TECHNICAL SPECIFICATION

ISO/TS 7849-1

First edition
2009-03-15

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

Part 1: Survey method using a fixed radiation factor

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

Partie 1: Méthode de contrôle employant un facteur de rayonnement fixe

Reference number
ISO/TS 7849-1:2009(E)

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Published in Switzerland

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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;

— an ISO Technical Specification (ISO/TS) represents an agreement between the members of a technical committee and is accepted for publication if it is approved by 2/3 of the members of the committee casting a vote.

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order to decide whether it will be confirmed for a further three years, revised to become an International Standard, or withdrawn.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again after a further three years, at which time it must either be transformed into an International Standard or be withdrawn.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 7849-1 was prepared by Technical Committee ISO/TC 43, *Acoustics*, Subcommittee SC 1, *Noise*.

This first edition of ISO/TS 7849-1, together with ISO/TS 7849-2, 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.

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)[12]] 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 machine.

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 A-weighted 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 in principle. For this part of ISO/TS 7849 a radiation factor of 1 is assumed allowing the determination of an upper limit for the radiated A-weighted sound power level. For typical machines this upper limit may exceed the true A-weighted sound power level determined by the intensity procedure of ISO 9614 (all parts)[12] by up to 10 dB. The A-weighted sound power level determined according to this part of ISO/TS 7849 can be used for sound power level comparison of relevant vibrating machinery noise of the same family with similar design.

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

Part 1:
Survey method using a fixed radiation factor

1 Scope

This part of ISO/TS 7849 gives basic requirements for reproducible methods for the determination of an upper limit for the A-weighted sound power level of the noise emitted by machinery or equipment by using surface vibration measurements. 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)[12], 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 3746[7] and ISO 9614 (all parts)[12].

NOTE 2 Problems can 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.

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, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

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.

3.2
machine
⟨airborne sound power level measurement⟩ equipment which incorporates a single or several noise sources

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 1 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.

NOTE 2 In this part of ISO/TS 7849, the vibratory velocity is usually applied with A-weighting, denoted v_A.

3.4
A-weighted vibratory velocity level
$L_{v\mathrm{A}}$
ten times the logarithm to the base 10 of the ratio of the square of the r.m.s. value of the A-weighted vibratory velocity, v_A, to the square of a reference value, v_0, expressed in decibels:

$$L_{v\mathrm{A}} = 10 \lg \frac{v_\mathrm{A}^2}{v_0^2} \text{ dB} \tag{3}$$

where

v_A is the A-weighted r.m.s. value of the vibratory velocity, in metres per second[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, $v_0 = 50$ 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
A-weighted radiation factor

ε_A

factor expressing the efficiency of sound radiation given by:

$$\varepsilon_A = \frac{P_A}{Z_c \, S \, \overline{v_A^2}} \tag{4}$$

where

P_A is the A-weighted airborne sound power emitted by the vibrating surface of the machine, determined according to ISO 9614 (all parts)[12];

S is the area of the defined outer surface of the machine under test (vibrating measurement surface; see 3.8);

$\overline{v_A^2}$ is the squared A-weighted r.m.s. value of the vibratory velocity averaged over S;

Z_c is the characteristic impedance of air.

NOTE The four quantities ε_A, P_A, $\overline{v_A^2}$, 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
A-weighted airborne sound power level

L_{WA}

ten times the logarithm to the base 10 of the ratio of the A-weighted airborne sound power emitted by the surface of a machine, P_A, to a reference value, P_0, expressed in decibels

$$L_{WA} = 10 \lg \frac{P_A}{P_0} \text{ dB} \tag{5}$$

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

3.7
upper limit of A-weighted airborne sound power level

$L_{WA,max}$

A-weighted airborne sound power level determined in accordance with the method described in this part of ISO/TS 7849

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

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. 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 (7), (8), and (11).

3.8
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.

3.9
extraneous vibratory velocity level
vibratory velocity level, caused by all sources other than the source under test

NOTE Extraneous vibratory velocity levels originate, for example, from coupled assemblies.

4 Principle

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

$$P_A = Z_c \overline{v_A^2} S \, \varepsilon_A \tag{6}$$

For the purpose of this part of ISO/TS 7849, the A-weighted radiation factor $\varepsilon_A = 1$ 3), and for Z_c the normalized characteristic impedance $Z_{c,n} = 411$ N s/m^3 is used.

NOTE The normalized characteristic impedance $Z_{c,n} = 411$ 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.

These assumptions yield the upper limit of the A-weighted airborne sound power

$$P_{A,max} = Z_{c,n} \overline{v_A^2} S \tag{7}$$

which forms the basis for the method described in this part of ISO/TS 7849, requiring only $\overline{v_A^2}$ and S to be determined.

4.2 The value of $\overline{v_A^2}$ is obtained from measurements of the A-weighted 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 $\overline{v_A^2}$ 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.

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3) Under certain specific conditions, values $\varepsilon_A > 1$ are possible, but they seldom occur in the practice of machinery noise radiation. However, it may be assumed that, within the measurement uncertainty to be expected, the upper limit of the A-weighted sound power level determined in accordance with this part of ISO/TS 7849 also covers deviations caused by radiation factors larger than 1.

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.

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 Annex A).

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 low-mass test objects for the highest frequency of interest (see Annex A).

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 of the order 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

Amplify the signals generated by the vibration transducer and indicate them as r.m.s. values. Measure structure vibration generated noise with a sound level meter or an equivalent measurement system complying with the relevant requirements of IEC 61672-1, Class 2, with the microphone replaced by the vibration transducer.

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)[13].

If the vibration transducer is calibrated by a sinusoidal acceleration signal, the resulting A-weighted vibratory velocity level, $L_{v\mathrm{A}}$, in decibels, is given by:

$$L_{vj} = 20 \lg \frac{\hat{a}_j}{2\pi f_j v_0 \sqrt{2}} \text{ dB} \tag{8}$$

where

$\hat{a}_{\mathrm{A}}$ is the A-weighted 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 $\hat{a}_{\mathrm{A}}$ of 9,81 m/s^2 and an f of 100 Hz, $L_{v\mathrm{A}}$ 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.

NOTE Further information on the calibration of vibration and shock transducers is given in ISO 16063 (all parts)[13].

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 that is typical of its operation.

6.4 Operating conditions

Operate the machine in a manner that is 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.

7.2 Vibrating measurement surface

7.2.1 General

Select suitable measurement surfaces in accordance with 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 10 %, corresponding to a maximum deviation of 0,4 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 A-weighted vibratory velocity level, 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 8.2).

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
$S < 1$	5
$1 \leqslant S \leqslant 10$	10
$S > 10$	S/S_0 where $S_0 = 1$ m^2

Increase the number of measurement positions if the difference between the highest and lowest A-weighted vibratory velocity level, in decibels, is larger than double the number of positions given in Table 1.

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 Criterion for extraneous vibratory velocity

The A-weighted vibratory velocity levels due to the level of the extraneous vibratory velocity averaged over the measurement positions on the measurement surface shall be at least 3 dB below the mean vibratory velocity level due to the noise source under test in operation when measured in the presence of this vibratory velocity (see 8.2).

7.5 Measurement procedure

For the specified operating conditions, determine the A-weighted vibratory velocity level (uncorrected, see 8.2), $L'_{v\mathrm{A}}$, at each measurement position. It may be determined from the acceleration signal by direct integration (see 5.5), thus avoiding calculations. 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 should be at least 10 s. 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 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 8.1).

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 8 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 Calculations

8.1 Correction for extraneous vibratory velocity

Correct the measured levels for extraneous vibratory velocity according to Table 2.

If $\Delta L_v > 10$ dB, $K_{1\mathrm{A}}$ is assumed to be zero.

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

Table 2 — Correction for extraneous vibratory velocity

Difference between the A-weighted vibratory velocity levels of the machine when operating and the levels of the extraneous vibratory velocity ΔL_v dB	Correction to be subtracted from the vibratory velocity levels in order to obtain the level generated by the machine alone K_{1A} dB
3	3
4	2
5	2
6	1
7	1
8	1
9	1
10	0

8.2 Determination of the mean A-weighted vibratory velocity level on the vibrating measurement surface

The A-weighted vibratory velocity levels, L_{vAi}, determined in accordance with 7.5 and corrected, if necessary, in accordance with 8.1, at the measurement positions i = 1 ... N, are given by:

$$L_{vAi} = L'_{vAi} - K_{1Ai} - K_{m,Ai} \tag{9}$$

where

L'_{vAi} is the uncorrected measured vibratory velocity level;

K_{1Ai} is the correction, in decibels, for extraneous vibratory velocity (see 8.1);

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

NOTE The correction $K_{m,Ai}$ 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'_{vAi}-values by a repeated measurement using a non-contacting transducer system: $K_{m,Ai} = L'_{vAi\,(\text{contacting})} - L'_{vAi\,(\text{non-contacting})}$.

The mean value, $\overline{L}_{vA}$, in decibels, as an arithmetic average over the vibrating measurement surface, S, is calculated in accordance with either Equation (10) or (11), as appropriate:

a) uniformly distributed measurement positions in accordance with 7.2.3

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

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

$$\overline{L}_{vA} = 10 \lg \left(\frac{1}{S} \sum_{i=1}^{N} S_i 10^{0,1 L_{vAi}} \right) \text{dB} \tag{11}$$

where

L_{vAi} is the A-weighted 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.

8.3 Calculation of the upper limit of the A-weighted airborne sound power level caused by radiation of structure vibration generated sound

From the values of $\overline{L}_{vA}$ calculated in accordance with 8.2, the upper limit of the A-weighted sound power level, $L_{WA,\max}$, in decibels, is calculated from Equation (12) [derived from Equations (5) and (6)]:

$$L_{WA,\max} = \overline{L}_{vA} + 10 \lg \frac{S}{S_0} \text{ dB} + 10 \lg \frac{411}{Z_{c,0}} \text{dB} \qquad (12)$$

where

$\overline{L}_{vA}$ is the mean vibratory velocity level (reference value:5 × 10^{-8} m/s) on the vibrating measurement surface (see 8.2);

S is the area of the vibrating measurement surface;

S_0 is the reference area, 1 m^2.

The sound power level determined by Equation (12) is the level, using the normalized characteristic impedance of air, $Z_{c,n}$, of 411 N s/m^3 (for the conditions, see 4.1, Note). The reference value for the acoustic impedance of air, $Z_{c,0}$, is 400 N s/m^3.

9 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 B.

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 the upper limit of sound power levels, $u(L_{WA,\max})$, determined in accordance with this part of ISO/TS 7849 may be estimated by:

$$u\left(L_{WA,\max}\right) \approx \sigma_{\text{tot}} \qquad (13)$$

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

$$\sigma_{\text{tot}} = \sqrt{\sigma_{R,\text{M}}^2 + \sigma_{\text{omc}}^2} \qquad (14)$$

in which

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

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_{omc}). The standard deviation for the operating and mounting conditions, σ_{omc}, 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 $\sigma_{R,\mathrm{M}}$ and σ_{omc} should be determined for families of noise sources, e.g. a certain type of machinery, and published in the relevant noise test codes.

The expected value for the standard deviation of reproducibility, $\sigma_{R,\mathrm{M}}$, of the upper limit of the A-weighted sound power levels determined in accordance with this part of ISO/TS 7849, according to present knowledge, is given in Table 3.

Table 3 — Expected standard deviation of reproducibility of the method, $\sigma_{R,\mathrm{M}}$, of the upper limit of the A-weighted sound power levels determined in accordance with this part of ISO/TS 7849

	Standard deviation of reproducibility of the method $\sigma_{R,\mathrm{M}}$ dB
A-weighted	3,0
NOTE Determine values for $\sigma_{\mathrm{tot,typ}}$ according to Equation (14).	

ISO/IEC Guide 98-3 requires an expanded measured uncertainty, U, to be reported, such that the intervals ($L_{W\mathrm{A,max}} - U$, $L_{W\mathrm{A,max}} + U$) cover a certain percentage of the values of $L_{W\mathrm{A,max}}$ that might reasonably be attributed to the measurand. To that purpose, a coverage factor, k, is used, such that

$$U = k\,u\left(L_{W\mathrm{A,max}}\right) = k\,\sigma_{\mathrm{tot}} \tag{15}$$

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

The A-weighted airborne sound power level, $L_{W\mathrm{A,max}}$, determined by this part of ISO/TS 7849, using $\varepsilon_{\mathrm{A}} = 1$ deviates systematically from the true airborne sound power level, $L_{W\mathrm{A}}$, by a value, $\Delta L_{W\mathrm{A}} = L_{W\mathrm{A,max}} - L_{W\mathrm{A}} > 1$. The systematic deviation characterized by a supplementary extra charge, $\Delta L_{W\mathrm{A}}$, may increase the A-weighted sound power level for typical machines by up to 10 dB compared to the relevant sound power level determined with the reference method [ISO 9614 (all parts)[12]].

10 Information to be recorded

10.1 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.

10.2 Measurement conditions

Record at least the following information:

a) atmospheric temperature, in degrees Celsius;

b) barometric pressure, in pascals.

10.3 Measuring instrumentation

Record at least the following information:

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

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

c) the mounting of the vibration transducer.

10.4 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 A-weighted vibratory velocity level for each measurement position;

c) the corrections, in decibels, if applied, for extraneous vibratory velocity and for the mass of the vibration transducer;

d) the mean A-weighted vibratory velocity level, $\overline{L}_{v\mathrm{A}}$, together with the reference value;

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

f) the upper limit of the A-weighted airborne sound power level, $L_{W\mathrm{A,max}}$, for the structure vibration generated sound;

g) 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

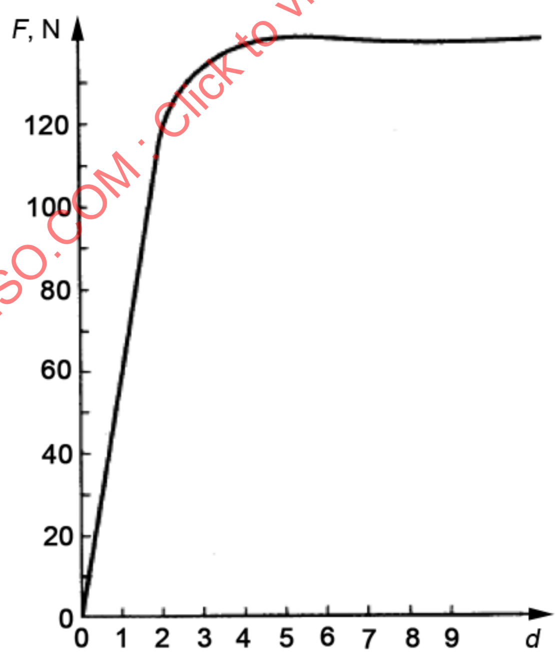
Follow the recommendations outlined in ISO 5348.

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

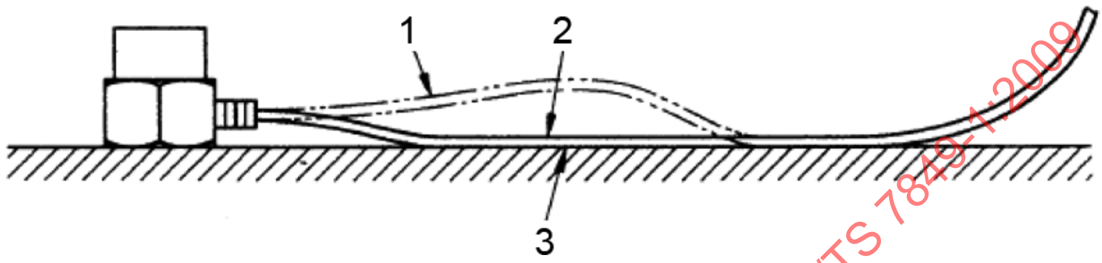
F adhering force

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 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
(informative)

Guidance on the development of information on measurement uncertainty

B.1 General

The information on measurement reproducibility given in Clause 9 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.

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

Preliminary estimations show that the upper limit of the sound A-weighted airborne sound power level of a noise source, $L_{W\mathrm{A,max}}$, is a function of a number of parameters, indicated by:

$$L_{W\mathrm{A,max}} = L\left(\overline{L}_{v\mathrm{A}}, S, \delta_{\mathrm{slm}}, \delta_{\mathrm{mount}}, \delta_{\mathrm{rep}}, \delta_{\mathrm{pick}}, \delta_{\varepsilon}\right) \text{ dB} \tag{B.1}$$

where

$\overline{L}_{v\mathrm{A}}$ is the mean measured A-weighted vibratory velocity level over the measurement surface;

S is the area of the relevant vibrating measurement surface;

δ_{mount} is an input quantity to allow for any variability in the mounting conditions of the noise source under test;

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

δ_{rep} is an input quantity to allow for any deviation in the operating conditions of the noise source under test from the nominal conditions;

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

δ_{ε} is an input quantity to allow for the deviation of the real radiation factor from that specified for this part of ISO/TS 7849 ($\varepsilon = 1$).

NOTE The input quantities included in Equation (B.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.