INTERNATIONAL STANDARD

ISO 9614-2

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

Part 2:
Measurement by scanning

Acoustique — Détermination par intensimétrie des niveaux de puissance acoustique émis par les sources de bruit —

Partie 2: Mesurage par balayage

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Reference number
ISO 9614-2:1996(E)

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.

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.

International Standard ISO 9614-2 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 A and B form an integral part of this part of ISO 9614. Annexes C, D, E and F are for information only.

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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. Previous International Standards which describe methods of determination of 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. Therefore ISO 3740 to ISO 3747 necessarily specify the source characteristics, the test environment characteristics and qualification procedures, together with measurement methods which are expected to restrict the uncertainty of the sound power level determination to within acceptable limits.

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

a) Costly 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. The sound power level is the *in situ* sound power level as determined by the procedure of this part of ISO 9614; it is physically a function of the environment, and may in some cases differ from the sound power level of the same source determined under other conditions.

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 and the series ISO 3740 to ISO 3747 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:

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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 1043 restricts measurements to the one-third-octave range 50 Hz to 6,3 kHz; band-limited A-weighted values are determined from the constituent one-octave or one-third-octave band values and not by direct A-weighted measurement.

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 in time. In the presence of sound sources operating outside the measurement surface, any system lying within the surface may 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 may 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.

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This method is based on sampling of the intensity field normal to the measurement surface by moving an intensity probe continuously along one or more specified paths. The resulting sampling error is a function of the spatial variation of the normal intensity component over the measurement surface, which depends upon the directivity of the source, the chosen sampling 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 may 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 may contain strong contributions from sources outside the measurement surface, but may be associated with little net sound energy flow, as in a reverberant field in an enclosure; or the field may 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 out of the volume through the remaining portion of the surface. This condition is caused by the presence of a strong extraneous source close to, but outside, the measurement surface.

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

Part 2:
Measurement by scanning

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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 noise 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 segments, and scanning the intensity probe over each segment along a continuous path which covers the extent of the segment. The measurement instrument determines the average normal intensity component and averaged squared sound pressure over the duration of each scan. The scanning operation may be performed either manually or by means of a mechanical system.

Band-limited weighted sound power level is calculated from the measured octave or 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 noises generated by the source under test and by other significant extraneous sources are stationary in time, as defined in 3.13. The source is defined by the choice of measurement surface. The method is applicable *in situ*, or in special-purpose test environments.

This part of ISO 9614 specifies certain ancillary procedures, described in annex B, 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 indicated quality of the determination does not meet the requirements of this part of ISO 9614, the test procedure is to be modified in the manner indicated.

This part of ISO 9614 does not apply in 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 in 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. Extraneous noise levels may exceed the dynamic capability of the measuring instrument or may 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.

NOTE 1 Other methods (e.g. determination of sound power levels from surface vibration levels as described in ISO/TR 7849) may be more suitable.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this part of ISO 9614. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this

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part of ISO 9614 are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

IEC 942:1988, *Sound calibrators.*

IEC 1043:1993, *Electroacoustics — Instruments for the measurement of sound intensity — Measurements with pairs of pressure sensing microphones.*

3 Definitions

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

3.1 Sound pressure levels

3.1.1 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. The reference sound pressure is 20 µPa.

Sound pressure level is expressed in decibels.

3.1.2 segment-average sound pressure level, L_{pi}: Ten times the logarithm to the base 10 of the ratio of the spatial-average mean-square pressure on segment i to the square of the reference sound pressure.

It is expressed in decibels.

3.2 instantaneous sound intensity, $\vec{I}(t)$: Instantaneous rate of flow of sound energy per unit of surface area in the direction of the local instantaneous acoustic particle velocity.

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

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

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 the time.

3.3 sound intensity, $\vec{I}$: Time-average value of $\vec{I}(t)$ in a temporally stationary sound field:

$$\vec{I} = \lim_{T \to \infty} \frac{1}{T} \int_0^T \vec{I}(t)\, dt \qquad \ldots (2)$$

where T is the integration period.

Also

I is the signed magnitude of $\vec{I}$; the sign is an indication of directional sense, and is dictated by the choice of positive direction of energy flow;

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

3.4 normal sound intensity, I_n: Component of the sound intensity in the direction normal to a measurement surface defined by the unit normal vector $\vec{n}$:

$$I_n = \vec{I} \cdot \vec{n} \qquad \ldots (3)$$

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_n}: Logarithmic measure of the unsigned value of the normal sound intensity, $|I_n|$, given by:

$$L_{I_n} = 10 \lg[|I_n|/I_0] \text{ dB} \qquad \ldots (4)$$

where I_0 is the reference sound intensity ($= 10^{-12}$ Wm^{-2}).

It is expressed in decibels.

When I_n is negative, the level is expressed as (−) *XX* dB, except when used in the evaluation of δ_{pI_0} (see 3.11).

3.6 Sound powers

3.6.1 partial sound power, P_i: Time-averaged rate of flow of sound energy through an element (segment) of a measurement surface, given by:

$$P_i = \langle I_{ni} \rangle S_i \qquad \ldots (5)$$

where

$\langle I_{ni} \rangle$ is the signed magnitude of the segment-average normal sound intensity measured on the segment i of the measurement surface;

S_i is the area of the segment i.

Also $|P_i|$ is the magnitude of P_i.

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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:

$$P = \sum_{i=1}^{N} P_i \quad \ldots (6)$$

and

$$|P| = \left| \sum_{i=1}^{N} P_i \right| \quad \ldots (7)$$

where N is the total number of segments of the measurement surface.

3.6.3 partial sound power level, L_{Wi}: Logarithmic measure of the sound power passing through segment i of the measurement surface, given by:

$$L_{Wi} = 10 \lg[|P_i|/P_0] \text{ dB} \quad \ldots (8)$$

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

It is expressed in decibels.

When P_i is negative, it is expressed as (–) XX dB.

3.6.4 sound power level, L_W: Logarithmic measure of the sound power generated by a source, as determined using the method given in this part of ISO 9614, given by:

$$L_W = 10 \lg[|P|/P_0] \text{ dB} \quad \ldots (9)$$

It is expressed in decibels.

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

3.7 measurement surface: Hypothetical surface on which intensity measurements are made, and which either completely encloses the noise source under test or, in conjunction with an acoustically rigid, continuous surface, encloses the noise source under test. 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.

3.8 segment: One of a set of smaller surfaces into which a measurement surface is divided.

3.9 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).

3.10 probe: That part of the intensity measurement system which incorporates the sensors.

3.11 pressure-residual intensity index, δ_{pI_0}: The difference between the indicated L_p and indicated L_I when the intensity probe is placed and oriented in a sound field such that the sound intensity is zero. It is expressed in decibels.

Details for determining δ_{pI_0} are given in IEC 1043.

$$\delta_{pI_0} = (L_p - L_I) \quad \ldots (10)$$

3.12 dynamic capability index, L_d: Given by:

$$L_d = \delta_{pI_0} - K \quad \ldots (11)$$

It is expressed in decibels.

The value of K is selected according to the grade of accuracy required (see table 1).

Table 1 — Bias error factor, K

Grade of accuracy[1)]	Bias error factor dB
Engineering (grade 2)	10
Survey (grade 3)	7

1) Defined in ISO 12001.

3.13 stationary signal: A signal of which the time-averaged properties during a measurement on one segment of the measurement surface are equal to those obtained on the same segment when the averaging period is extended over the total time taken to measure on all segments.

NOTE 2 Cyclic signals are, by this definition, stationary, if on each segment the measurement period extends over at least ten cycles.

3.14 field indicators F_{pI} and $F_{+/-}$: See annex A.

3.15 scan: A continuous movement of an intensity probe along a specified path on a segment of a measurement surface.

3.16 scan-line density: Inverse of the average separation of adjacent scan lines.

4 General requirements

4.1 Size of noise source

The size of the noise source is unrestricted. The extent of the source is defined by the choice of the measurement surface.

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4.2 Character of noise radiated by the source

The signal shall be stationary in time, as defined in 3.13. If a source operates according to a duty cycle, within which there are distinct continuous periods of steady operation, for the purposes of application of this part of ISO 9614, an individual sound power level is determined and reported for each distinct period. Action should be taken to avoid measurement during times of operation of non-stationary extraneous noise sources of which the occurrences are predictable (see table B.1 in annex B).

4.3 Measurement uncertainty

The value of the sound power of a noise 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, but the confidence that the value determined lies within a certain range about the true value can be stated, on the reasonable 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 of environmental conditions at the test sites and of experimental technique. 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. For the procedures specified in this part of ISO 9614, the highest standard deviations of reproducibility are stated in table 2.

NOTES

3 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 2.

4 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 2. Statistical methods for the characterization of batches of machines are described in ISO 7574-4.

5 The procedures of this part of ISO 9614 and the standard deviations stated in table 2 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.

For the purposes of application of this part of ISO 9614, two grades of accuracy are defined in table 2. The stated uncertainties allow for random errors associated with the measurement procedure, together with the maximum measurement bias error which is limited by the selection of the bias error factor K appropriate to the required grade of accuracy (see table 1). They do not account for tolerances in nominal instrument performance which are specified in IEC 1043. Nor do they account for the effects of variation in source installation, mounting and operating conditions.

NOTE 6 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 octave bands from 63 Hz to 4 kHz, and one-third-octave bands from 50 Hz to 6,3 kHz. The A-weighted value which is computed from octave band levels in the range 63 Hz to 4 kHz, and 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 for 31 Hz to 40 Hz and 8 kHz to 10 kHz. For the purpose 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 10.6 b).

The uncertainty of determination of the sound power level of a noise source is related to the nature of the sound field of the source, to the nature of the extraneous sound field, to the absorption of the source under test, and to 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 A). The results of this initial test are used to select an appropriate course of action according to table B.1.

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Table 2 — Uncertainty in the determination of sound power levels

Octave band centre frequencies Hz	One-third-octave band centre frequencies Hz	Standard deviations, s	
		Engineering (grade 2) dB	**Survey** (grade 3) dB
63 to 125	50 to 160	3	
250	200 to 315	2	
500 to 4 000	400 to 5 000	1,5	
	6 300	2,5	
A-weighted 1)		1,5 2)	4

NOTE — The stated uncertainty of the A-weighted estimate does not apply if the total A-weighted power in the one-third-octave bands outside the range 400 Hz to 5 000 Hz exceeds the total within this range; individual band uncertainties then apply.

1) 63 Hz to 4 kHz or 50 Hz to 6,3 kHz.

2) The true value of the A-weighted sound power level is expected with a certainty of 95 % to be in the range of ± 3dB about the measured value.

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 more than one 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.

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 is measured by the particular instrument employed, as given in IEC 1043, is not invalidated. 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 equation (B.2) of annex B]. Attempt to reduce the value of indicator F_{pI} (A.2.1 of annex A) to less than 10 dB by an appropriate choice of measurement surface and control of extraneous intensity.

NOTE 7 If substantial quantities of absorbing material are part of the source under test, high levels of extraneous intensity may lead to an under-estimate of the sound power. Annex D 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 minimized 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 the selection of appropriate periods of measurement.

5.3 Wind and gas flows

Annex C describes the adverse effects of flow and turbulence on sound intensity measurement. A probe windscreen shall 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. Unless it can be demonstrated by measurement that the maximum time-average wind/flow speed at all locations on the measurement surface is less than 4 m/s, the following procedure shall be used to qualify the test environment prior to the commencement of the sound power determination.

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Select a measurement segment on which the unsteadiness of the wind or gas flow is considered to be maximum. Determine the segment-average normal sound intensity level L_{I_n} according to the selected scanning procedure (8.1) by means of two successive scans only. Verify that criterion 3 of B.1.3 is satisfied. Source sound power determination according to this part of ISO 9614 is not possible in those frequency bands in which criterion 3 is not satisfied. It is not permissible to continue repetition of the procedure until satisfaction of criterion 3 is achieved.

5.4 Temperature

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

NOTE 8 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, as far as possible, remain unchanged during the performance of a test; 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 at any position. 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. The effects of these quantities on instrument calibration shall be ascertained and appropriate corrections shall be made to indicated intensities (see IEC 1043).

6 Instrumentation

6.1 General

A sound intensity measurement instrument and probe that meet the requirements of the IEC 1043 shall be used. Class 1 instruments shall be used for grade 2 determinations and either class 1 or 2 instruments shall be used for grade 3 determinations. Adjust the intensity measurement instrument to allow for ambient air pressure and temperature in accordance with IEC 1043. Record the pressure-residual intensity index of the instrument used for measurements, as defined by IEC 1043, for each frequency band of measurement.

6.2 Calibration and field check

The instrument, including the probe, shall comply with IEC 1043. Verify compliance with IEC 1043 either at least once a year in a laboratory making calibrations in accordance with appropriate standards, or at least every two years if an intensity calibrator is used before each sound power determination. Report the results in accordance with 10.5.

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 following procedure to indicate anomalies within the measuring system that may have occurred during transportation, etc.

6.2.1 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 942.

6.2.2 Intensity

Place the intensity probe on the measurement surface, with the axis oriented normal to the surface, at a position where the 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 octave or one-third-octave bands, the two values of I_n shall have opposite signs and the difference between the two sound intensity levels shall be less than 1,5 dB in all bands for the measuring equipment to be acceptable.

7 Installation and operation of the source

7.1 General

Mount the source or place it in a proper way representative of normal use or the way stated in a noise test code for the particular type of machinery or

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equipment. 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

The general procedure is described in figure B.1.

8.1 Scanning

Carry out scanning 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 on the measurement surface.

Move the intensity probe continuously (scan) along specified paths on each segment of the selected measurement surface. Set the measuring instrumentation to time-average the sound intensity and sound pressure over the total duration T of a scan on one segment. Perform the scanning operation in such a manner that the specified scan path is accurately followed, 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. In the case of mechanized scanning, it is technically possible to satisfy these conditions closely on any form of measurement surface.

In the case of manual scanning, it is virtually impossible to satisfy these conditions closely on irregular, or doubly curved, measurement surfaces. Consequently, simple, regular surface forms are preferred (see annex E). The basic element of a scan is a single straight line. The scan path shall be such that it provides uniform coverage of each segment at a uniform speed. An example is shown in figure 1. The average distance between adjacent lines shall be equal and, on the initial measurement surface, shall not exceed the average distance of the segment from the source surface. The scan line density is defined in 3.16.

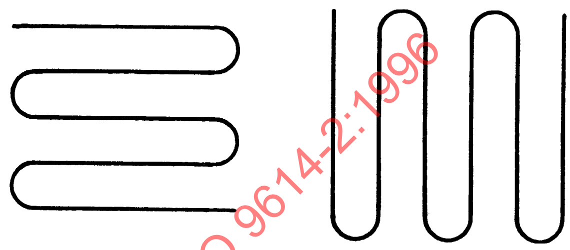

Figure 1 — Example of a scanning pattern

Manual scanning shall be performed at a speed within the range 0,1 m/s to 0,5 m/s and mechanized scanning shall be performed at speeds within the range 0 to 1 m/s.

The duration of any one scan over an individual segment shall not be less than 20 s. Initiate time-averaging at the beginning of the scan over any one segment and terminate it upon the completion of the scan over that segment (see annex E).

NOTE 9 Time-averaging may be temporarily suspended while the probe negotiates obstacles in the scan path.

During manual scanning, the operator shall not stand facing the segment being scanned but shall stand to the side so that his or her body does not impede the radiation of sound from the source. In the case of mechanized scanning, the scattering cross-sections of the components of the scanning mechanism shall be minimized in order to reduce the interference effects created by the presence of the scanning mechanism.

NOTE 10 In cases where F_{pI} is found to exceed 10 dB, scanning speeds of more than 0,25 m/s are likely to produce results which do not satisfy criterion 3 of B.1.3, irrespective of the steadiness of the field.

8.2 Initial measurement surface

Define an initial measurement surface around the source under test. The chosen surface may incorporate areas of non-absorbent surface (diffuse-field absorption coefficient less than 0,06), such as a

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concrete floor or masonry wall, where convenient. Intensity measurements shall not be made on such surfaces, and the areas of such surfaces shall not be included in the evaluation of source sound power according to equation (6).

The measurement surface shall be divided into at least four segments. The geometric form of each segment shall be such that it is possible to scan the probe along the predetermined path while maintaining the axis of the probe normal to the chosen surface and to be able to accurately determine the surface area (see annex E). In the case of manual scanning, planar or singly curved surfaces are recommended. Examples of suitable planar segments are shown in figure E.1 in annex E.

Segments shall be selected, as far as practicable, so as to be associated with individual components of the source, or parts thereof, as defined by geometric features, material type, joints, apertures, etc. Where it is evident that a large portion of the total sound power is radiated by a particular region or regions of the source, segments shall be defined, as far as possible, to separate regions of above- and below-average sound power. Segments of the measurement surface shall be defined, as far as practicable, in such a manner as to separate regions of the surface which are likely to pass predominantly negative partial sound power from those likely to pass predominantly positive partial sound power: for example, regions of the measurement surface lying between the source under test and strong extraneous sources. The maximum dimension of any segment shall be such that it is possible to scan the probe along the specified path at constant speed with a constant line density and with the probe axis maintained normal to the surface.

In cases where the source under test takes the form of an extended plate- or shell-like vibrating surface, the average distance of a segment from the source surface shall be no less than 200 mm. In cases where the source is rather small and compact in form, this distance may be reduced to 100 mm; in the latter cases, action code "a" of table B.1 and figure B.1 does not apply.

8.3 Initial test

Make measurements of segment-average normal sound intensity levels and sound pressure levels on each segment in those frequency bands in which the sound power determination is to be made.

8.3.1 Partial power repeatability

For grade 2 determinations, make two separate scans on each segment of the measurement surface, and separately record the partial sound power levels $L_{Wi}(1)$ and $L_{Wi}(2)$ for all frequency bands of measurement, according to 3.6.3: the two individual scan paths shall be orthogonal (scan pattern rotated by 90°) wherever possible (see figure 1). Introduce the difference between partial sound power levels into equation (B.3) of B.1.3. In cases where criterion 3 is not satisfied, attempt to identify the cause of the difference and suppress it where practicable. If such action is not effective or practicable, take action according to B.2.

On segments and in frequency bands where criterion 3 is still not satisfied, a determination of the partial sound power level according to this part of ISO 9614 is not possible, and a statement shall be made in the report to the effect that the uncertainty of the source sound power level determination in these bands exceeds that stated in table 2 for the desired grade of accuracy. If, in any one frequency band, the sum of the partial sound powers passing through segments on which criterion 3 is not satisfied is estimated to be more than 10 dB below the source sound power determined from the remaining partial powers passing through segments on which criterion 3 is satisfied, a determination of source sound power may be made according to this part of ISO 9614.

8.3.2 Evaluation of instrument capability

Evaluate indicator F_{pI} for all frequency bands of measurement according to equation (A.1) of A.2.1 and introduce the values into the formula given for qualification procedure B.1. Every effort should be made to restrict the value of indicator F_{pI} to less than 10 dB.

8.3.3 Evaluation of negative partial power

Evaluate indicator $F_{+/-}$ for all frequency bands of measurement according to equation (A.2) of A.2.2 and introduce the values into the formula given for the qualification procedure of B.1.2. Evaluation of indicator $F_{+/-}$ is not mandatory for grade 3 determinations.

8.4 Further action

For grade 2 determinations, where each of the criteria 1, 2 and 3 is satisfied in each frequency band, the initial sound power determination is qualified as a final result. For grade 3 determinations, satisfaction of only criteria 1 and 3 is required. Otherwise, take

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appropriate action according to B.2. Measure the normal sound intensity component levels and associated sound pressure levels using the modified measurement configuration. Recalculate field indicators F_{pI} and $F_{+/-}$, and assess according to B.1. Take action according to B.2. Repeat this procedure until the required grade of accuracy, as indicated by B.1, is attained. In cases where repeated action fails to satisfy the specified criteria, record a null test result and state the associated reasons.

9 Calculation of sound power level

9.1 Calculation of partial sound powers for each segment of the measurement surface(s)

Calculate a partial sound power in each frequency band for each segment of the measurement surface from the equation:

$$P_i = \langle I_{ni} \rangle S_i \qquad \ldots (12)$$

where

P_i is the partial sound power for segment i;

$\langle I_{ni} \rangle$ is the mean segment-average normal sound intensity component measured on segment i of the measurement surface:

$$\langle I_{ni} \rangle = [\langle I_{ni}(1) \rangle + \langle I_{ni}(2) \rangle]/2$$

S_i is the area of segment i;

and $\langle I_{ni}(1) \rangle$ and $\langle I_{ni}(2) \rangle$ are the values of $\langle I_{ni} \rangle$ obtained from two separate scans of segment i.

When the normal sound intensity level $L_{I_{ni}}$ for segment i is expressed as XX dB, calculate the value of I_{ni} from the equation

$$I_{ni} = I_0 \left(10^{XX/10} \right)$$

When the normal sound intensity level $L_{I_{ni}}$ for segment i is expressed as (–) XX dB, calculate the value of I_{ni} from the equation

$$I_{ni} = -I_0 \left(10^{XX/10} \right)$$

In these equations $I_0 = 10^{-12}$ Wm^{-2}.

NOTES

11 Where $\langle I_{ni}(1) \rangle$ and $\langle I_{ni}(2) \rangle$ are expressed in logarithmic terms, an arithmetic mean of these levels may be used for the calculation of $\langle I_{ni} \rangle$ provided they satisfy criterion 3 of B.1.3.

12 Where the A-weighted sound power level is to be determined, the normal sound intensity levels $L_{I_{ni}}$ are the A-weighted values.

9.2 Calculation of the sound power level of the noise source

Calculate the sound power level of the noise source, L_W, in each frequency band from the equation:

$$L_W = 10 \lg \left| \sum_{i=1}^{N} P_i / P_0 \right| \text{ dB} \qquad \ldots (13)$$

where

N is the total number of measurement segments;

P_i is the partial sound power for segment i, calculated from equation (12);

P_0 is the reference sound power $\left(= 10^{-12} \text{ W} \right)$.

If $\sum_{i=1}^{N} P_i$ is negative in any frequency band, the method given in this part of ISO 9614 is not applicable to that band.

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10 Information to be reported

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

10.1 Test

Date and location of test.

10.2 Sound source under test

a) Type.

b) Technical data.

c) Dimensions.

d) Manufacturer.

e) Machine serial number.

f) Year of manufacture.

g) Description of the source under test (including its major dimensions and surface texture).

h) Qualitative description of the character of the source under test, including tonal or cyclic character and variability.

i) Mounting conditions.

j) Operating conditions.

10.3 Acoustic environment

a) 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 a physical description of the test environment.

b) Air temperature in degrees Celsius, barometric pressure in pascals, and relative humidity.

c) Mean wind speed and direction, where relevant.

d) 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.

e) Qualitative description of any gas/air flows and unsteadiness.

10.4 Instrumentation

a) Equipment used for measurements, including names, types, serial numbers and manufacturers and probe configuration.

b) Method(s) used for checking calibration and field performance.

c) Places and dates of calibration and verification of test equipment.

d) Form of windscreen used.

e) The pressure-residual intensity index in accordance with IEC 1043.

10.5 Measurement procedure

a) Description of the mounting, or support system, of the scanning mechanism, and of the intensity probe.

b) Description of the scan, including geometry and speed.

c) Quantitative description of the measurement surface(s) and its segments; each segment shall be allocated a number and an area, and a drawing shall be presented.

d) Average time on each segment.

e) Description of any steps found necessary to improve measurement accuracy.

10.6 Acoustical data

a) Tabulation of the field indicators F_{pI} (for grades 2 and 3) and $F_{+/-}$ (for grade 2) in each frequency band of the sound power determination, calculated from each set of measurements on each measurement surface used.

b) Tabular presentation of the calculated value of the sound power level of the source in all frequency bands used. Where an A-weighted sound power level determination is to be made, the contribution of frequency bands in which criterion 1 and/or criterion 2 is 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.

c) Presentation of the results of the probe-reversal field checks specified in 6.2.2, if appropriate.

10.7 Grade of accuracy of the sound power level determination

The grade of accuracy attained in the final test, according to table 2, shall be stated. In the special case that the grade of accuracy can only be met for a sound power level over a restricted frequency range, a statement to this effect shall be made according to 10.6 b).

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Annex A
(normative)

Calculation of field indicators

A.1 General

Field indicators F_{pI} and $F_{+/-}$ shall be evaluated according to the equations given in A.2 for each measurement surface and segment array used, in each frequency band used for the determination of sound power levels.

NOTE 13 Evaluation of $F_{+/-}$ is not mandatory for grade 3 determinations.

A.2 Determination of field indicators

A.2.1 Surface pressure-intensity indicator

Calculate the surface pressure-intensity indicator F_{pI} from the equation

$$F_{pI} = [L_p] - L_W + 10 \lg(S/S_0) \text{ dB} \qquad \text{. . . (A.1)}$$

where

$[L_p]$ is the surface-average sound pressure level given by:

$$[L_p] = 10 \lg\left[(1/S)\sum_{i=1}^{N} S_i 10^{0,1 L_{pi}}\right] \text{ dB}$$

S is the total area of the measurement surface ($= \sum_{i=1}^{N} S_i$);

S_0 is the reference surface area $\left(= 1 \text{ m}^2\right)$.

NOTE 14 F_{pI} is equivalent to F_3 of ISO 9614-1 in the special case of uniform segment areas.

A.2.2 Negative partial power indicator

$$F_{+/-} = 10 \lg \left[\frac{\sum |P_i|}{\sum P_i} \right] \text{ dB} \qquad \text{. . . (A.2)}$$

where P_i and $|P_i|$ are given in 3.6.1.

NOTE 15 $F_{+/-}$ is equivalent to $F_3 - F_2$ of ISO 9614-1 in the special case of uniform segment areas.

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Annex B
(normative)

Procedure for achieving a desired grade of accuracy

B.1 Qualification requirements

In the application of this part of ISO 9614, the sound field conditions on the initial measurement surface may vary widely at measurement positions. 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, scan) in relation to the sound field/environment condition particular to the specific measurement. The general procedure is summarized in figure B.1.

B.1.1 Adequacy of the measurement equipment

For a measurement surface to qualify as being suitable for the determination of the sound power level of a noise source according to this part of ISO 9614, the dynamic capability index L_d of the measurement instrumentation according to 3.12 shall be greater than the indicator F_{pI} determined in accordance with A.2.1 of annex A in each frequency band of measurement:

criterion 1

$$L_d > F_{pI} \qquad \text{... (B.1)}$$

If a chosen measurement surface does not satisfy criterion 1, take action according to table B.1 and figure B.1.

B.1.2 Limit on negative partial power

For Grade 2 determinations, the following check should be made on the suitability of the measurement conditions:

criterion 2

$$F_{+/-} \leqslant 3 \text{ dB} \qquad \text{... (B.2)}$$

NOTE 16 This criterion is optional for grade 3 determinations.

B.1.3 Partial-power repeatability check

criterion 3

$$|L_{Wi}(1) - L_{Wi}(2)| \leqslant s \qquad \text{... (B.3)}$$

where s is given in table 2.

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

Table B.1 specifies the actions to be taken in cases where the chosen measurement surface and/or array does not qualify according to B.1.

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Table B.1 — Actions to be taken to increase grade of accuracy of determination

Criteria	Action code (see figure B.1)	Action
$F_{pI} > L_d$ and $F_{+/-} > 3$ dB	a	Halve the average distance of the measurement surface from source to not less than a minimum average value of 100 mm and double the scan-line density.
	or b	Shield the measurement surface from strong extraneous noise sources by means of a screen.
	or f	Reduce the adverse influence of the reverberant sound field by introducing additional absorption into the test space at locations remote from the source.
$F_{pI} > L_d$ and $F_{+/-} \leqslant 3$ dB	a	Halve the average distance of the measurement surface from source to not less than a minimum average value of 100 mm and double the scan-line density.
	or f	Reduce the adverse influence of the reverberant sound field by introducing additional absorption into the test space at locations remote from the source.
$\lvert L_{Wi}(1) - L_{Wi}(2) \rvert > s$	c	Identify and suppress causes of temporal variation in field conditions or, if this fails,
	d	double the scan-line density on the same segment.
$\lvert L_{Wi}(1) - L_{Wi}(2) \rvert > s$ and $F_{+/-} \leqslant 1$ dB	e	Double the average distance from the measurement surface to the source keeping the same scan-line density.

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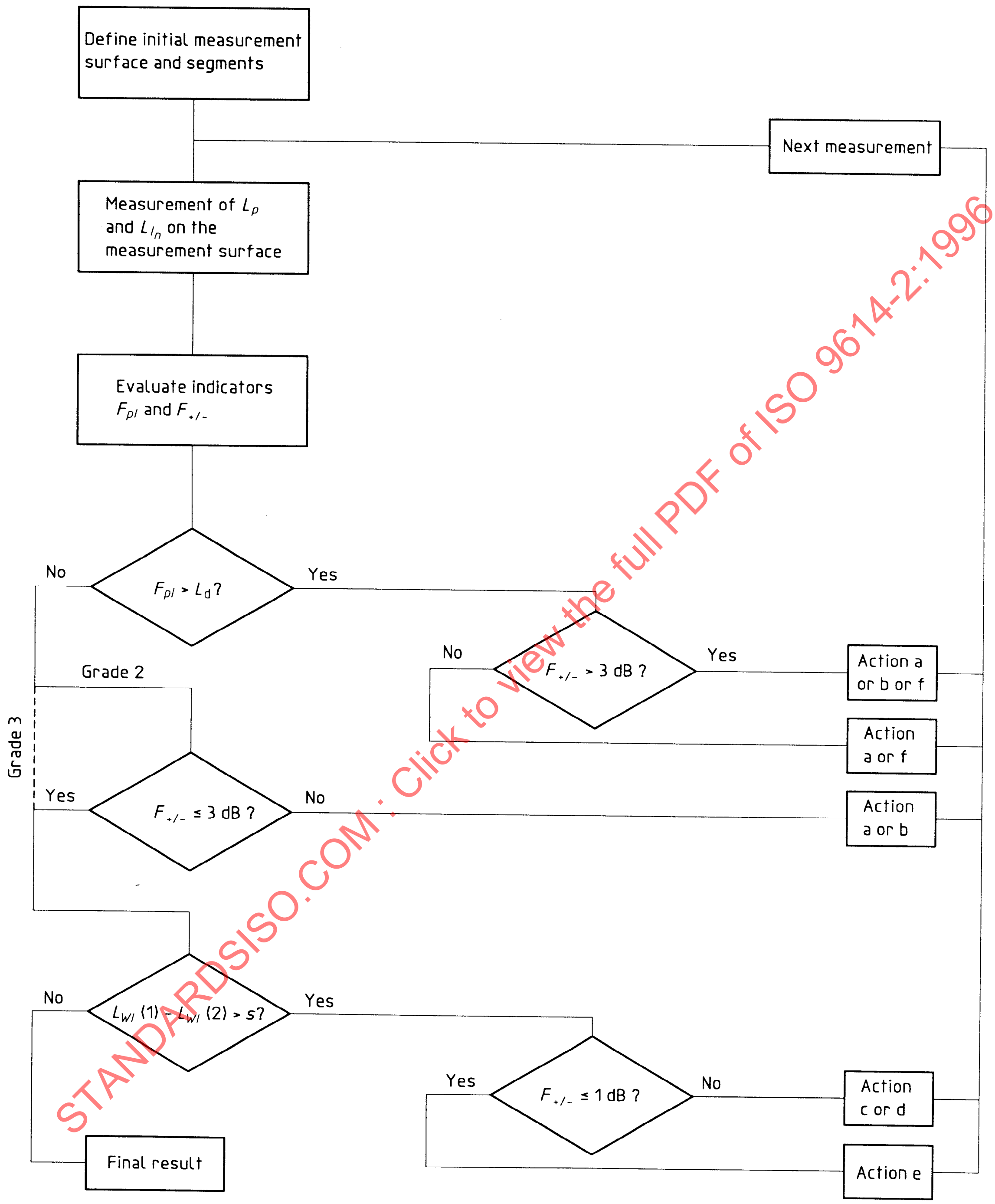

Figure B.1 — Scheme for the procedure for achieving the desired grade of accuracy

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Annex C
(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 by $p - p$ probes 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 flow impinging on a probe, and it may also be caused by the presence of the probe itself. The fluid momentum fluctuations inherent to turbulence are associated with fluctuating pressures; these are non-acoustic and are normally uncorrelated 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.

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 must 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 may 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-octave or 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. A major adverse effect of turbulence contamination is a reduction of useful dynamic range for the measurement of sound intensity signals, especially where auto-ranging instrumentation is employed.

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