TECHNICAL
SPECIFICATION

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Acoustics — Determination of airborne sound power levels emitted by machinery using vibration measurement —

Part 2:
Engineering method including determination of the adequate radiation factor

Acoustique — Détermination des niveaux de puissance acoustique aériens émis par les machines par mesurage des vibrations —

Partie 2: Méthode d'expertise incluant la détermination d'un facteur de rayonnement approprié

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Foreword

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

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

In other circumstances, particularly when there is an urgent market requirement for such documents, a technical committee may decide to publish other types of document:

- an ISO Publicly Available Specification (ISO/PAS) represents an agreement between technical experts in an ISO working group and is accepted for publication if it is approved by more than 50 % of the members of the parent committee casting a vote;
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An ISO/PAS or ISO/TS is reviewed after three years in order to decide whether it will be confirmed for a further three years, revised to become an International Standard, or withdrawn. If the ISO/PAS or ISO/TS is confirmed, it is reviewed again after a further three years, at which time it must either be transformed into an International Standard or be withdrawn.

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

ISO/TS 7849-2 was prepared by Technical Committee ISO/TC 43, *Acoustics*, Subcommittee SC 1, *Noise*.

This first edition of ISO/TS 7849-2, together with ISO/TS 7849-1, cancel and replace the first edition of ISO/TR 7849:1987, which has been technically revised.

ISO/TS 7849 consists of the following parts, under the general title *Acoustics — Determination of airborne sound power levels emitted by machinery using vibration measurement*:

- *Part 1: Survey method using a fixed radiation factor*
- *Part 2: Engineering method including determination of the adequate radiation factor*

The following part is under preparation:

- Part 3: Amplitude and phase measurements

Introduction

This part of ISO/TS 7849 gives a procedure for the determination of the sound power of the airborne noise caused by machinery vibration, including determination and application of the adequate radiation factor.

The determination of airborne noise emission of a machine by measuring vibration of the machine's outer surface may be of interest when:

- undesired background noise (e.g. noise from other machines or sound reflected by room boundaries) is high compared with the noise radiated directly by the machine under test;
- noise radiated by structure vibration is to be separated from noise of aerodynamic origin;
- noise radiated by structure vibration is high compared to the aerodynamic component so that the total noise radiation is predominantly affected by the structure vibration;
- sound intensity measurement techniques [ISO 9614 (all parts)[14]] cannot easily be applied;
- structure vibration generated noise from only a part of a machine, or from a component of a machine set, is to be determined in the presence of noise from the other parts of the whole source.

ISO/TS 7849 (all parts) describes methods for the determination of the airborne noise emission of a machine caused by vibration of its outer surface, expressed by the associated airborne sound power being related to normalized meteorological conditions. This airborne sound power is determined under the assumption that this quantity is proportional to the mean square value of the normal component of the velocity averaged over the area of the vibrating outer surface of the machine, and is directly proportional to the area of the vibrating surface.

The calculation of the airborne sound power needs data of the radiation factor, ε, as a function of frequency for the machine under test. These values can be taken as unity ($\varepsilon = 1$) independently of frequency, yielding an upper limit for the sound power (see ISO/TS 7849-1); or, it can be determined for specific machines as described in this part of ISO/TS 7849.

Details of ISO/TS 7849 (all parts) are given in the foreword.

Acoustics — Determination of airborne sound power levels emitted by machinery using vibration measurement —

Part 2:
Engineering method including determination of the adequate radiation factor

1 Scope

This part of ISO/TS 7849 gives basic requirements for a reproducible method for the determination of the sound power level of the noise emitted by machinery or equipment by using surface vibration measurements, together with the knowledge of the machinery specific sound radiation factor in the frequency bands. The method is only applicable to noise which is emitted by vibrating surfaces of solid structures and not to noise generated aerodynamically.

This vibration measurement method is especially applicable in cases where accurate direct airborne noise measurements, e.g. as specified in ISO 3746[7], ISO 3747[8], and ISO 9614 (all parts)[14], are not possible because of high background noise or other parasitic environmental interferences; or, if a distinction is required between the total radiated sound power and its structure vibration generated component.

NOTE 1 One of the applications of this part of ISO/TS 7849 is the distinction between the radiation of airborne sound power generated by structure vibration and the aerodynamic sound power components. Such a distinction is not feasible with ISO 3744[5], ISO 3745[6], ISO 3746[7] and ISO 9614 (all parts)[14].

NOTE 2 Problems may occur if the noise is generated by small parts of machinery surfaces (sliding contacts, e.g. slip ring brush or the commutator and the brush in electrical machines).

The methods described in this part of ISO/TS 7849 apply mainly to processes that are stationary with respect to time.

Recommendations on the selection of frequency bands are given in Annex C.

2 Normative references

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

ISO 5348, *Mechanical vibration and shock — Mechanical mounting of accelerometers*

ISO/IEC Guide 98-3:2008, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

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

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

3 Terms and definitions

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

3.1
structure vibration generated sound

airborne sound caused by structure vibration in the audible frequency range

NOTE For the purposes of this part of ISO/TS 7849, structure vibration generated sound is determined either from the vibratory velocity or the vibratory acceleration of the surface of the solid structure.

[ISO/TS 7849-1:2009]

3.2
machine

⟨airborne sound power level measurement of single item⟩ equipment which incorporates a single or several noise sources

[ISO/TS 7849-1:2009]

3.3
vibratory velocity

v

root-mean square (r.m.s.) value of the component of the velocity of a vibrating surface in the direction normal to the surface

NOTE The vibratory velocity, v, is the time integral of the vibratory acceleration, whose r.m.s. value is given for sinusoidal vibration by:

$$v = \frac{a}{2\pi f} \tag{1}$$

where

a is the r.m.s. acceleration;

f is the frequency.

The vibratory velocity, v, is the time derivative of the vibratory displacement, s, $\mathrm{d}s/\mathrm{d}t$. For sinusoidal vibration, the r.m.s. velocity, v, is given by:

$$v = 2\pi f s \tag{2}$$

where s is the r.m.s. displacement.

[ISO/TS 7849-1:2009]

3.4
frequency band vibratory velocity level

L_{vj}

ten times the logarithm to the base 10 of the ratio of the square of the r.m.s. value of the vibratory velocity for the jth frequency band, v_j, to the square of a reference value, v_0, expressed in decibels:

$$L_{vj} = 10 \lg \frac{v_j^2}{v_0^2} \text{ dB} \tag{3}$$

where

v_j is the r.m.s. value of the vibratory velocity, in metres per second, for the jth frequency band [1];

v_0 is the reference value for the velocity and is equal to 5×10^{-8} m/s) [2].

NOTE For airborne and structure vibration generated sound, the reference value $v_0 = 5 \times 10^{-8}$ m/s (or 50 nm/s) has the property that it leads, together with $p_0 = 2 \times 10^{-5}$ Pa, to the reference value of the intensity level $I_0 = 1 \times 10^{-12}$ W/m^2 and to the characteristic impedance of air by $p_0/v_0 = 400$ N s/m^3.

3.5
frequency band radiation factor

ε_j

factor expressing the efficiency of sound radiation given by:

$$\varepsilon_j = \frac{P_j}{Z_\text{c}\, S\, \overline{v_j^2}} \tag{4}$$

where

P_j is the airborne sound power in the jth frequency band, emitted by the vibrating surface of the machine, determined according to ISO 9614 (all parts)[14];

S is the area of the defined outer surface of the machine under test (vibrating measurement surface; see 3.7);

$\overline{v_j^2}$ is the squared r.m.s. value of the vibratory velocity measured for the jth frequency band and averaged over S;

Z_c is the characteristic impedance of air.

NOTE The four quantities ε_A, P_A, $\overline{v_\text{A}^2}$, and Z_c relate to the same period of time and to the same meteorological conditions (atmospheric temperature, θ, and barometric pressure, B).

3.6
airborne sound power level

L_{Wj}

ten times the logarithm to the base 10 of the ratio of the frequency band airborne sound power emitted by the surface of a machine, P_j, to a reference value, P_0, expressed in decibels:

$$L_{Wj} = 10 \lg \frac{P_j}{P_0} \text{ dB} \tag{5}$$

where the reference value, P_0, is 10^{-12} W.

NOTE The width of a restricted frequency band is indicated, e.g. octave-band sound power level, one-third-octave-band sound power level.

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[1] 1) A subscript “eff” is dropped since only r.m.s. values are used throughout this part of ISO/TS 7849.

[2] 2) In ISO 1683[1], two reference values for the velocity level are mentioned: $v_0 = 10^{-9}$ m/s and 5×10^{-8} m/s (= 50 nm/s). The latter is intended for cases of airborne and structure vibration generated sound and is therefore used in this part of ISO/TS 7849. A choice of $v_0 = 10^{-9}$ m/s results in a vibratory velocity level which is 34 dB higher than the level used in this part of ISO/TS 7849. Therefore, if $v_0 = 10^{-9}$ m/s is used, subtract 34 dB from the right-hand sides of Equations (9), (14), (17) and (D.2).

3.7
vibrating measurement surface
surface of a machine radiating the structure vibration generated sound where the measurement positions are located

NOTE Its area is designated by the symbol S.

[ISO/TS 7849-1:2009]

3.8
extraneous vibratory velocity level
vibratory velocity level, caused by all sources other than the source under test

NOTE Extraneous vibratory velocity levels originate, e.g. from coupled assemblies.

[ISO/TS 7849-1:2009]

4 Principle

4.1 The airborne sound power radiated by a machine or equipment caused by structure vibrations of its outer surface only, P_j, is generally determined by Equation (6) [see also Equation (4)]

$$P_j = Z_\mathrm{c} \overline{v_j^2} S \varepsilon_j \tag{6}$$

For the purpose of this part of ISO/TS 7849, for Z_c the normalized characteristic impedance $Z_\mathrm{c,n} = 411$ N s/m^3 is used.

NOTE The normalized characteristic impedance $Z_\mathrm{c,n} = 411$ N s/m^3 is used in accordance with the basic International Standards for which ISO 3740[2] gives usage guidelines, and corresponds to meteorological conditions for atmospheric temperature, $\theta_0 = 23{,}0$ °C, and barometric pressure, $B_0 = 1{,}013 \times 10^5$ Pa.

As the normalized characteristic impedance, $Z_\mathrm{c,n}$, is a constant, Equation (6) requires $\overline{v_j^2}$, S, and ε_j to be determined.

4.2 The value of $\overline{v_j^2}$ is obtained from frequency band measurements of the r.m.s. vibratory velocity component perpendicular to the outer surface of the machine and taken for a sufficient number of measurement positions distributed over its relevant outer surface. The array and number of measurement positions can be regarded as sufficient if the value of $\overline{v_j^2}$ remains stable within the precision of the method for an increasing number and changed array of measurement positions.

It may be desirable to subdivide the surface area of the machine in order to rank the sound power radiated from different components. The implication of this subdivision is that each area radiates sound independently.

The spatial variation of vibration velocity depends on

a) the number of resonant modes excited simultaneously in the frequency band of interest;

b) the degree of non-uniformity of the structure (e.g. stiffness and inertia variation);

c) the spatial distribution of the exciting forces.

A major problem occurs when only a very few modes are excited within a frequency band of interest.

4.3 The area of the relevant outer surface of the machine, S, can be calculated easily if the shape of the outer surface of the machine is simple (e.g. cylindrical, spherical or composition of flat plates).

One problem is the radiation from connected structures, such as pipes, mounts, and supports, and the radiation from the framework, rib surfaces, perforated surfaces, and supporting structures.

It is recommended that S be defined for specific kinds of machinery in connection with its radiation factor in the relevant noise test code.

4.4 The radiation factor, ε_j, depends on the factors described in 4.4.1 to 4.4.4.

4.4.1 The dimension of the radiating surface compared with the airborne wavelength of the sound for the relevant frequencies.

4.4.2 The shape of the radiating surface.

4.4.3 The modal pattern in the frequency band.

The value of ε_j is determined not only by the geometry of the structure and its mechanical properties (such as characteristic damping, and hysteresis damping), but also by the distribution and manner of excitation and by the internal loss factor. Therefore, for a certain machine, ε_j may vary if the field of exciting forces changes (e.g. between idling and load).

The radiation factor of individual modes of certain idealized uniform structures, such as spheres, flat plates and circular cylinders, is already known. Information dealing with the physical mechanism and radiation factors of airborne noise radiated by vibrating practical structure borne surfaces, such as machines, are given e.g. in References [27], [28], [29], [31].

4.4.4 The time characteristics of the process (stationary or non-stationary).

The radiation factor is determined according to Clause 8.

5 Measuring instrumentation

5.1 General

Measuring instrumentation using vibration transducers and other non-contacting equipment is described here. For contacting accelerometers, it is convenient to make use of low mass-loading accelerometers, keeping in mind the frequency range of interest. However, for special purposes, other kinds of equipment and measurement techniques may be needed, e.g. non-contact devices and laser-Doppler methods (see Annexes A and C).

5.2 Vibration transducer

The vibration transducer usually loads the vibrating surface.

For vibration measurements covering a wide frequency range, piezoelectric accelerometers are preferred. When selecting an accelerometer for a particular application, allowance should be made for the parameters of the transducer and the environmental conditions in which it is to be used.

Measurements are normally limited to the flat portion of the frequency-response of the accelerometer, which is limited by the resonance of the transducer at the high frequency end. As a rule of thumb, the upper frequency limit for the measurements can be set to one-third of the resonance frequency of the accelerometer so that vibration components measured at this limit are not affected by more than 1 dB compared with those at lower frequencies.

Small, low-mass accelerometers may have high resonance frequencies but, in general, they have low sensitivity (dynamic range). Therefore, a compromise has to be made because high sensitivity normally entails a large piezoelectric assembly and, consequently, a relatively large, heavy unit with low resonance frequency.

The mass of the accelerometer becomes important when measuring on low-mass test objects for the highest frequency of interest (see Annexes A and C).

5.3 Non-contacting transducers

There are several transducers available for a non-contacting vibration measurement: capacitive transducers, eddy current transducers, and magnetic transducers. Holographic methods, laser triangulation sensors and laser Doppler vibrometers may also be used.

The transfer coefficient of capacitive transducers is inversely proportional to the distance between the transducer and the vibrating surface. Therefore, when using a capacitive transducer, a very fine geometric model of the surface of the structure vibration generating sound source is required, as well as an exact positioning system in order to keep the required (small) measurement distance. The same applies for magnetic transducers; furthermore, the transfer coefficient depends on the permeability of the outer surface.

When using laser holographic methods, the vibration data can be determined for a mesh of the whole surface in one shot, but for each point of the mesh only one magnitude and phase value can be received. Although necessary for sound radiation calculations, no spectral resolution of an operational deflection shape is possible with holography.

Laser Doppler vibrometers determine the vibration displacement with a resolution in the range of nanometres. The distance between transducer and vibrating surface can be chosen within a wide range (usually using focusing optics) and has no influence on the measured value. Since a laser Doppler vibrometer determines the time signal of the vibration, a fast Fourier transform analysis can be performed.

In summary, among the methods considered, the use of a laser Doppler vibrometer is particularly recommended for non-contacting vibration measurements on surfaces of machines or equipment.

5.4 Amplifier and filter

The signals generated by the vibration transducer shall be amplified, filtered and indicated as r.m.s. values. The structure vibration generated noise shall be measured with a sound level meter or an equivalent measurement system complying with the relevant requirements of IEC 61672-1, Class 1, with the microphone replaced by the vibration transducer. The filters shall meet the requirements of IEC 61260, Class 1.

5.5 Integrator

If an integrator to transform acceleration signals to velocity signals is used, it shall have characteristics which match the dynamic range of the measuring system. If this requirement is not satisfied and the signal to be measured is too low, calculate the vibratory velocity levels directly from the vibratory acceleration levels.

5.6 Calibration

Information on the calibration of vibration and shock transducers is given in ISO 16063 (all parts)[15].

If the vibration transducer is calibrated by a sinusoidal acceleration signal, the resulting vibratory velocity level, L_{vj}, in decibels, is given by:

$$L_{vj} = 20 \lg \frac{\hat{a}_j}{2\pi f_j v_0 \sqrt{2}} \text{ dB} \tag{7}$$

where

$\hat{a}_j$ is the peak acceleration value;

f is the frequency;

v_0 is the reference value, 5×10^{-8} m/s, for the velocity.

EXAMPLE For a calibration with an $\hat{a}_j$ of 9,81 m/s^2 and an f of 100 Hz, L_{vj} is 106,9 dB.

Check the calibration of the entire measurement system at one or more frequencies within the frequency range of interest before each series of measurements. Use every component of the measurement system within the manufacturer's specifications.

6 Installation and operation of source under test

6.1 General

In most cases, the emitted sound power depends on both the installation and the operating conditions (for general recommendations, see 6.2 to 6.4). If, however, airborne noise measurement test codes for the relevant family of machines exist, use the installation and operating conditions specified in those codes.

6.2 Description of the machine

If the machine includes auxiliary equipment or components which emit sound, these should be identified. Specify the items of auxiliary equipment required to run during the test.

Sources of extraneous vibratory velocity levels should be identified.

The procedures specified in this part of ISO/TS 7849 do not allow the direct measurement of extraneous vibratory velocity levels. The use of correlation measurements or the comparison of vibration spectra of coupled assemblies may be necessary.

Decomposition of the noise emitted by auxiliary equipment and the main noise source (machine) is also useful.

6.3 Installation

As far as possible, install and mount the machine in a fashion typical of its operation.

6.4 Operating conditions

Operate the machine in a manner representative of its normal use. One or more of the following operating conditions may be appropriate (see also 6.1):

a) machine under nominal load or nominal operating conditions;

b) machine under full load, if different from a);

c) machine under no load (idling);

d) machine under operating conditions corresponding to maximum sound generation within the range of normal operation;

e) machine under simulated load, operating under precisely defined conditions.

7 Determination of the vibratory velocity on the vibrating measurement surface

7.1 General

The specifications of 7.2 to 7.6 are of a general nature, but if test codes for the relevant family of machines exist, use the specific requirements in those codes.

NOTE The accuracy of the measurement results depends to a large extent on the number and distribution of the measurement positions, and the distribution of the vibratory velocity on the vibrating measurement surface.

Where an individual bandwidth contains a single strong tonal component, the uncertainty of the estimate determined by the method can be high.

7.2 Vibrating measurement surface

7.2.1 General

Select suitable measurement surfaces according to the criteria outlined in 7.2.2 to 7.2.4.

The area of the measurement surface should be determined with a maximum deviation of 5 %, corresponding to a maximum deviation of 0,2 dB for 10 lg (S/S_0) dB, where S_0 is the reference area, 1 m^2.

The results of any preliminary investigations (see 7.2.4) and the structures of the radiating areas (e.g. the presence of stiffeners) should be taken into account when selecting the measurement surface.

7.2.2 Uniformly repeated structures

If the machine possesses uniformly repeated structures, and if there are geometrical symmetries and symmetries in the excitation forces, then, provided that preliminary investigations have proved all elements to be equivalent with respect to the mean vibratory velocity level in any frequency band, measurements may be carried out on a single structure.

7.2.3 Uniformly distributed measurement positions

The vibrating measurement surface area, S, shall be divided into N elements, each of area S/N. One measurement position shall be situated in the centre of each partial surface.

7.2.4 Non-uniformly distributed measurement positions

If elements of the vibrating measurement surface are known from preliminary investigations to vibrate more intensely than others, the measurement positions may be distributed more densely over those parts vibrating more intensely.

In this case, each measurement position, i, represents one partial surface area, S_i (see 9.2).

7.3 Number of measurement positions

The initial number of measurement positions on the vibrating measurement surface may be chosen from Table 1.

Table 1 — Initial number of measurement positions

Vibrating measurement surface area S m^2	Number of measurement positions
$S < 1$	10
$1 \leqslant S \leqslant 10$	20
$S > 10$	$2S/S_0$ where $S_0 = 1$ m^2

Increase the number of measurement positions if the difference between the highest and lowest vibratory velocity level, in decibels, in any frequency band is larger than the number of positions given in Table 1.

NOTE Such an increase in the number of measurement positions may, for example, be necessary if a predominant pure tone exists within the relevant bandwidth. Information on the identification of pure tones is given in e.g. ISO 7779:1999[12], Annex D or IEC 61400-11[16].

7.4 Environmental conditions

7.4.1 General

Select the measuring equipment according to the environmental conditions following the manufacturer's specifications. The influence of any cable (see Clause A.2) may be reduced by using vibration transducers with integrated impedance transducers.

7.4.2 Criteria for extraneous vibratory velocity

The time-averaged vibratory velocity level of the extraneous vibratory velocity measured and averaged (see 9.2) over the measurement positions on the measurement surface shall be at least 6 dB, and preferably more than 15 dB, below the corresponding uncorrected time-averaged vibratory velocity level of the noise source under test when measured in the presence of this extraneous vibratory velocity. For measurements in frequency bands, this requirement shall be met in each frequency band within the frequency range of interest. If this requirement is met, the extraneous vibratory velocity criteria of this part of ISO/TS 7849 are satisfied.

7.5 Measurement procedure

For the specified operating conditions, determine the vibratory velocity level (uncorrected, see 9.2), L'_v, at each measurement position for all frequency bands within the frequency range of interest. It may be determined from the acceleration signal by direct integration (see 5.5), thus avoiding calculations. (If only A-weighted vibratory velocity levels are to be determined, integration is necessary.) Carry the measurement out by using the “slow” time-weighting characteristic of the sound level meter or by an integrating-averaging sound level meter.

Choose the measurement time period so that it is appropriate for the type of sound radiated by the structure and the signal processing techniques.

For steady sound, for example, the measurement time shall be at least 10 s for centre frequencies of 200 Hz and higher. For time-varying sound, the measurement time shall be chosen in such a way that the noise of the machine is measured unambiguously for the specified operating mode.

If the preliminary investigations have shown that at particular measurement positions the vibratory velocity levels (or acceleration levels, see Annex D) of the extraneous sound are less than 10 dB below the levels of the machine under test when operating, they shall also be determined by a suitable method (see 6.2, paragraphs 3 and 4) and a correction made (see 9.1).

NOTE If it is not possible to determine the vibratory velocity levels of the extraneous sound separately (e.g. owing to the inseparable coupling of the machine under test with other assemblies), the results calculated in accordance with Clause 9 are overestimated.

7.6 Mounting of the vibration transducer

Mount the vibration transducer so that it senses as closely as possible the true velocity of the vibrating surface at the measurement position over the frequency range of interest. Mount it in accordance with ISO 5348 with its vibration axis normal to the vibrating surface. For recommendations on mounting methods, see Annex A.

8 Determination of the machinery specific frequency band radiation factor

This part of ISO/TS 7849 assumes the knowledge of the frequency band radiation factor, ε_j, and its uncertainty as a function of frequency band, j, for the machine under test, n_m. In general, this requires values of ε_j to be measured on several machines:

a) on the batch to which the machine under test belongs;

b) on the well defined machinery family to which the machine under test belongs;

c) for a well defined mounting and operating condition.

The radiation factor for the jth frequency band determined for the n_mth machine, $\varepsilon_{j,n_\mathrm{m}}$, is given by:

$$\varepsilon_{j,n_\mathrm{m}} = \frac{P_{j,n_\mathrm{m}}}{Z_\mathrm{c,n} \overline{v^2_{j,n_\mathrm{m}}} S} \tag{8}$$

where

P_{j,n_m} is the airborne sound power for the jth frequency band determined for the n_mth machine, measured as specified in ISO 9614 (all parts)[14], under the meteorological conditions of 4.1, Note,

in which

n_m = 1 ... N_m;

N_m is the number of machines used for the determination of the radiation factor;

S is determined according to Clause 7;

$\overline{v^2_{j,m}}$ is determined according to Clause 7;

$Z_\mathrm{c,n}$ is the characteristic impedance of air, of value 411 N s/m^3 under the conditions of 4.1, Note.

In order to avoid influences of near field errors, the determination of P_{j,n_m} according to the methods of ISO 3744[5] or ISO 3745[6] is not recommended.

The mean value, $\bar{\varepsilon}_j$, of all N_m measured radiation factors, given by

$$\bar{\varepsilon}_j = \frac{1}{N_\mathrm{m}} \sum_{n_\mathrm{m}=1}^{N_\mathrm{m}} \varepsilon_{j,n_\mathrm{m}} \tag{9}$$

is used to estimate the standard deviation of the radiation factor for the whole batch or machine family:

$$\sigma_{\varepsilon_j} = \sqrt{\frac{1}{N_\mathrm{m}-1} \sum_{n_\mathrm{m}=1}^{N_\mathrm{m}} (\varepsilon_{j,n_\mathrm{m}} - \bar{\varepsilon}_j)^2} \tag{10}$$

The quantity σ_{ε_j} derived by Equation (10) includes deviations caused by non-uniform machine production, the use of extremely different measurement sites, different measurement equipment, different transducer arrays, and different operators, for example. These deviations can be reduced by testing the relevant number of machines using the same measurement site, same measurement equipment, same transducer array, and same personnel.

It is recommended to include the mean value of the radiation factor, $\overline{\varepsilon}_j$, together with its standard deviation, σ_{ε_j}, in the noise test code for the relevant machinery family, if relevant stable values are confirmed by experiment. By giving reference to such a complement noise test code, repeated measurements of $\overline{\varepsilon}_j$ for each actual measurement situation can be avoided.

Report the mean value and standard deviation of the radiation factor together with the definition of the batch or machine family and the operating and mounting conditions in accordance with Clause 11.

In some cases, it is possible to approximate the radiation factor, $\overline{\varepsilon}_j$, of a batch or machinery family determined as described before by the radiation factor, $\varepsilon_{j,n}$, of a spherical source of order, n. This requires a standard deviation of $\left| 10 \lg \left(\overline{\varepsilon}_j / \varepsilon_{j,n_\text{m}} \right) \right| \text{dB} < 1$ dB for all frequency bands of interest.

Report the order, n, of the relevant spherical source in accordance with Clause 11, in addition to the uncertainty of the ε_j values for the machinery family used for the determination of $\overline{\varepsilon}_j$.

If prior experimental or theoretical evidence concerning a group of related machine structures is available, a basis for smoothing the curve may be suggested. Extrapolations and interpolations obtained from this will be useful for the purposes of 9.3.

NOTE 1 If the bandwidth is small, the ε_j-curve may show numerous peaks.

For each relevant machinery family or batch, the values of its radiation factor, ε_j, as a function of frequency, together with its standard deviation should be specified by machinery specific test codes.

NOTE 2 The airborne sound power in the jth frequency band, P_j, of Equation (8) should not be contaminated by additionally radiated aerodynamically generated noise, e.g. from a leaky enclosed machine.

9 Calculations

9.1 Correction for extraneous vibratory velocity

Calculate the correction for extraneous vibratory velocity, $K_{1j,i}$, using Equation (11):

$$K_{1j,i} = -10 \lg \left(1 - 10^{-0,1 \Delta L_v} \right) \text{dB} \tag{11}$$

where

$\Delta L_v = \overline{L}'_{v(\text{ST})} - \overline{L}_{v(\text{B})}$

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

$\overline{L}_{v(\text{B})}$ is the mean frequency-band or A-weighted time-averaged vibratory velocity level of the extraneous vibratory velocity (B) from the array of measurement positions over the measurement surface, in decibels.

If 6 dB $\leqslant \Delta L_v \leqslant$ 15 dB, calculate corrections according to Equation (11) and apply them.

If $\Delta L_v >$ 15 dB, $K_{1j,i}$ is assumed equal to zero, and no correction for extraneous vibratory velocity is required.

If $\Delta L_v <$ 6 dB for one or more one-third-octave bands, the accuracy of the result(s) may be reduced and the value of $K_{1j,i}$ to be applied in the case of these bands is 1,3 dB (the value for $\Delta L_v = 6$ dB). In this case, state clearly in the text of the report, both in graphs and tables of results, that the data in such bands represent upper bounds to the sound power level of the noise source under test.

Refer to 7.4.2 for the criteria for background noise and to determine whether the measurements meet the background noise requirements of this part of ISO/TS 7849.

9.2 Determination of the mean vibratory velocity level on the vibrating measurement surface

The vibratory velocity levels, $L_{vj,i}$, determined in accordance with 7.5 and corrected, if necessary, in accordance with 9.1, at the measurement positions $i = 1 \dots N$ for each frequency band j, are given by

$$L_{vj,i} = L'_{vj,i} - K_{1j,i} - K_{mj,i} \tag{12}$$

where

$L'_{vj,i}$ is the uncorrected measured vibratory velocity level;

$K_{1j,i}$ is the correction for extraneous vibratory velocity (see 9.1), in decibels;

$K_{mj,i}$ is the correction for the mass of the vibration transducer, in decibels.

NOTE The correction $K_{mj,i}$ is equal to zero for non-contacting transducers, and can be neglected if the mass of the contacting transducer is not greater than 0,1 times the effective (dynamic) mass of that part of the surface where the transducer is mounted. The influence can be tested for specific machinery by checking the $L'_{vj,i}$ values by a repeated measurement using a non-contacting transducer system: $K_{mj,i} = L'_{vj,i\,\text{(contacting)}} - L'_{vj,i\,\text{(non-contacting)}}$.

The mean value, $\overline{L}_{vj}$, in decibels, as an arithmetic average over the vibrating measurement surface, S, is calculated in accordance with either Equation (13) or (14), as appropriate:

a) uniformly distributed measurement positions in accordance with 7.2.3

$$\overline{L}_{vj} = 10 \lg \left(\frac{1}{N} \sum_{i=1}^{N} 10^{0,1 L_{vj,i}} \right) \text{dB} \tag{13}$$

b) Non-uniformly distributed measurement positions in accordance with 7.2.4

$$\overline{L}_{vj} = 10 \lg \left(\frac{1}{S} \sum_{i=1}^{N} S_i 10^{0,1 L_{vj,i}} \right) \text{dB} \tag{14}$$

where

$L_{vj,i}$ is the vibratory velocity level at the measurement position i;

N is the number of the non-uniform partial surfaces;

S $= \sum_{i=1}^{N} S_i$

S_i is the partial area of the outer surface of the vibrating machine associated with the measurement position i.

9.3 Calculation of the airborne sound power level caused by radiation of structure vibration generated sound

Calculate the sound power level, L_{Wj}, in decibels, from Equation (15) [derived from Equations (5) and (6)]:

$$L_{Wj} = \overline{L}_{vj} + 10 \lg \frac{S}{S_0} \text{ dB} + 10 \lg \varepsilon_j \text{ dB} + 10 \lg \frac{411}{Z_{\text{c},0}} \text{ dB} \tag{15}$$

where

$\overline{L}_{vj}$ is the mean vibratory velocity level (reference value: 5×10^{-8} m/s) on the vibrating measurement surface (see 9.2);

S is the area of the vibrating measurement surface;

S_0 is the reference area, 1 m^2;

ε_j is the radiation factor as determined according to Clause 8.

The sound power level determined by Equation (15) is the level, using the normalized characteristic impedance of air, $Z_{\text{c,n}}$, of 411 N s/m^3 (for the conditions, see 4.1, Note). The reference value for the acoustic impedance of air, $Z_{\text{c},0}$, is 400 N s/m^3.

The A-weighted airborne sound power level, if required, shall be calculated from the sound power levels in the frequency bands in accordance with Annex B.

10 Measurement uncertainty

The uncertainties associated with sound power levels determined in accordance with this part of ISO/TS 7849 shall be evaluated preferably in compliance with ISO/IEC Guide 98-3. A guideline on how to draw up a quantitative uncertainty statement following ISO/IEC Guide 98-3 is given in Annex E.

Users of this part of ISO/TS 7849 are encouraged to collect knowledge in respect to the uncertainty quantities in order to improve the application of the concept of ISO/IEC Guide 98-3.

Otherwise, the uncertainties of sound power levels, $u(L_W)$, determined in accordance with this part of ISO/TS 7849 may be estimated by:

$$u(L_W) \approx \sigma_{\text{tot}} \tag{16}$$

where σ_{tot} is the total standard deviation given by

$$\sigma_{\text{tot}} = \sqrt{\sigma_{R,\text{M}}^2 + \sigma_{\text{omc}}^2} \tag{17}$$

in which

$\sigma_{R,\text{M}}$ is the standard deviation of reproducibility of the method, applied for a source of stable sound emission ($\sigma_{\text{omc}} = 0$);

σ_{omc} is a standard deviation describing the uncertainty due to the limited stability of the operating and mounting conditions.

The standard deviation of reproducibility of the method, $\sigma_{R,\mathrm{M}}$, is determined by interlaboratory tests according to ISO 5725 (all parts)[10] using sources with a constant sound emission (deviations in the sound emission of the source are covered by σ_{oc}). The standard deviation for the operating conditions, σ_{oc}, may be determined by calculating the standard deviation from at least six repeated sound power measurements carried out at the same test site and using the same instrumentation. The operating conditions have to be varied as much as permitted by the underlying noise test code throughout these measurements.

The values for σ_R and σ_{oc} should be determined for families of noise sources, e.g. a certain type of machinery, and published in the relevant noise test codes.

Expected values for the standard deviation of reproducibility of the method, $\sigma_{R,\mathrm{M}}$, according to present knowledge, are given in Table 2.

Table 2 — Expected standard deviation of reproducibility of the method, $\sigma_{R,\mathrm{M}}$, of sound power levels determined in accordance with this part of ISO/TS 7849

Octave midband frequency Hz	**One-third-octave midband frequency** Hz	**Standard deviation of reproducibility of the method** $\sigma_{R,\mathrm{M}}$ dB
125	100 to 160	3
250	200 to 315	2
500 to 4 000	400 to 5 000	1,5
8 000	6 300 to 10 000	2,5
A-weighted		1,5
Determine values for σ_{tot} according to Equation (17).		

ISO/IEC Guide 98-3 requires an expanded measurement uncertainty, U, to be reported, such that the intervals ($L_W - U$, $L_W + U$) cover a certain percentage of the values of L_W that might reasonably be attributed to the measurand. To that purpose, a coverage factor, k, is used, such that

$$U = k\, u\left(L_W\right) = k\,\sigma_{\mathrm{tot}} \tag{18}$$

For the purposes of this part of ISO/TS 7849, a normal distribution is assumed. Thus, use a coverage factor, $k = 2$, corresponding to a coverage probability of 95 %.

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

11 Information to be recorded

11.1 Machine under test

Record at least the following information:

a) a description of the machine (dimensions, construction elements of the radiating structure);

b) the installation conditions;

c) the operating condition;

d) the test environment;

e) identification of the different sound sources of the machine operating during the measurement, if relevant;

f) the date of test.

11.2 Measurement conditions

Record at least the following information:

a) atmospheric temperature, in degrees Celsius;

b) temperature of the outer surface of the machine, in degrees Celsius, if different from environmental air temperature;

c) barometric pressure, in pascals.

11.3 Measuring instrumentation

Record at least the following information:

a) the measuring instrumentation used, including type, serial number, and manufacturer;

b) the filter bandwidth used;

c) the calibration method used for the measuring system, and the date and place of calibration;

d) the mounting of the vibration transducer.

11.4 Acoustical data

Record at least the following information:

a) a description of the vibrating measurement surface, its dimensions and distribution of measurement positions (drawing);

b) the uncorrected vibratory velocity level for each measurement position (for each frequency band or A-weighted);

c) the corrections, in decibels, if applied, in each frequency band (or A-weighted), for extraneous vibratory velocity and for the mass of the vibration transducer;

d) the mean vibratory velocity level, $\overline{L}_v$, in each frequency band (or A-weighted), together with the reference value;

e) the area of the vibrating measurement surface, S;

f) the radiation factor in frequency bands, ε_j, and the method of derivation (see Clause 8);

g) the standard deviation of the radiation factor calculated from the spread of the ε_j values of the related group of machinery used for its determination (see Clause 8);

h) a clear description of the group of machines which is used as the basis for the determination of the radiation factor;

i) the airborne sound power level, L_W, for the structure vibration generated sound, in each frequency band and/or A weighted;

j) the expanded measurement uncertainty of the results, in decibels, together with the associated coverage probability.

Annex A
(informative)

Use of the vibration transducer

A.1 Recommendations for mounting the vibration transducer

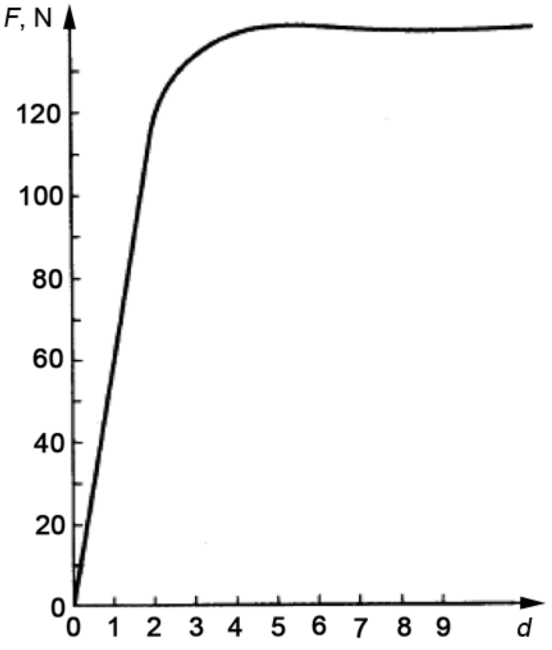
Follow the recommendations outlined in ISO 5348.

The preferred method of mounting is to screw the vibration transducer to the vibrating surface, but for measurements up to 10 kHz it is more convenient to use adhesives recommended by the manufacturer. Adhesive wax, used in thin layers, is also suitable up to 10 kHz, but not for surfaces at elevated temperature.

For smooth flat surfaces of steel, clamping magnets may also be used at frequencies below 2,5 kHz. The maximum acceleration which can be measured depends on the adhering force and the mass of magnet plus vibration transducer. For a typical magnet, the maximum adhering force as a function of plate thickness is shown in Figure A.1.

If a magnet, with a mass of 110 g, is used in combination with a 30 g vibration transducer, the maximum admissible acceleration would be 1 000 m/s^2 provided that the steel plate exceeds 4 mm in thickness. Follow the advice of the vibration transducer manufacturer.

The adhering force of a magnet is considerably diminished if the vibrating surface is not smooth and flat or if it is painted; this can lead to unreliable measurements. Smoothing the surface may be much more time-consuming than using adhesives.



Key

d thickness of steel plate

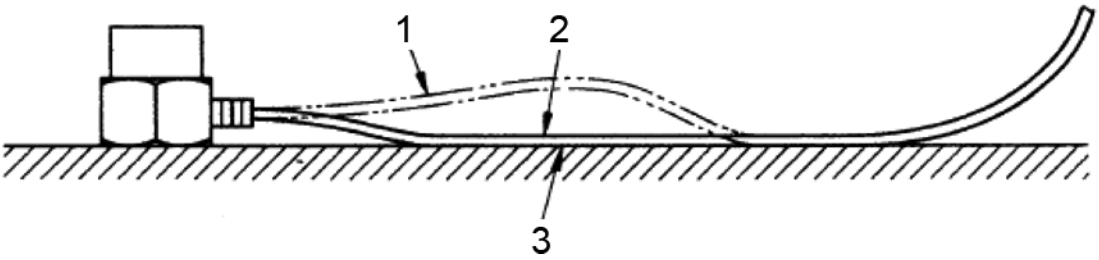
F adhering force

Figure A.1 — Maximum adhering force as a function of plate thickness for a typical magnet

A.2 Recommendations on positioning the cable of the vibration transducer

Vibration of the cable relative to the vibration transducer may induce extraneous voltages in the circuit. In order to avoid this, fix the cable on the machine at a point as close as possible to the vibration transducer (see Figure A.2).

The problem can also be solved by using vibration transducers with integrated impedance transducers (see ISO 5348).



Key

1 wrong

2 right

3 fixing by adhesive

Figure A.2 — Cable mounting

A.3 Recommendations for non-contacting equipment

Use a laser Doppler vibrometer for a non-contacting vibration measurement.

Orient the laser beam perpendicular to the surface in order to gather the normal component of the vibration velocity. When a scanning laser vibrometer is used, the laser beam can only be perpendicular to the surface once per scan. Therefore divide the whole surface into partial areas and always arrange the scanning laser vibrometer in such a way that for the measurement position in the middle of the partial area the laser beam is perpendicular to the surface. Ensure that the angle between the laser beam and the normal direction does not exceed a given degree in relation to the total measurement uncertainty.

Some surfaces do not provide enough backscattering of laser light. In this case, attach an appropriate retro-reflecting foil, coating or spray-paint to the surface.

The holographic method using a microphone array (referred to as near-field acoustical holography) provides the operational deflection shape for plane, cylindrical or spherical surfaces only. The use of this method to determine vibration data requires intensive documentation and validation. It lies outside of the scope of this part of ISO/TS 7849.

Laser triangulation sensors determine the distance between the vibration surface and the transducer with a resolution in the range of several micrometres. Hence, the distance resolution of triangulation systems is too small in respect to the vibration displacement of machinery surfaces — especially above 1 kHz.

Annex B
(normative)

Procedures for calculating A-weighted sound power levels from octave band or one-third-octave band levels

Calculate the A-weighted sound power level, $L_{W\mathrm{A}}$, in decibels (reference value: 10^{-12} W), from

$$L_{W\mathrm{A}} = 10 \lg \sum_{j=1}^{j_{\mathrm{max}}} 10^{0,1(L_{Wj} + C_j)} \text{ dB} \qquad \text{(B.1)}$$

where

C_j is given in Table B.1 for octave-band data and in Table B.2 for one-third-octave-band data;

j_{max} has a value of 7 for octave-band data and a value of 21 for one-third-octave-band data;

L_{Wj} is the level in the jth octave or one-third-octave band.

For calculations with octave-band data, $j_{\mathrm{max}} = 7$, and C_j is given in Table B.1.

Table B.1 — Values of j and C_j for octave-band data

j	**Octave midband frequency** Hz	C_j dB
1	125	−16,1
2	250	−8,6
3	500	−3,2
4	1 000	0
5	2 000	+1,2
6	4 000	+1,0
7	8 000	−1,1

For calculations with one-third-octave band data, $j_{\text{max}} = 21$, and C_j is given in Table B.2.

Table B.2 — Values of j and C_j for one-third-octave band data

j	One-third-octave midband frequency Hz	C_j dB
1	100	−19,1
2	125	−16,1
3	160	−13,4
4	200	−10,9
5	250	−8,6
6	315	−6,6
7	400	−4,8
8	500	−3,2
9	630	−1,9
10	800	−0,8
11	1 000	0
12	1 250	+0,6
13	1 600	+1,0
14	2 000	+1,2
15	2 500	+1,3
16	3 150	+1,2
17	4 000	+1,0
18	5 000	+0,5
19	6 300	−0,1
20	8 000	−1,1
21	1 0000	−2,5

Annex C
(informative)

Recommendations concerning the frequency bands of interest

The frequency range of interest normally contains either all octave bands with centre frequencies between 125 Hz and 8 000 Hz or all the one-third-octave bands with centre frequencies between 100 Hz and 10 000 Hz. All frequency bands in which vibratory velocity levels are at least 10 dB lower than the highest vibratory velocity level measured in any one frequency band may be disregarded. In special cases, the frequency range may be expanded on both sides, provided that the measurement equipment still fulfils the requirements in Clause 5. The frequency range can be restricted (non-symmetrically, if necessary) provided that the sound is radiated predominantly at high or low frequencies.

Annex D
(informative)

Determination of the vibratory velocity level from the vibratory acceleration level

The frequency band vibratory velocity level, L_{vj}, in decibels, is given by:

$$L_{vj} = 10 \lg \frac{v_j^2}{v_0^2} \text{ dB} \tag{D.1}$$

where

v_j is the r.m.s. value of the vibratory velocity for the jth frequency band;

v_0 is the reference value, 5×10^{-8} m/s.

Alternatively L_{vj} can be determined from the vibratory acceleration level according to Equation (D.2) [which is derived from Equations (1) and (3)]:

$$L_{vj} = L_{aj} - \left(20 \lg \frac{f_{\text{mid}\,j}}{f_0} - 10 \right) \text{ dB} \tag{D.2}$$

where

$f_{\text{mid}j}$ is the centre frequency, in hertz, of the jth frequency band;

f_0 is the reference value for frequency, 1 Hz;

$$L_{aj} = 10 \lg \frac{a_j^2}{a_0^2} \text{ dB}$$

in which

a_j is the r.m.s. value of the vibratory acceleration, in metres per second squared, for the jth frequency band;

a_0 is the reference value for acceleration, 10^{-6} m/s^2.

NOTE 1 Since the highest velocity level for tonal components does not normally appear exactly at the centre frequency of the frequency band, the value of L_{vj} could be wrong by up to as much as $20 \lg\sqrt{2}$ dB≈3 dB for octave bands. This error can be reduced by using one-third-octave band measurements.

NOTE 2 If using a reference value for acceleration of $\pi \times 10^{-4}$ m/s^2 and a reference value for frequency of 1 kHz, the value of the velocity spectrum at 1 kHz is identical to the acceleration spectrum.

Equation (D.2) is not valid for A-weighted levels; A-weighted velocity levels can only be determined from integrated acceleration signals (see 5.5).

When measuring vibration with a sound level meter connected to an acceleration transducer, the indicated level, L_{xj}, is not the acceleration level L'_{aj}. By taking into consideration the voltage sensitivity, Y, of the acceleration transducer used, the acceleration level, L'_{aj} (reference value $a_0 = 10^{-6}$ m/s^2), in decibels, is calculated from

$$L'_{aj} = 20 \lg \left(\frac{10^{L_{xj}/20}}{Y \times 10^{-6}} \right) \text{ dB} \qquad \text{(D.3)}$$

where Y is expressed in microvolts per metre per second squared.

EXAMPLE If the acceleration due to gravity, g_0, is 9,81 m/s^2 and the potential difference, V, is 51 mV, then the voltage sensitivity, Y, is given by

$$Y = \frac{V}{g_0}$$

or 5 200 µV s^2/m. If L_{xj} is 100 dB, Equation (D.4) gives an L'_{aj} of 145,7 dB.

Annex E
(informative)

Guidance on the development of information on measurement uncertainty

E.1 General

The information on measurement reproducibility given in this part of ISO/TS 7849 (see Clause 10) can be helpful towards the derivation of measurement uncertainties, but it is incomplete. In particular, it gives no indication of any systematic bias which might occur between sound power levels determined using the methods of different standards, nor does it give a final analysis of the various components of measurement uncertainty and their magnitudes. The accepted format for expressing the uncertainties, generally associated with methods of measurement, is that given in ISO/IEC Guide 98-3. This format incorporates an uncertainty budget, in which all the various sources of uncertainty are identified and quantified, from which the combined total uncertainty can be obtained. The data necessary to enable such a format to be adopted in the case of this part of ISO/TS 7849 were not available at the time it was being prepared. However, the intention of this annex is to provide a basis for the development of suitable information and to encourage relevant investigations by which ISO/IEC Guide 98-3 could be applied.

E.2 Expression for the calculation of the sound power level

Preliminary estimations show that the sound power level of a noise source, L_W, is a function of a number of parameters, indicated by:

$$L_W = L\left(\overline{L}_v,\ S,\ \delta_{\mathrm{slm}},\ \delta_{\mathrm{mount}},\ \delta_{\mathrm{oc}},\ \delta_{\mathrm{pick}},\ \delta_{\varepsilon}\right)\ \mathrm{dB} \qquad \text{(E.1)}$$

where

$\overline{L}_v$	is the mean measured vibratory velocity level over the measurement surface;
S	is the area of the relevant vibrating measurement surface;
δ_{slm}	is an input quantity to allow for any uncertainty in the measuring instrumentation;
δ_{mount}	is an input quantity to allow for any variability in the mounting conditions of the noise source under test;
δ_{oc}	is an input quantity to allow for any deviation in the operating conditions of the noise source under test from the nominal conditions;
δ_{pick}	is an input quantity to allow for any uncertainty due to the finite number of measurement positions;
δ_{ε}	is an input quantity to allow for any deviation in the determination of the radiation factor.

NOTE The input quantities included in Equation (E.1) were thought to be applicable in the state of knowledge at the time this part of ISO/TS 7849 was being prepared, but further research could reveal that there are others.

E.3 Contributions to measurement uncertainty

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

The combined standard uncertainty, $u(L_W)$, associated with the value of the sound power level depends on each of the input quantities, their respective standard uncertainties, u_i, and sensitivity coefficients, c_i. The sensitivity coefficients are a measure of how the values of the sound power level are affected by changes in the values of the respective input quantities. Mathematically, these coefficients are equal to the partial derivatives of the function, L_W [Equation (E.1)], with respect to the relevant input quantities (see Reference [30]). The contributions of the respective input quantities to the overall uncertainty are then given by the products of the standard uncertainties, u_i, and their associated sensitivity coefficients c_i.

E.4 Determination of total standard deviation

The combined standard uncertainty, $u(L_W)$, is approximated by the total standard deviation, σ_{tot}, which is given by the standard deviation of reproducibility of the method, $\sigma_{R,\text{M}}$, and by the standard deviation of the operating and mounting conditions, σ_{omc}, according to Equation (17). Thereby the uncertainty components δ_{mount} and δ_{oc} are already covered by σ_{omc}, and $\sigma_{R,\text{M}}$ includes the remaining uncertainty components, δ, of Equation (E.1).

To determine σ_{omc} for specific families of noise sources repeated sound power determinations are to be carried out (see Clause 9), and expected standard deviations of reproducibility of the method, $\sigma_{R,\text{M}}$, are generally given in Table 3.

Values of $\sigma_{R,\text{M}}$ for specific families of noise sources can be determined by interlaboratory tests according to ISO 5725 (all parts)[10]. Such tests yield σ_{tot} values from which $\sigma_{R,\text{M}}$ can be calculated using Equation (17).

For the case of negligible correlation between the input quantities described by Equation (E.1), $\sigma_{R,\text{M}}$ can be calculated according to the modelling approach of ISO/IEC Guide 98-3 by:

$$\sigma_{R,\text{M}} = \sqrt{\sum_{i=1}^{N_\text{M}} (c_i u_i)^2} \tag{E.2}$$

where

c_i are the sensitivity coefficients;

N is the number of input quantities in Equation (E.1) relevant for the method (i.e. except δ_{mount} and δ_{oc});

u_i are the standard uncertainties relevant to the various input uncertainty components which are relevant for the method.

Finally the total standard deviation is given by

$$\sigma_{\text{tot}} = \sqrt{\sigma_{R,\text{M}}^2 + \sigma_{\text{omc}}^2} = \sqrt{\sum_{i=1}^{N_\text{M}} (c_i\, u_i)^2 + \sigma_{\text{omc}}^2} \tag{E.3}$$

E.5 Expanded measurement uncertainty

ISO/IEC Guide 98-3 requires an expanded measurement uncertainty, U, to be specified, such that the interval $[L_W - U, L_W + U]$ covers e.g. 95 % of the values of L_W that might reasonably be attributed to L_W. For that purpose, a coverage factor, k, is used, such that $U = k\,\sigma_{\text{tot}}$. The coverage factor depends on the probability distribution associated with the measurand.

By convention, a coverage probability of 95 % is usually chosen, and assuming a normal distribution the associated two-sided coverage factor is 2. To avoid misinterpretation, the coverage probability shall be stated in test reports, together with the expanded measurement uncertainty.

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

NOTE 2 The expanded measurement uncertainty as described in this Technical Specification does not include the standard deviation of production which is used in ISO 4871[9] for the purpose of making a noise declaration for batches of machines.

Bibliography

[1] ISO 1683, *Acoustics — Preferred reference values for acoustical and vibratory levels*

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

[3] ISO 3741, *Acoustics – Determination of sound power levels of noise sources using sound pressure — Precision methods for reverberation rooms*

[4] ISO 3743 (all parts), *Acoustics — Determination of sound power levels of noise sources — Engineering methods for small, movable sources in reverberant fields*

[5] ISO 3744, *Acoustics — Determination of sound power levels of noise sources using sound pressure — Engineering method in an essentially free field over a reflecting plane*

[6] ISO 3745, *Acoustics — Determination of sound power levels and sound energy levels of noise sources using sound pressure — Precision methods for free-field test rooms and hemi-free-field test rooms*[3]

[7] ISO 3746, *Acoustics — Determination of sound power levels of noise sources using sound pressure — Survey method using an enveloping measurement surface over a reflecting plane*

[8] ISO 3747, *Acoustics — Determination of sound power levels and sound energy levels of noise sources using sound pressure — Engineering/survey methods for use* in situ *in a reverberant environment*

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

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

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

[12] ISO 7779:1999, *Acoustics — Measurement of airborne noise emitted by information technology and telecommunications equipment*

[13] ISO/TS 7849-1[4], *Acoustics — Determination of airborne sound power levels emitted by machinery using vibration measurement — Part 1: Survey method using a fixed radiation factor*

[14] ISO 9614 (all parts), *Acoustics — Determination of sound power levels of noise sources using sound intensity*

[15] ISO 16063 (all parts), *Methods for the calibration of vibration and shock transducers*

[16] IEC 61400-11, *Wind turbine generator systems — Part 11: Acoustic noise measurement techniques*

[17] JUNGER, M.C., FEIT, D. *Sound, structures, and their interaction*, 2nd edition. M.I.T. Press, Cambridge, MA, 1986. 448 p

---

[3] To be published. (Revision of ISO 3745:2003)

[4] Under preparation.

[18] Hübner, G. Analysis of errors in measuring machine noise under free-field conditions, *J. Acoust. Soc. Am.* 1973, **54**, pp. 967-977

[19] Gösele, R., Kötter, W. Einfluss der Befestigung von Schwingungsaufnehmern auf die Messgenauigkeit. *Konstr. Masch. Apparate Geräteb*. 1979, **31**, pp. 393-398

[20] Richards, E.J. Noise from industrial machines. In: White, R.G., Walker, J.G., editors. *Noise and vibration*, pp. 525-545. Ellis Horwood, Chichester, 1982

[21] Fahy, F.J. Structure-fluid interaction. In: White, R.G., Walker, J.G., editors. *Noise and vibration*, pp. 247-267. Ellis Horwood, Chichester, 1982

[22] Hübner, G. Determination of sound power radiated by structural components of machinery using vibration measurements — A direct finite element method. *Rev. Acoust*. 1983, **10**, pp. 163-166

[23] Millot, P., Guyader, J.L., Boisson, L. Recommandations d'une procédure expérimentale pour la mesure d'énergie vibratoire des plaques [Recommendations for an experimental procedure to measure the vibratory energy of plates]. In: *Proceedings of the 11th ICA Congress*, Paris, 1983

[24] Wallace, C.E. Radiation resistance of a rectangular panel. *J. Acoust. Soc. Am*. 1972, **51**, pp. 946-952

[25] Bijl, L.A. *Measurement of vibrations complementary to sound measurements*. Oil companies' international study group for conservation of clean air and water in Europe, The Hague, 1977. (CONCAWE Report No. 8/77.)

[26] Föller, D. Der Abstrahlgrad von Platten [The radiation degree of plates]. In: *Proceedings of Jahrestagung für Akustik* (DAGA), pp. 237-240. VDE, Berlin, 1980

[27] Hübner, G., Rieger, W. Application of DFM both for calculation and measurement of sound power radiated by vibrating surfaces. *Rev. Fr. Méc*. 1991, (special issue: CETIM Congress on Prediction of Noise Emitted by Vibrating Structures, Senlis, France, March 1991), pp. 487-499

[28] Hübner, G., Gerlach, A. Determination of the airborne sound power radiated by structure-borne sound sources of arbitrary shape — Using non-contacting vibration measurements. In: *Proceedings of InterNoise 1998*, Christchurch, New Zealand, 1998

[29] Hübner, G., Gerlach, A. *Schallleistungsbestimmung mit der DFEM* [Sound power level regulation with the DFEM]. Bundesanstalt für Arbeitsschutz und Arbeitsmedizin [Federal Institute of Occupational Safety and Health], Dortmund/Berlin, 1999. (*Fachbericht* [Technical report] 846.)

[30] Hübner, G. Remarks on the *Guide to the expression of uncertainty in measurement* (*GUM*). Paper presented at: InterNoise 2002, Dearborn, MI, 2002

[31] Hübner, G. The one-sided driving interaction between two monopoles — Effective as the core of the 3-dimensional DFEM sound power and scattering description. Paper presented at: EuroNoise 2002, Sevilla, 2002. Available (2008-12-12) at: http://www.sea-acustica.es/Sevilla02/num03001.pdf

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