TECHNICAL SPECIFICATION

ISO/TS 7849-2

First edition
2009-03-15

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

Reference number
ISO/TS 7849-2:2009(E)

Contents

Page

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order to decide whether it will be confirmed for a further three years, revised to become an International Standard, or withdrawn.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again after a further three years, at which time it must either be transformed into an International Standard or be withdrawn.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:

$$v = \frac{a}{2\pi f} \quad (1)$$

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, ds/dt. For sinusoidal vibration, the r.m.s. velocity, v, is given by:

$$v = 2\pi f s \quad (2)$$

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:

$$L_{v\,j} = 10 \lg \frac{v_j^2}{v_0^2} \text{ dB} \quad (3)$$

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:

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

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, $\overline{v_A^2}$, 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) 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 (= 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.