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Acoustics — Estimation of airborne noise emitted by machinery using vibration measurement

Acoustique — Estimation du bruit aérien émis par les machines par mesurage des vibrations

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ISO/TR 7849 was prepared by Technical Committee ISO/TC 43, *Acoustics.*

The reasons which led to the decision to publish this document in the form of a technical report type 2 are explained in the Introduction.

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0 Introduction

0.1 Reasons for publication as a technical report type 2

The proposal to prepare an International Standard on measurement and characterization of noise radiated by structure-borne components of machinery was initiated in 1979 at the ISO/TC 43/SC 1 meeting. A draft proposal was prepared for discussion. However, in 1982 it was decided that the text of this DP should be amended on the basis of the member body comments, and as the subject had not sufficiently advanced to prepare an International Standard, the amended text should be submitted for adoption as a Technical Report. This proposal to publish as a Technical Report was supported by the majority of participating members of TC 43.

This document is published in the form of a technical report type 2 as the subject cannot yet be considered suitable for an International Standard because of the lack of present knowledge on some measurement characteristics; the accuracy of the method remains, for example, uncertain when applied to specific families of machines which are most relevant in noise radiation. The subject is still under study and this Technical Report may encourage further practical investigation in this field, producing basic data to change this Technical Report into an International Standard in future.

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0.2 General

The determination of airborne noise emission of a machine by measuring vibrations of the machine's outer surface may be of interest in the following cases:

- 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;

- when the noise radiated by structural vibration is to be separated from noise of aerodynamic origin (also in cases where the new noise intensity measuring technique cannot easily be applied);

- where the structure-borne 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.

This Technical Report gives a procedure for estimating the sound power of the airborne noise emitted by machinery from vibration measurements. Under certain conditions, the measurement procedure can be applied without great difficulty if

- the shape of the machine's outer surface is more or less simple;

- vibrations at different measurement locations are not significantly correlated, and a large number of resonant modes of vibration are found within the frequency band.

Certain well correlated sources of simple shape can also be treated (vibration of a source of zero order, piston vibration). If these conditions are not fulfilled, some problems arise as described in 0.3. For such cases it is not yet possible to give exact requirements for the measurement procedures, but some measurement procedures are put forward in this Technical Report.

0.3 Assumptions and problems in determining the sound power from a knowledge of the mean square value of the surface velocity of vibration of machines

0.3.1 The airborne sound power radiated by a machine or equipment caused by structural vibrations of its outer surface only, P_S, can be estimated by using the following equation:

$$P_S = \varrho c \, \overline{v^2} \, S_S \sigma$$

where

ϱc is the fluid characteristic impedance,

where

ϱ is the mean density of the fluid (i.e. air),

c is the velocity of sound in the fluid (i.e. air);

$\overline{v^2}$ is the mean square value of the normal vibratory velocity averaged over the surface area S_S;

S_S is the area of the defined outer surface of the machine;

σ is the radiation factor.

As the characteristic impedance ϱc is a constant for known meteorological conditions, the formula given above requires the three quantities $\overline{v^2}$, S_S and σ to be determined.

0.3.2 The value of $\overline{v^2}$ is obtained from measurements of the r.m.s. vibratory velocity component perpendicular to the machine's outer surface and taken for a sufficient number of measurement locations distributed over the relevant outer surface of the machine. The array and number of measurement locations can be regarded as sufficient if the value of $\overline{v^2}$ remains stable within the precision of the method for an increasing number and changed array of measurement locations. A random distribution of vibration pick-ups appears to be desirable. Guidelines on a practical approach are given in 7.2 and 7.3.

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

The spatial variation of vibration velocity depends on

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

b) the degree of non-uniformity of the structure (e.g. presence of stiffness, holes variation and thickness of material);

c) the spatial distribution of the exciting forces.

The major problem occurs when very few modes are excited at resonance in a frequency band.

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

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

It is recommended to define S_S for specific kinds of machinery in connection with the relevant radiation factor (see the "Bibliography").

0.3.4 The radiation factor, σ, depends on the following factors:

a) The dimension of the radiating surface compared with the wavelength of the sound in air for the relevant frequencies.

b) The shape of the radiating surface.

c) The modal pattern in the frequency band.

The value of σ is determined not only by the structure, but also by the distribution and manner of excitation and by the internal loss factor. So for a certain machine, σ 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 known. The modal-average radiation factor of such structures is also known on the assumption of equal modal energy. Certain kinds of excitation may result in non-uniform modal energy, e.g. airborne excitation, single excitation, impulsive excitation.

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

The radiation factor can be determined as follows:

a) Theoretically, as described above (see the "Bibliography").

b) Experimentally from measurements on one or more structures being representative of a certain family of machines or equipment.

This method uses the equation given in 0.3.1 in the following form:

$$\sigma = \frac{P_S}{\varrho c S_S \overline{v^2}}$$

where

P_S is the airborne sound power determined either in accordance with ISO 3741, ISO 3742, ISO 3743, ISO 3744, ISO 3745 or ISO 3746 or by using sound intensity measurement;

ϱc, S_S and $\overline{v^2}$ are determined as described previously.

c) By assuming estimated σ-values as a function of frequency.

Such values may be derived for machines having similar acoustical behaviour as compared with sound sources being investigated carefully according to methods a) and b).

According to some investigations the radiation factor $\sigma(f)$ of a spherical source of zero order (see 8.3.2) approximates, for example, the radiation factor of a large number of sound sources (machines, equipment).

A very rough estimation of σ is given by the value $\sigma = 1$. In general, this assumption allows one to estimate an upper value for the radiated sound power, P_S.

1 Scope and field of application

This Technical Report gives basic requirements for reproducible methods for estimating the sound power emitted by machines or equipment by using surface vibration measurements. The method is especially applicable in cases where accurate direct airborne noise measurements as specified in ISO 3741, ISO 3742, ISO 3743, ISO 3744 and ISO 3745 are not possible because of high background noise or other parasitic environmental influences. The methods are only applicable to noise which is emitted by vibrating surfaces of solid structures and not to noise generated aerodynamically. The method described in this Technical Report applies mainly to processes which are stationary with respect to time. Research into the possibility of extending these techniques to non-stationary processes is, however, encouraged.

Guidelines for the estimation of the radiation factor variation with frequency are given in annex D. Recommendations on the selection of frequency bands are given in annex E.

This Technical Report specifies procedures by which the sound power radiated from individual parts of the whole of the vibrating surface of large machines can be estimated by vibration measurements.

2 References

ISO 1683, *Acoustics — Preferred reference quantities for acoustic levels.*

ISO 3741, *Acoustics — Determination of sound power levels of noise sources — Precision methods for broad-band sources in reverberation rooms.*

ISO 3742, *Acoustics — Determination of sound power levels of noise sources — Precision methods for discrete-frequency and narrow-band sources in reverberation rooms.*

ISO 3743, *Acoustics — Determination of sound power levels of noise sources — Engineering methods for special reverberation test rooms.*

ISO 3744, *Acoustics — Determination of sound power levels of noise sources — Engineering methods for free-field conditions over a reflecting plane.*

ISO 3745, *Acoustics — Determination of sound power levels of noise sources — Precision methods for anechoic and semi-anechoic rooms.*

ISO 3748, *Acoustics — Determination of sound power levels of noise sources — Engineering method for small, nearly omnidirectional sources under free-field conditions over a reflecting plane.* [1)]

ISO 5348, *Mechanical vibration and shock — Mechanical mounting of accelerometers.* [1)]

IEC Publication 225, *Octave, half-octave and third-octave band filters intended for the analysis of sounds and vibrations.*

IEC Publication 651, *Sound level meters.*

3 Definitions

For the purposes of this Technical Report, the following definitions apply.

3.1 structure-borne sound: Vibration transmitted through solid structures of a machine in the frequency range of audible sound. It is determined either from the vibratory velocity or the vibratory acceleration of the surface of the solid structure.

3.2 machine:

(1) Item of equipment which incorporates a single noise source.

(2) Assembly of items of equipment which incorporates several noise sources.

3.3 vibratory velocity: Component of the velocity of the vibrating surface in the direction normal to the surface. The root-mean square (r.m.s.) value of the vibratory velocity is designated by the symbol v.

NOTE — The vibratory displacement is the time integral of the vibratory velocity. The r.m.s. displacement for sinusoidal vibration, s, with frequency f is given by the following equation:

$$s = \frac{v}{2\pi f} \qquad \ldots (1)$$

The vibratory acceleration is the time derivative of the vibratory velocity. The r.m.s. acceleration for sinusoidal vibration, a, with frequency f is given by the following equation:

$$a = 2\pi f v \qquad \ldots (2)$$

1) At present at the stage of draft.