}{R_{\mathrm{L}}T} \tag{H.5}$$

$$c = \sqrt{\gamma R_{\mathrm{L}} T} \tag{H.6}$$

where

$B$ is the static pressure;

$T$ is the temperature in kelvin ($T$ = 273,15 + $\theta$, where $\theta$ is the temperature in degrees Celsius);

$\gamma$ is the specific-heat ratio;

$R_{\mathrm{L}} = \dfrac{ZR}{M_{\mathrm{a}}}$

$R$ is the universal gas constant;

$M_{\mathrm{a}}$ is the molar mass of air;

$Z$ is the compressibility factor of air (≈ 1).

From equations (H.4), (H.5) and (H.6), the following equation is derived:

$$C^{*} = -10 \ \lg \frac{B}{B_0} \ \mathrm{dB} \ +15 \ \lg \left( \frac{273{,}15 + \theta}{T_0} \right) \ \mathrm{dB} \tag{H.7}$$

where $B_0$ is the reference barometric pressure (101 325 Pa) and $T_0$ is the reference temperature (273,15 + 23 = 296,15).

By considering the additional influence of the Reynolds number on the correction for the static pressure $B$, the following equation [equation (10) in the main text] is obtained [21], [22].

$$C = -15 \lg \frac{B}{B_0} \ \mathrm{dB} + 15 \lg \left( \frac{273{,}15 + \theta}{T_0} \right) \ \mathrm{dB} = -15 \lg \left[ \frac{B}{101\,325} \times \frac{296{,}15}{273{,}15 + \theta} \right] \ \mathrm{dB} \tag{H.8}$$

When assuming $n = -1$, the uncertainty in the correction term is less than 0,2 dB for sound radiation due to structural vibration, monopole or dipole sound sources for a temperature range from 15 °C to 30 °C [23], [24], [25].

# Annex I
(informative)

# Field indicators used in ISO 9614-1, -2 and -3

Table I.1 shows the correspondences of the field indicators and their symbols used in ISO 9614-1, ISO 9614-2 and ISO 9614-3. In ISO 9614-3, it was intended that inconsistencies of naming existing in ISO 9614-1 and 2 would be avoided.

**Table I.1 — Field indicators used in ISO 9614-1, -2, and -3**

| Indicator | | ISO 9614-1 | ISO 9614-2 | ISO 9614-3 |
|---|---|---|---|---|
| **Temporal variability indicator** | | $F_1 = \frac{1}{I_\mathrm{n}}\sqrt{\frac{1}{M-1}\sum_{k=1}^{M}(I_{\mathrm{n}k}-\overline{I_\mathrm{n}})^2}$<br>$^*I_\mathrm{n}$ should read $\overline{I_\mathrm{n}}$ | — | $F_T = \frac{1}{\overline{I_\mathrm{n}}}\sqrt{\frac{1}{M-1}\sum_{m=1}^{M}(\overline{I_\mathrm{n}}_{\,m}-\overline{I_\mathrm{n}})^2}$ |
| **Field non-uniformity indicator** | | $F_4 = \frac{1}{I_\mathrm{n}}\sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(I_{\mathrm{n}i}-\overline{I_\mathrm{n}})^2}$<br>$^*\ I_\mathrm{n}$ should read $\overline{I_\mathrm{n}}$ | — | $F_\mathrm{S} = \frac{1}{\overline{I_\mathrm{n}}}\sqrt{\frac{1}{N-1}\sum_{j=1}^{N}(\overline{I_\mathrm{n}}_{\,j}-\overline{I_\mathrm{n}})^2}$ |
| **Pressure intensity indicator** | **unsigned** | **surface pressure intensity indicator**<br>$F_2 = \overline{L_p} - \overline{L_{\lvert I_\mathrm{n}\rvert}}$<br>$\overline{L_p} = 10\lg(\frac{1}{N}\sum_{i=1}^{N}10^{0,1L_{pi}})$ dB<br>$\overline{L_{\lvert I_\mathrm{n}\rvert}} = 10\lg(\frac{1}{N}\sum_{i=1}^{N}(\lvert I_{\mathrm{n}i}\rvert / I_0)$ dB | **negative partial power indicator**<br>$F_{+/-} = 10\lg[\sum \lvert P_i\rvert / \sum P_i]$<br>$P_i = \langle I_{\mathrm{n}i}\rangle S_i \quad P = \sum_{i=1}^{N} P_i$<br>$^*\ F_{+/-} = F_3 - F_2$ in a special case | **unsigned pressure intensity indicator**<br>$F_{p\lvert I_\mathrm{n}\rvert} = \bar{L}_p - L_{\lvert I_\mathrm{n}\rvert}$<br>$\bar{L}_p = 10\ \lg(\frac{1}{N}\sum_{j=1}^{N}\overline{p_j^2} / p_0^2)$ dI<br>$\bar{L}_{\lvert I_\mathrm{n}\rvert} = 10\lg(\frac{1}{N}\sum_{j=1}^{N}\lvert\overline{I_\mathrm{n}}\rvert_j / I_0)$ dB |
| | **signed** | **negative partial power indicator**<br>$F_3 = \overline{L_p} - \overline{L_{I_\mathrm{n}}}$<br>$\overline{L_{I_\mathrm{n}}} = 10\ \lg(\frac{1}{N}\sum_{i=1}^{N} I_{\mathrm{n}i} / I_0)$ dB | **sound field pressure-intensity index**<br>$F_{pI} = [L_p] - L_W + 10\lg(S/S_0)$ dB<br>$[L_p] = 10\ \lg\left[\frac{1}{S}\sum_{i=1}^{N}(S_i 10^{0,1L_{pi}})\right]$ dB<br>$S = \sum_{i=1}^{N} S_i,\ S_0 = 1\ \mathrm{m}^2$<br>$^*\ F_{pI} = F_3$ in a special case | **signed pressure intensity indicator**<br>$F_{pI_\mathrm{n}} = \bar{L}_p - \bar{L}_{I_\mathrm{n}}$<br>$\bar{L}_{I_\mathrm{n}} = 10\lg\left\lvert\frac{1}{N}\sum_{j=1}^{N}\overline{I_\mathrm{n}}_{\,j} / I_0\right\rvert$ dB |

NOTE The signed pressure-intensity indicator $F_{pI_\mathrm{n}}$ is termed as negative partial power indicator $F_3$ in ISO 9614-1. This indicator is equivalent to the sound field pressure-intensity indicator $F_{pl}$ specified in ISO 9614-2 in the special case of uniform segment area. $F_{pI_\mathrm{n}} - F_{p\lvert I_\mathrm{n}\rvert}$ is equivalent to the negative partial power indicator $F_{+/-}$ specified in ISO 9614-2 in the special case of uniform segment area.

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