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Acoustics — Characterization of sources of structure-borne sound with respect to sound radiation from connected structures — Measurement of velocity at the contact points of machinery when resiliently mounted

Acoustique — Caractérisation des sources de bruit solidien pour estimer le bruit rayonné par les structures auxquelles elles sont fixées — Mesurage de la vitesse aux points de contact des machines à montage élastique

Reference number
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Foreword

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

International Standard ISO 9611 was prepared by Technical Committee ISO/TC 43, *Acoustics*, Subcommittee SC 1, *Noise*.

Annexes A to D form an integral part of this International Standard. Annexes E to J are for information only.

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Introduction

This International Standard is one of a series of frame documents specifying various methods for the characterization of machines or equipment as sources of structure-borne sound with respect to sound radiation from connected structures.

The application of this International Standard to a certain family of machines needs additional requirements such as, for example, well-defined operating conditions given in a specific test code. This International Standard describes how, at each connection point for a resilient element, six components of the vibration can be measured and gives estimated standard deviations for their measurement uncertainty for frequencies in a given range of frequency. For a specific machine, a family of machines or for a specific application, fewer components may be sufficient to characterize the source, thus the number of components measured could be reduced and the defined frequency range could be appropriately expanded or reduced.

0.1 General considerations

Airborne sound in buildings, ships and vehicles and the underwater sound radiated by ships is very often caused by vibrations of machinery or equipment. In general, such sound is emitted in at least two ways:

a) directly from the outer surface of the machine into surrounding air; measurement methods for its determination are given in the series ISO 3740 to ISO 3747 and in ISO/TR 7849; and

b) from structures connected to the machine; this sound radiation results from structure-borne sound being emitted by the machine into the connected structures such as foundation, pipes, other coupled machines or linked auxiliary equipment.

This International Standard deals according to b) with machines or equipment which are sources of structure-borne sound emission into connected structures with respect to airborne or liquid-borne sound radiation of connected structures.

The measurement and evaluation of machinery vibration with respect to human response, trouble-free operation of coupled or connected machinery, as well as structural fatigue and the lifetime of the machine itself are outside the scope of this International Standard. These fields are covered by International Standards of Technical Committee ISO/TC 108, *Mechanical vibration and shock* (see, for example, ISO 10816-1).

A major problem associated with the measurement of structure-borne sound emission is the choice of the quantities that characterize the "strength" of a source. The complete and fully accurate characterization of a source of structure-borne sound would involve an extremely large number of measurements; thus, one has somehow to trade accuracy against the simplicity of the method. In the context of standardization, emphasis is on simplicity; therefore an attempt has been made to describe the "strength" by a limited number of frequency-dependent quantities.

Simplified source descriptions are possible when the two following assumptions are both satisfied:

a) the connections of the machine with the surrounding structure can be treated as "points"; and

b) there is a considerable mobility mismatch for all degrees of freedom of vibration at the connection points.

In such cases, the sources can be described with a limited number of force spectra if the source has relatively high mobilities, and with a limited number of velocity spectra if the source has relatively low mobilities as compared with the corresponding point mobilities of the receiving structure. An important feature is the fact that, for a certain range of receiving structures, these source descriptions are independent of the precise characteristics of the receiving structure.

For many practical purposes, the resulting source descriptions are still too complicated and a further simplification to one-, two- or three-frequency dependent quantities is necessary. The annexes give guidelines for the selection of circumstances under which further simplifications are possible.

0.2 Specific considerations

This International Standard is one of a series specifying various methods for the characterization of sources of structure-borne sound (i.e. for the characterization of sources of vibrations) in the frequency range of audible sound. It gives a detailed description of a first method of a series[1]. The results of this International Standard may be used for the following purposes:

a) obtaining data for preparing technical specifications;

b) comparing the structure-borne sound emission of resiliently mounted machines of the same type and size;

c) obtaining input data for planning and noise purposes (e.g. input data for the calculation of structure-borne sound transmission through resilient mountings into the connected structure).

The method concerns the measurement of translational and angular velocity levels on the supports and other contact points of a machine which is mounted on resilient mountings (isolators). In the frequency range of the method, the selected isolators, flexible connections and foundation are such that the vibration of the contact point is not significantly affected by their presence. Consequently the results represent the free vibratory velocity levels of the contact points. The method is further restricted by the requirement that a machine support or the contact structure of a machine to another flexible connection can be considered to vibrate as a rigid body. This implies an upper frequency limit.

The direct application of the results is limited by the above restrictions. In spite of these restrictions, there is a large variety of machines for which the method may be valuable. Examples are diesel engines, diesel gener-

1) International Standards describing the other methods and one giving a basic summary are in preparation.

ators, electric motors, compressors, fans, lathes and presses. For most of these machines, it will be possible to apply the method in the frequency range between about 20 Hz and at least 1 kHz, which is the most important frequency range for practical problems of structure-borne sound.

This International Standard describes measurements for all six degrees of freedom, i.e. six components of velocity (three orthogonal translations and three orthogonal rotations) at each contact. For specific machines and specific applications, some of these components can be neglected.

There is significant experience with the method for some types of machines (e.g. diesel generators for shipboard applications) which provides the basis for this International Standard.

This International Standard should be taken as a general document which may be used to define a standard measurement procedure for a specific class of machine. Details about the operational conditions of the machine under test, the type of mounting and foundation to be applied, the vibrational components to be taken into account, the procedure for selecting or averaging data, checks of the test arrangements and the accuracy of the method and the applicability of the results should be given.

The following International Standards were mainly consulted when preparing this International Standard: ISO 1683, ISO 2017, ISO 2041, ISO 5347-1 (and other parts), ISO 5348, ISO 7626-1, ISO 10816-1, IEC 651 and IEC 1260. To a certain extent, this International Standard is a further elaboration of ISO 10816-1, especially with respect to the solution of acoustical problems.

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Acoustics — Characterization of sources of structure-borne sound with respect to sound radiation from connected structures — Measurement of velocity at the contact points of machinery when resiliently mounted

1 Scope

1.1 General

This International Standard specifies an approximate method of characterizing sources of structure-borne sound by the measurement of one-third-octave-band free velocity level spectra (or, if appropriate, octave-band velocity level spectra) on the supports or other connection points of machines mounted on resilient isolators. This structure-borne sound emission is considered with respect to the airborne or liquid-borne sound radiation of structures connected to the source under test. The results are only valid for applications in which the machine is mounted on sufficiently soft isolators on a sufficiently stiff and heavy foundation.

NOTE 1 More conditions are given in annex H. A survey of the theoretical background is given in annex E.

It is possible to satisfy the requirements for the test arrangement in almost any surroundings.

Velocities measured at defined contact points give no complete description of structure-borne sound emission of the machinery. But, under specific conditions as described in this International Standard for resiliently mounted machinery, they give a subset of the source data required for a characterization.

The results can be used

a) to obtain data for technical specifications;

b) for comparison with machines of similar type and size; and

c) to obtain input data for computations on the transfer of structure-borne sound.

1.2 Frequency range

The frequency range for which the method is applicable is limited by a low frequency f_1 and an upper frequency f_2.

The low frequency limit f_1 is set by the requirement that the supports vibrate freely; i.e. they are not affected by the isolators and the foundation structure on which the isolators are mounted. Annex A gives instructions on how to determine f_1.

The upper frequency limit f_2 is determined by assuming that the supports behave as point sources of structure-borne sound. Annex B gives guidelines for the determination of f_2.

NOTES

2 For many machines, isolators can be selected which provide a frequency f_1 between 20 Hz and 40 Hz.

3 Many machines have such a structure that f_2 has a value between 1 kHz and 4 kHz.

1.3 Type of noise

This International Standard applies to steady noise.

1.4 Degrees of freedom

The procedures are described for all six components of the velocity: three orthogonal translational velocities and three orthogonal angular velocities.

If it can be shown that, for a specific machine and a specific application, fewer components are sufficient to characterize the source, then it is permissible to reduce the number of measured components (see annex F).

1.5 Types of connection point

The procedures in this International Standard are described for the main supports of a machine. The method is, however, applicable to other mounting faces at resilient elements such as the flange for a flexible coupling in the shaft of a diesel engine or the connection with pipes. In such cases, the methods for the determination of f_1 and f_2 (see annexes A and B) can be adapted to the unique conditions that apply.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 5348:1987, *Mechanical vibration and shock — Mechanical mounting of accelerometers.*

IEC 651:1979, *Sound level meters.*

IEC 804:1985, *Integrating-averaging sound level meters.*

IEC 1260:1995, *Electroacoustics — Octave-band and fractional-octave-band filters.*

3 Definitions

For the purposes of this International Standard, the following definitions apply.

3.1 structure-borne sound: Vibrations transmitted through solid structures in the frequency range of audible sound.

3.2 contact area: An area through which structure-borne sound is transmitted from the machine to the surrounding structure. (See figure 2.)

3.3 connecting point: A contact area connected to an isolator.

3.4 structure-borne sound point source: A contact area which vibrates as a surface of a rigid body.

3.5 translational velocity level, L_v: Level given by

$$L_v = 10 \lg \frac{v^2}{v_0^2} \quad \text{dB} \qquad \ldots (1)$$

where

v is the r.m.s. value of the vibratory translational velocity, in metres per second, in a specific direction and for a specific frequency band;

v_0 is the reference velocity (5×10^{-8} m/s) [2].

It is expressed in decibels.

3.6 angular velocity level, L_Ω: Level given by

$$L_\Omega = 10 \lg \frac{\Omega^2}{\Omega_0^2} \quad \text{dB} \qquad \ldots (2)$$

where

Ω is the r.m.s. value of the vibratory angular velocity, in radians per second, about a specific axis and for a specific frequency band;

Ω_0 is the reference angular velocity (5×10^{-8} s^{-1}) [2].

It is expressed in decibels.

3.7 repeatability standard deviation, σ_r: The standard deviation of test results obtained under repeatability conditions.

NOTE 4 It is a measure of the dispersion of the distribution of test results under repeatability conditions. (See also ISO 3534-1 and ISO 5725-1.)

3.8 repeatability conditions: Conditions where independent test results are obtained with the same method on an identical test material in the same laboratory/test site by the same operator using the same equipment within short intervals of time. (See also ISO 3534-1 and ISO 5725-1.)

3.9 reproducibility standard deviation, σ_R: The standard deviation of test results obtained under reproducibility conditions.

NOTE 5 It is a measure of the scatter of the distribution of test results under reproducibility conditions. (See also ISO 3534-1 and ISO 5725-1.)

3.10 reproducibility conditions: Conditions where test results are obtained with the same method on an

2) The choice of a reference velocity of 10^{-9} m/s and 10^{-9} s^{-1} for translational or angular velocity, respectively, would result in a translational/angular velocity level 34 dB higher than that level obtained when using 5×10^{-8} m/s and 5×10^{-8} s^{-1}, respectively.

identical test material in different laboratory/test sites with different operators using different equipment. (See also ISO 3534-1 and ISO 5725-1.)

4 Quantities to be measured

The three orthogonal one-third-octave band translational velocity level spectra and the three one-third-octave band orthogonal angular velocity level spectra are measured on each of the machine supports (or, if appropriate, the corresponding octave band spectra) (see figure 1).

5 Test arrangement

5.1 Test surroundings and background noise

The machine is mounted on isolators (see 5.2). For other structural connections which may be necessary, see 5.3. It is possible to locate the test arrangement outlined in figure 1 in any surroundings, for example a manufacturer's workshop, a special test bed, any laboratory space which is sufficiently large, and *in situ*. It is essential that the velocity levels of the supports induced by other sources are at least 10 dB lower than the levels induced by the machine under test. Furthermore, it is essential that the velocity levels of the supports are not affected by airborne sound which is radiated by the machine under test. See also annex D.

NOTE 6 Small, rigid machines (e.g. electric motors up to 10 kW) can also be tested while suspended in such a way that the machine can operate and the machine supports are not mechanically loaded; f_1 can be very low in such an arrangement.

5.2 Isolators and foundation

The isolators shall be flexible mountings capable of supporting the machine in a proper way. The dynamic characteristics of the isolators shall be such that the lower limiting frequency f_1 is sufficiently low (see clause 7 and annex A), and that no significant transmission of structure-borne sound to the foundation occurs at frequencies above f_1. The isolator shall be mounted on a low-mobility foundation.

NOTE 7 In general, these conditions can best be satisfied with soft rubber mountings or air springs. Soft metal isolators with rubber pads at the contact planes are also suitable. More background information regarding the choice of isolators is presented in annex G.

The flanges of the isolators at the side of the machine shall not significantly increase the mass or the stiffness of the feet of the machine.

NOTE 8 More specific guidelines should be given in machinery-specific documents.

Over the frequency range of the method, the foundation for the isolators shall be so heavy and stiff that the combination of isolators and foundation does not give a significant dynamic loading of the machine supports (see also 7.1 and annex G).

5.3 Other structural connections between the machine and the test surroundings

In many cases, machines require connections to be made to their surroundings (e.g. pipes, shafts, cables or secondary supports). These connections shall have flexible elements so that they result in either no increase or only a very slight increase in the lowest natural frequencies of the system consisting of the mass of the machine and the stiffness of the main isolator.

Further information about "flanking paths" is given in annex D.

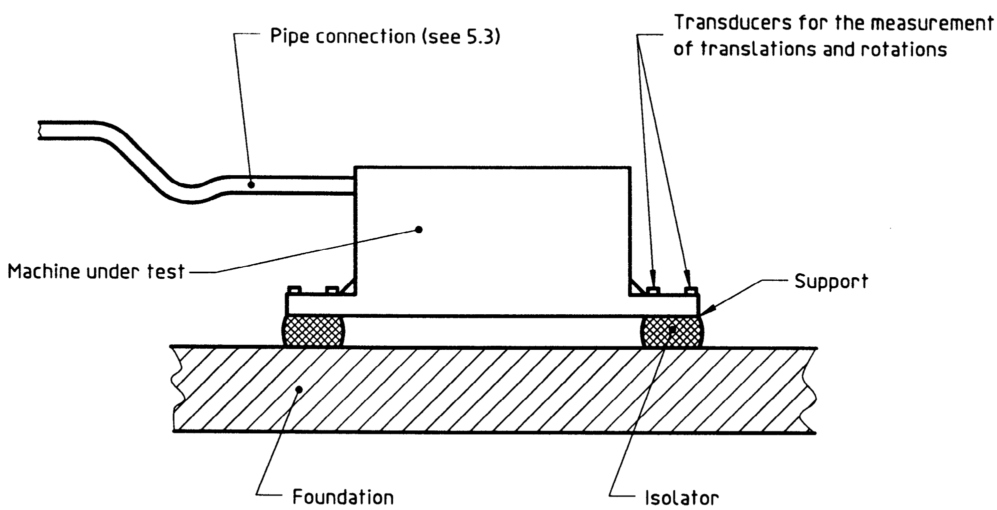

Figure 1 — Test arrangement

5.4 Position and orientation of vibration

5.4.1 Recommended arrangement

It is recommended that the translational and the angular velocity of the machine supports be measured with the aid of accelerometer pairs.

For the measurement of L_{vz} and $L_{\Omega y}$, the accelerometers shall either be mounted as shown in figure 2 or, if there is insufficient space alongside the isolator, the accelerometers shall be mounted at positions as indicated in figure 3. The distance between the two accelerometers shall not be smaller than $0{,}5D_x$ and not larger than $1{,}5D_x$, where D_x is the width of the contact area in the x-direction. The orthogonal coordinates shall be as follows: z is normal to the contact area, and y is parallel to the length axis of the machines. In all cases the accelerometers shall be placed at symmetrical positions referred to as A in figures 2 and 3; A is the geometric centre of the support (i.e. the area in contact with the isolator).

For the determination of $L_{\Omega x}$, use a set of accelerometers with the same orientation at similar positions as shown in figures 2 and 3, but rotated by 90° around the z-axis.

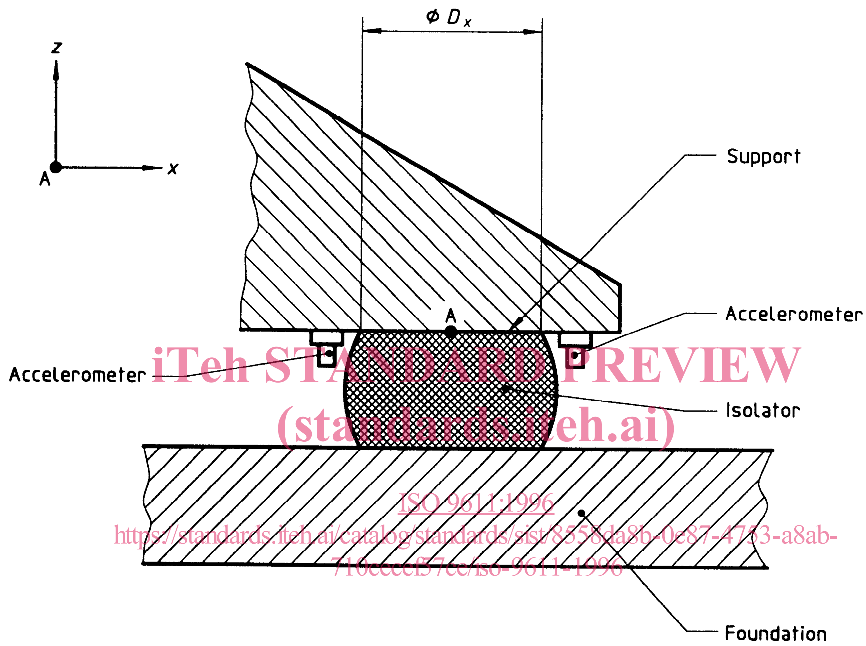

Figure 2 — Position of the accelerometers for measurement of L_{vz} and $L_{\Omega y}$

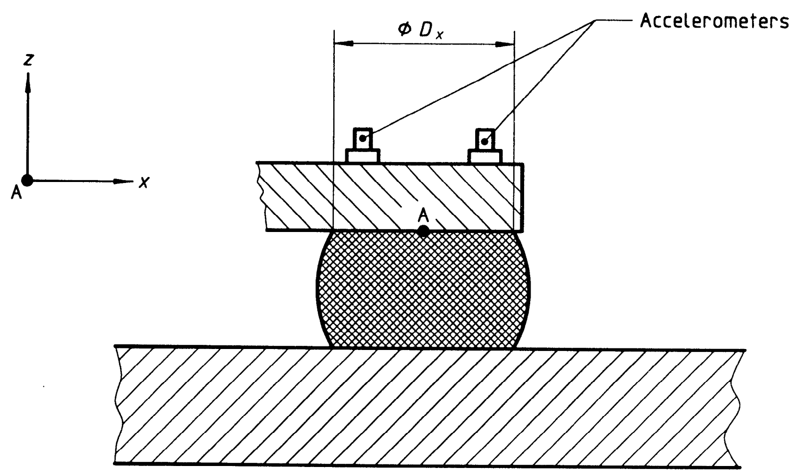

Figure 3 — Position of the accelerometers for measurement of L_{vz} and $L_{\Omega y}$ when there is no space alongside the isolator and the machinery foot has a surface parallel to the mounting face of the isolator

For the measurement of L_{vx} and L_{vy}, orient pairs of accelerometers in the x- and y-directions, respectively. Position the accelerometers so that they are either

a) symmetrically positioned about A at distances between $0{,}25D_x$ and $0{,}75D_x$ or $0{,}25D_y$ and $0{,}75D_y$ from A or, if this is not possible,

b) in the position shown in figure 3.

The accelerometer pairs which are suitable for the measurement of L_{vx} and L_{vy} can also be used for the measurement of $L_{\Omega z}$.

In cases where the centres of sensitivity of the accelerometers are not mounted on a line through A, some of the translational components are not measured correctly and it is necessary to apply corrections as indicated in annex C.

The accelerometers shall be attached to the support structure by methods which are in accordance with ISO 5348.

5.4.2 Alternative arrangement

Under certain conditions it is allowable to measure the vibration components of the support with the aid of one vibration sensor. These conditions are different for the different components.

L_{vz} may be measured with the aid of one translational vibration sensor positioned on top of the support structure, provided that the following conditions are satisfied (see also figure 4):

$$h < \frac{1}{5} D_x \quad \text{and} \quad h < \frac{1}{5} D_y$$

$$x < \frac{1}{20} D_x$$

$$y < \frac{1}{20} D_y$$

L_{vy} may be measured with one translational vibration sensor provided that is positioned at one of the three areas shown in figure 5.

Position 1 is on or near the z-axis on top of the support structure. The conditions are as follows:

$$h < \frac{1}{20} D_x \quad \text{and} \quad z_1 < \frac{1}{20} D_y$$

$$y_1 < \frac{1}{10} D_y$$

$$x_1 < \frac{1}{10} D_x$$

Position 2 is at the side of the support structure. The conditions are as follows:

$$h > \frac{1}{10} D_y$$

$$y_2 < D_y$$

$$z_2 < \frac{1}{20} D_y$$

Position 3 is at the side of the mounting flange of the isolator. The condition is as follows:

$$-z_3 < \frac{1}{20} D_y$$

The conditions for the measurement of L_{vx} with one sensor are similar to those for L_{vy} (replace above every y by x and every x by y).

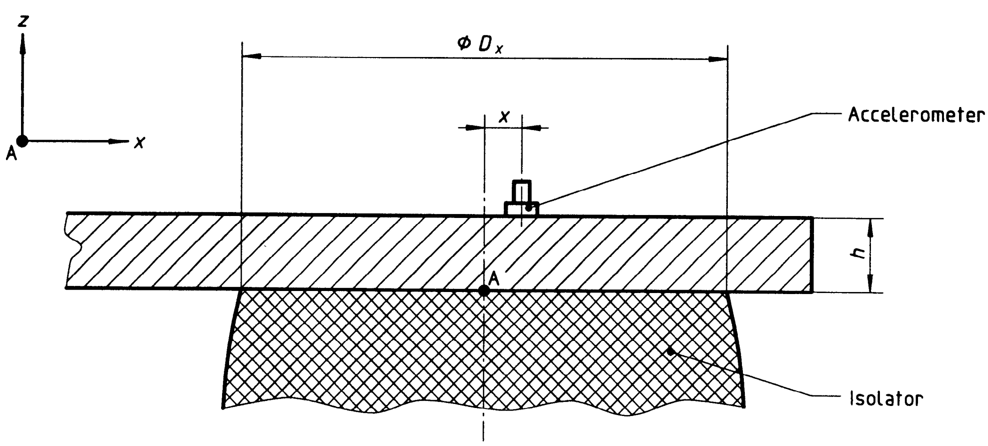

Figure 4 — Location of the sensor for measurement of L_{vz}