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Reciprocating internal combustion engines — Test code for the measurement of structure-borne noise emitted from high-speed and medium-speed reciprocating internal combustion engines measured at the engine feet

Moteurs alternatifs à combustion interne — Code d'essai pour le mesurage du bruit solidien émis par les moteurs alternatifs à combustion interne à vitesse élevée et moyenne, mesuré aux pieds du moteur

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

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.

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

International Standard ISO 13332 was prepared by Technical Committee ISO/TC 70, *Internal combustion engines*.

Annex A of this International Standard is for information only.

Introduction

Noise in buildings, structures, ships, aircraft and land vehicles often arises from the use of internal combustion engines, particularly reciprocating engines, and there may be situations where these are the dominant noise source. Even where it is not dominant, it may form an unwelcome background noise. These noises, arising within the building, etc., can be transmitted in at least two ways as given below.

a) Directly into the surrounding air. This is called airborne sound and ISO 6798 specifies methods for determining the airborne noise output of internal combustion engines.

b) Through excitation or vibration in the supporting structure, pipes and shafts. These vibrations then pass through the structure as structural vibration, exciting in turn the walls and panels of the structure, resulting in the radiation of so-called secondary sound or structure-borne noise.

The ability of the source of vibration (the engine) to generate vibration in the structure in which it is mounted depends on the amount of motion of the engine at its mounting points, the properties of the engine mounting system and the mobility of the receiving structure. Vibration from the engine feet may be in the vertical sense, which is the one most easily visualised, but may also be longitudinal or transverse with respect to the crankshaft axis. The vibration source may also cause rotational input, resolved about each of the three orthogonal axes.

The passage through the structure of any vibration which has been caused in it can be very difficult to control, particularly at low frequencies. There are many possible modes of vibration of the structure which could be responsible for the transmission (compression, torsional or flexural modes). Only breaks in the continuity of the structure are likely to be completely effective, and this is not usually possible. Damping of the structure may be effective for some propagation modes, particularly at high frequencies/short wavelengths, but will not be sufficiently effective at low frequencies.

In spite of the difficulties in controlling the propagation of vibration within the structure, there are obvious benefits in knowing the characteristics of the engine as a potential vibration source so that a choice may be made amongst various competing mounting engines, or the structure and engine mounts can be designed to comply with the properties of the engine selected.

Reciprocating internal combustion engines — Test code for the measurement of structure-borne noise emitted from high-speed and medium-speed reciprocating internal combustion engines measured at the engine feet

1 Scope

This International Standard defines the procedure for measuring the capacity of a high-speed or medium-speed engine to generate vibration and the determination of the frequency limits of validity of the information quoted. The method described in this International Standard is not suitable for low-speed engines. This International Standard describes an engineering and not a precision method. Whether the tests are carried out on the test bed or on site shall be agreed between the user and the manufacturer.

This International Standard applies to high-speed and medium-speed reciprocating internal combustion engines for land, rail traction and marine use, excluding engines used to propel agricultural tractors, road vehicles and aircraft. This International Standard may be applied to engines used to propel road-construction and earth-moving machines, industrial trucks and for other applications where no suitable International Standard for these engines exists.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 1503:1977, *Geometrical orientation and direction of movements.*

ISO 2954:1975, *Mechanical vibration of rotating and reciprocating machinery — Requirements for instruments for measuring vibration severity.*

ISO 3046-1:—[1)], *Reciprocating internal combustion engines — Performance — Part 1: Declarations of power, fuel and lubricating oil consumptions, and test methods — Additional requirements.*

ISO 3046-3:1989, *Reciprocating internal combustion engines — Performance — Part 3: Test measurements.*

ISO 3046-7:1995, *Reciprocating internal combustion engines — Performance — Part 7: Codes for engine power.*

ISO 9611:1996, *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.*

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1) To be published. (Revision of ISO 3046-1:1995)

3 Terms and definitions

For the purposes of this International Standard, the following terms and definition apply.

3.1
structure-borne noise
vibration transmitted through solid structures in the frequency range of audible sound

3.2
contact area
area of engine supports in contact with the surrounding structure, in particular rubber mounts

[Figures 3 and 4]

4 Symbols

Symbols and units used in this International Standard are listed in Table1.

Table 1 — Symbols with their designations and units

Symbol	Designation	Unit
d	thickness of the engine foot plate	mm
d_{y1}	distance of the accelerometer from position 1 in the transverse direction	mm
D_x	dimension of the isolator in longitudinal direction	mm
D_y	dimension of the isolator in transverse direction	mm
f_0	the highest rigid-body natural frequency of the engine on its mounts	Hz
f_1	lower frequency limit	Hz
f_2	upper frequency limit	Hz
L_{vxi}	velocity level in longitudinal direction at position i	dB
L_{vyi}	velocity level in transverse direction at position i	dB
L_{vzi}	velocity level in vertical direction at position i	dB
$\bar{L}_{vx}$	mean velocity level in longitudinal direction	dB
$\bar{L}_{vy}$	mean velocity level in transverse direction	dB
$\bar{L}_{vz}$	mean velocity level in vertical direction	dB
n	number of engine mounts	1
$\bar{v}_z$	arithmetic mean of velocities v_{1z} and v_{2z}	m/s
v_{1z}	velocity at position 1z	m/s
v_{2z}	velocity at position 2z	m/s
X	longitudinal direction	–
Y	transverse direction	–
Z	vertical direction	–

5 Technical background

On the basis of information currently available, the requirement of this International Standard is for translation measurements of mount vibration only[2], in three orthogonal directions. This requirement is based partly on the results of recent calculations and early measurements which suggest that rotational input is a secondary effect.

The essence of the method is to determine the amount of vibration (in three orthogonal directions) which would occur at the mounting feet of an engine, where they have to be supported by a flexible mounting system which provides negligible restriction to their motion.

The vibration measurements will be in the three orthogonal axes with respect to the engine defined in clause 4 of ISO 1503:1977.

NOTE In addition, the knowledge of structure-borne noise levels of a reciprocating internal combustion engine enables comparison and calculation of the vibration input into a mounting system, provided that the source (engine), mounting system and load (receiving structure) impedances are known.

In practice, the vibration generated will be a function of frequency, and it will not be possible to provide a mounting system which will be suitable, or which will allow the engine's vibration performance to be assessed, over the whole range of frequencies.

6 Test conditions

6.1 Mounting

During the taking of measurements, the engine under investigation shall be supported on appropriate mounts, be provided with the required services (air, fuel, exhaust, coolant, lubricant, electrical supply) and also be equipped with a load system to absorb the power developed. The provision of these services shall be by means of flexible connectors which do not significantly influence the vibration of the engine. The engine shall be tested with its standard flywheel, and with a sufficient bend and torsional coupling to the load. The type and characteristics of the flexible coupling arrangement shall be declared in the test report.

6.2 Mounting conditions

Mounting systems for diesel engines can vary widely, depending on weight, power and application. Whilst the supports for the engine feet are commonly resilient for high-speed and medium-speed engines, these mountings may not always be suitable for effective assessment of the structure-borne noise emission from the particular engine being measured.

NOTE In order that the assessment be carried out to a frequency (f_1) as low as is necessary, the following characteristics of the mounting system should be observed if at all possible:

1) the resilient elements should be mounted on a massive, rigid foundation;

2) f_0 should be as low as practically possible.

Practical limits can be set for f_0 however, both by the known characteristics of the human ear, and the fundamental properties of the engine firing cycle (2-/4-stroke cycle).

2) There may be, nevertheless, a requirement for rotational vibration input to be assessed in particular instances to be agreed between customer and manufacturer. This is recognized to be a particularly difficult measurement. Rotational measurements are not covered in this International Standard. Rotational-vibration measurement should be carried out in accordance with ISO 9611.

6.3 Engine operating conditions

The operating conditions for measurement of structure-borne noise, rated speed and 100 % load, in accordance with ISO 3046-1 and ISO 3046-7, shall be defined by the manufacturer. Other operating points may be agreed upon between the customer and the manufacturer.

During the course of the measurements, the engine output shall not deviate more than 10 % from the declared or other agreed engine output. The engine shall run under steady-state conditions.

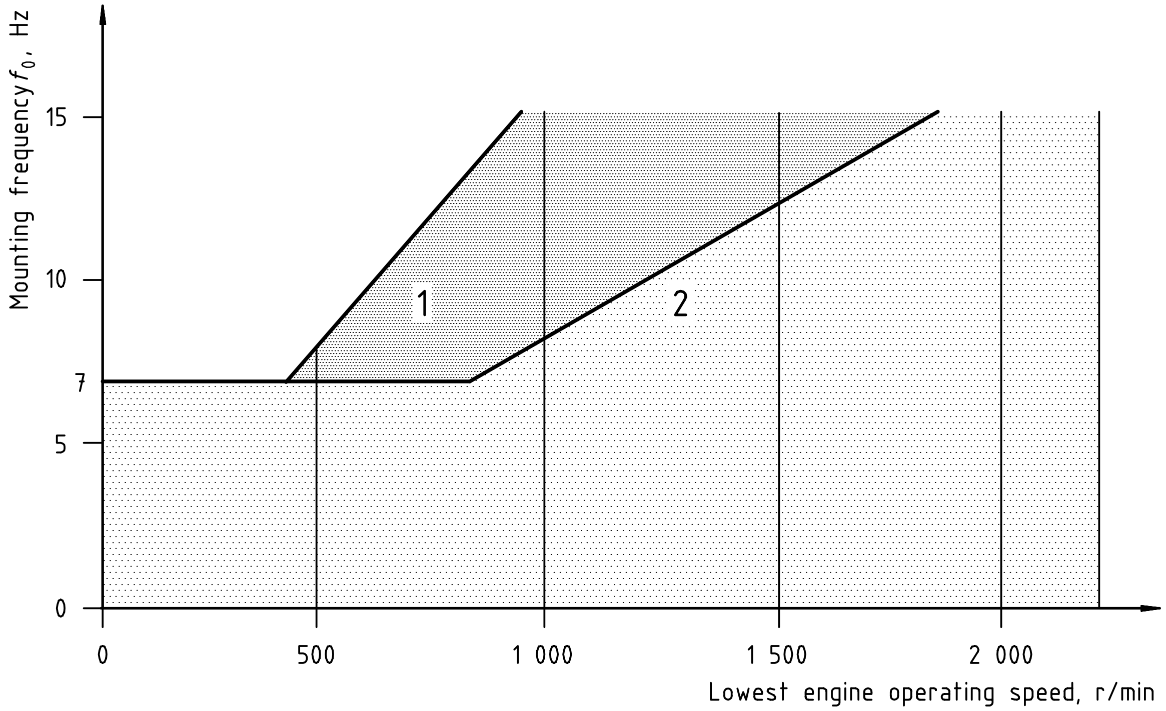
The measurement of engine speed and power shall be in accordance with ISO 3046-1 and ISO 3046-3 and shall be documented in the test report.

7 Frequency range

The lowest frequency which the human ear is usually assumed to be able to hear is around 20 Hz. Measurements below this frequency are not important from the point of view of structure-borne noise, and vibration isolation of the engine feet is not required below this frequency. Thus, the highest natural frequency of the engine on its mounts (f_0) may be – but does not have to be – lower than 7 Hz. There may be situations in which the isolation can be limited to higher frequencies, recognizing that the lowest frequency which a 2-stroke engine is capable of exciting, is the crankshaft rotational speed, whilst the lowest frequency for a 4-stroke engine is one-half of the crankshaft speed.

The natural frequency (f_0) of the mounting system required for the test to be carried out to a satisfactory lower limit can thus be determined from Figure 1, relating f_0 to the lowest service speed of the engine, which should lie on or below the appropriate curve.

NOTE If the parties involved agree, the natural frequency (f_0) of the mounting system may be above the line in the diagram.



Key

1 For 2-stroke engines

2 For 4-stroke engines

NOTE f_0 lies in the lower hatched zone, but may be close to its upper boundary

Figure 1 — Relationship between mounting-system resonant frequency (f_0) and lowest engine speed

The lowest frequency limit (f_1) at which reliable determination of structure-borne noise can be carried out is about $3 \times f_0$. This ensures that no dynamic amplification of the measured values occur due to resonance at the natural frequencies of the mounting system.

In order that the upper frequency limit for reliable measurements (f_2) is as high as possible, the mounting feet on the engine shall be as rigid as possible.

It shall be recognized that there may be regions in the frequency range between f_1 and f_2 where the mounts do not provide sufficient (>10 dB) isolation.

In order that the true characteristic vibration of the engine foot be determined, the mass and stiffness of the foot in the test mounting (including the mounting flange of the test mount) shall be the same as the mass and stiffness of the foot and flange combination used in service, i.e., the same foot and mount shall be used for both test and service.

The lowest frequency limit (f_1) shall be determined by the characteristics of the mounting system. The lowest frequency limit (f_1) is the frequency below which measurement is not considered reliable. It is the frequency below which the vibration attenuation provided by the mounting system for the mount/foot in question and the direction of motion under consideration is less than 10 dB. It is because of the difficulty in providing suitable resilient mounts that this method cannot be applied to low-speed engines.

The upper frequency limit (f_2) is the frequency above which that part of the mounting foot in contact with the resilient element develops its first vibration mode. When this happens, the accelerometers used for measurement cannot describe reliably the mean motion of the foot.

NOTE The frequency-measuring range may exceed the value of f_2 because the frequency range of audible sound in most cases far exceeds the upper frequency limit (f_2). Furthermore, it is important to know the behaviour of structure-borne noise up to 10 kHz. In such cases, the user should be aware that the measurements are performed at frequencies of higher modes of the engine foot.

8 Principle of measurement

The measurement principle may be understood by referring to Figure 2. Figure 2 a) illustrates installation of the engine under assessment on a mounting system which is known to be suitable for the test. The isolator shall be soft enough to meet the requirement that – at all frequencies investigated – it does not significantly restrict vibratory motion of the engine foot.

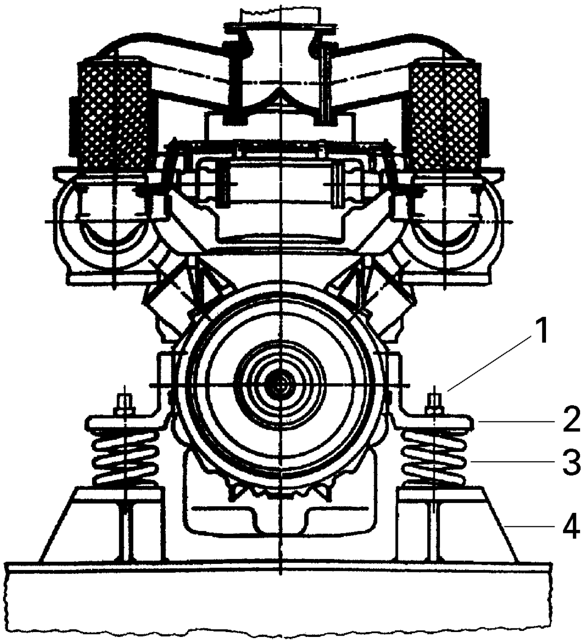
This will be assured if the lowest frequency limit (f_1) is equal to or greater than three times the highest natural frequency of the engine as a rigid body (f_0). The necessary value for f_0 is discussed in clause 7.

Figure 2 b) shows a detail of the mounting foot with suitable accelerometers attached to it. The accelerometer shall be positioned immediately above the effective centre of the mount under investigation, or as close to it as possible. The accelerometer shall be mounted and connected in accordance with ISO 2954. Special attention must be paid to the necessary rigidity of the accelerometer mounting and the type of cable connecting the accelerometer to the recording/analysis equipment.

Where it is not possible to attach a single accelerometer at the centre on the upper surface of the engine mounting foot, a pair of accelerometers equally spaced either side of the centre shall be used, and the average of their respective outputs noted. These accelerometers shall nevertheless be attached as close to the centre of the mount as possible.

The upper frequency limit (f_2) is the frequency at which modes of vibration develop within the surface supported by the isolator, so that the system can no longer be regarded as a rigid body as f_2 represents a local mode. This frequency shall be determined by means of a subsidiary investigation in order to find the first mode of vibration within the surface supported by the isolator. A simple hammer-tap input to the foot may be sufficient, using the installed accelerometers to measure the response. This may be replaced or supplemented by appropriate modal analysis.

Although this clause has considered vertical vibration in the example, similar considerations apply to the other directions of motion, which can also be assessed using appropriately placed accelerometers.



Key

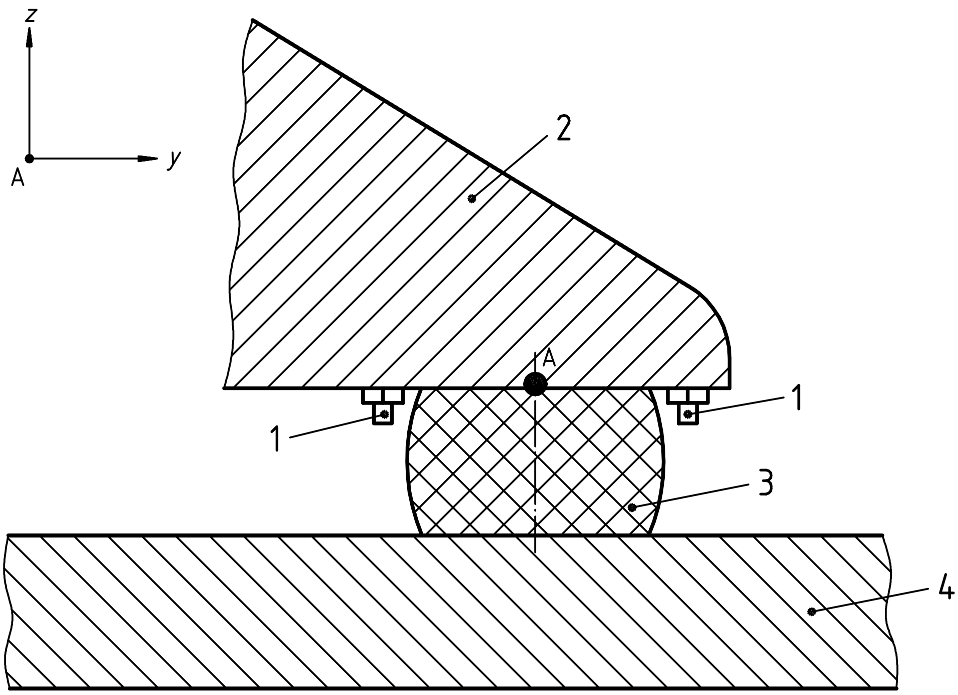
1 Accelerometer for the measurement of translational vibrations

2 Foot

3 Isolator

4 Foundation

a) Engine arrangement



Key

1 Alternative accelerometer positions

2 Foot

3 Isolator

4 Mounting flange of the isolator

b) Foot arrangement

Figure 2 — Principle of the test arrangement

9 Mount selection

In order to keep the investigation manageable, the mounts to be measured shall be chosen according to the following:

— up to four mounts on the engine: all mounts to be measured;

— five to eight mounts on the engine: the four mounts furthest apart to be measured;

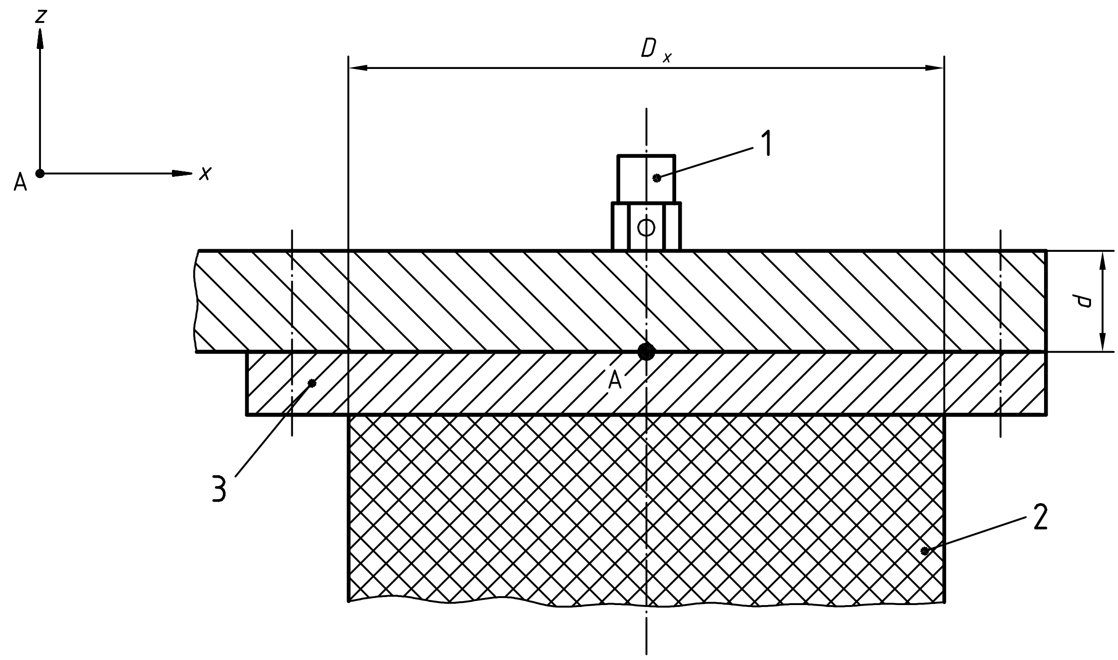
— nine or more mounts on the engine: the four mounts furthest apart, together with the two mounts closest to the centre of gravity to be measured;

— for an engine which has a continuous side mounting flange, the above guidance shall be applied to the array of positions at which discrete mounts are attached.

Tests on additional mounts may be included by agreement between the customer and manufacturer, particularly in cases where the engine is permanently coupled to other equipment.

10 Measurement positions

The accelerometer shall be mounted on the engine foot above the centre of the isolator contact area as shown in Figures 3 and 4.



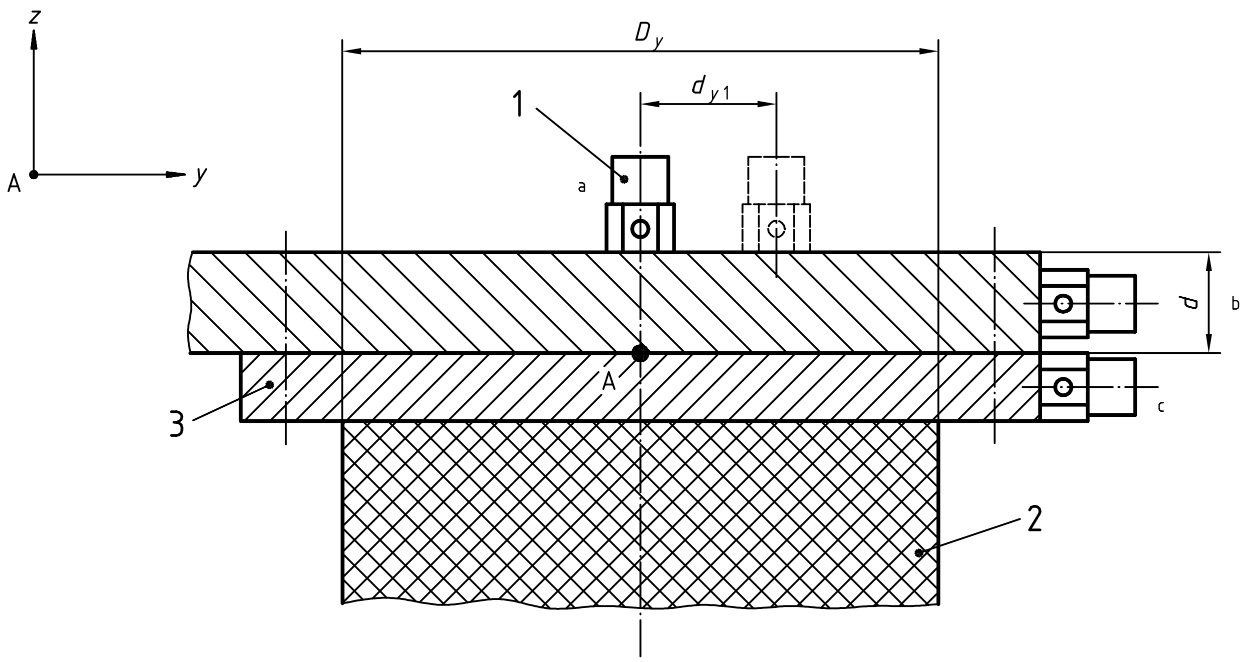
Key

1 Accelerometer

2 Isolator

3 Mounting flange of the isolator

Figure 3 — Location of the accelerometer for measurement of L_{vz}



Key

1 Accelerometer
2 Isolator
3 Mounting flange of the isolator

[a] Position 1
[b] Position 2
[c] Position 3

Figure 4 — Location of the accelerometer for measurement of $\overline{L}_{vz}$ (position 1) and possible locations of accelerometer for measurement of $\overline{L}_{vy}$ (position 2 or 3)

In practice, as there are often bolts or motion limiters located on the engine foot above the centre of the contact area, it is not always possible to mount the accelerometer exactly at the centre. In this case, the accelerometer shall be positioned as follows:

— on the x-axis within the dimension D_x

— on the y-axis within the distance d_{y1} where d_{y1} < 1/10 D_y

To obtain exact measurement results over the entire frequency range, the accelerometers shall be in firm contact with the surface on which the structure-borne noise is to be measured. For this purpose, three possible installation methods are recommended:

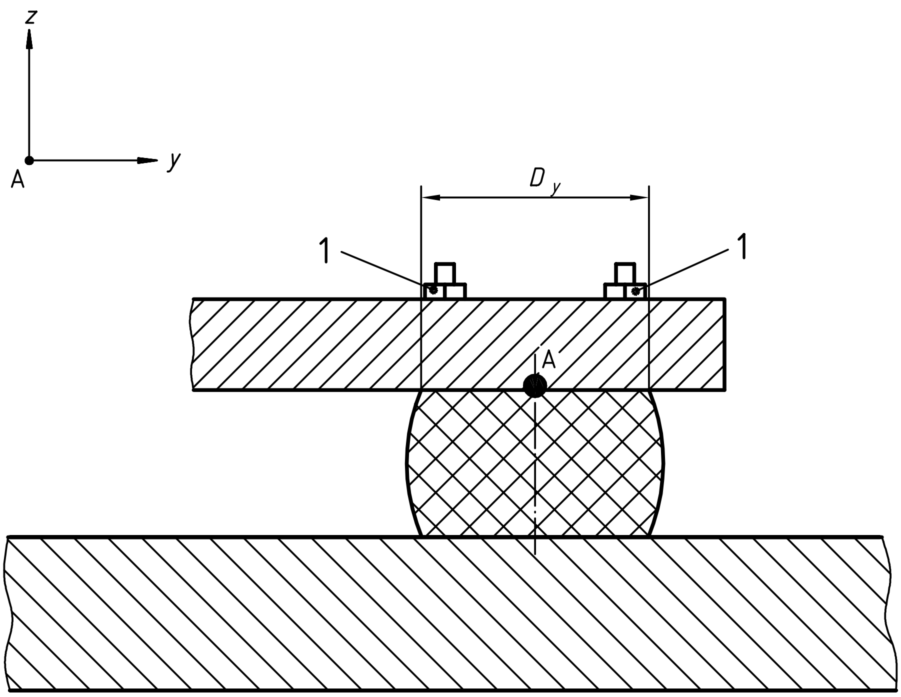
a) the accelerometer is bolted directly to the surface;

b) using a two-component epoxy adhesive, the accelerometer is glued directly to the surface;

c) the accelerometer is bolted to a metal adapter plate, which can either be glued or bolted to the surface.

NOTE Structure-borne noise in all three directions may also be measured with a combination "Triax" accelerometer which is able to measure all three directions at once.

If it is not possible to position an accelerometer within the distance d_{y1}, two accelerometers shall be used, positioned as shown in Figures 5 and 6. The translational velocity (v_z) is then the arithmetic mean of velocities v_{1z} and v_{2z} in accordance with ISO 9611. Both accelerometers shall have the same sensitivity and phase-frequency characteristics. For measurement of the transverse direction, it is also possible to attach the accelerometer at either position 1, 2 or 3 of Figure 4.

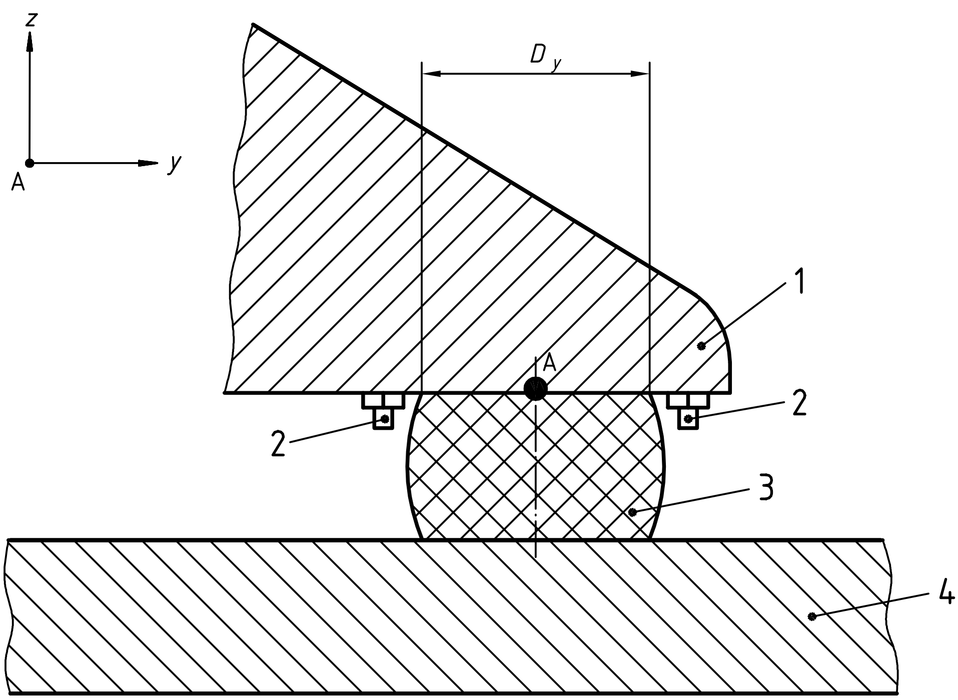


Key

1 Accelerometers

$\bar{v}_z = \frac{v_{1z} + v_{2z}}{2}$

Figure 5 — Location of two accelerometers for measurement of $\bar{L}_{vz}$



Key

1	Support	3	Isolator
2	Accelerometer	4	Foundation

Figure 6 — Location of two accelerometers for measurement of $\bar{L}_{vz}$ if it is not possible to mount them at right angles to the engine foot above the centre of the contact area

The accelerometer shall always be mounted at right angles to the engine-foot contact area, even if the mounting flange of the isolator is not horizontal.

11 Measurement and assessment

The test requirements are as follows.

a) Calibration of the measuring equipment.

b) Measurement of the background noise.

c) Measurement in the three orthogonal/coordinate axes as described in ISO 1503 within at least the range of frequencies from f_1 to f_2, on each axis and for each type of foot. The steps needed are as follows:

   1) determination of f_0[3];

   2) derivation of f_1;

   3) determination of f_2 for each foot to be measured, in each coordinate axis;

   4) measurement and analysis (or recording and subsequent analysis) of the vibration from each foot measured in each coordinate direction with the engine running under steady-state conditions and at the specified operating parameters;

   5) analysis in octave or 1/3-octave band frequency spectra for each case measured;

   6) display of one graph per assessed foot overlaying, but nevertheless clearly identifying the measured octave or 1/3-octave band spectra for each measurement direction (dB 10^{-9} m/s)[4] over the range of octave or 1/3-octave bands measured. The frequencies f_1 and f_2 shall be clearly identified on the graph as the range of reliable measurement;

   7) one graph per measurement direction, over all of the points measured, showing the mean velocity level, together with the maximum and minimum values in each octave or 1/3-octave band.

All of the required information shall be included in a test report as shown in annex A.

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3) f_0 can either be measured or calculated. If f_0 is calculated, the dynamic stiffness should be used. If f_0 is measured, the engine can either be running or stopped.

4) Using a reference level of 5×10^{-8} m/s will result in levels which are 34 dB lower than using a reference level of 10^{-9} m/s.

Annex A
(informative)

Engines — Structure-borne noise characterization — Test report form

A.1 Administrative Information

Measurements carried out by: (company/clause/persons)

on: (date)

in: (location)

Measurement purpose: (standard characterization)

Supervisory company: (if required by customer)

Engine supplier:

A.2 General information about installation

A.2.1 Engine

Manufacturer:

Method of operation: (2- or 4-stroke)

Model designation:

Serial number:

Rated speed (r/min):

Rated power (kW):

Fuel characteristics: (cetane number, viscosity, etc.)

Mass of engine: (as measured)

Analysis sheet: (yes/no)
(to cover special conditions if agreed upon)

A 2.2 Driven equipment

Flexible coupling

Type:

Manufacturer:

Model:

Intermediate shaft

Type:

Manufacturer:

Model:

Machinery

Type: (dynamometer, generator, compressor, gearbox, etc.)

Manufacturer:

Model:

A 2.3 Engine resilient mounting

Type of feet: (individual/continuous)

Mounts

Manufacturer:

Type:

Number:

Arrangement: (illustrate with a sketch or photograph)

Type of foundation:

Total sprung mass: (with fluids, mounting equipment, etc.)

Record calculated (or measured) values of the three translational natural frequencies of the resiliently mounted engine as a rigid body on its mounts (in some cases it may be necessary to determine all six natural frequencies).

A.3 Measurement

A 3.1 Parameter for assessment

Either rms velocity or rms acceleration:

A 3.2 Measuring equipment

Sensors: (manufacturer/model)

Signal-conditioning system: (manufacturer/model)

Recording equipment: (manufacturer/model, recording mode/frequency range)

Analysis equipment: (manufacturer/model)

Sensor calibration: (unit, e.g. 1 g)

Averaging time: (signal conditioning)

A 3.3 Units and frequency range

To be presented as rms velocities in octave or 1/3-octave band frequency spectra expressed in dB 10^{-9} m/s or 5×10^{-8} m/s. For special investigations, it may be necessary to present narrow-band analyses.

A 3.4 Definition of measurement points

Total number of feet:

Total feet measured:

Location: (illustrated by sketch)

General location on the engine:

Exact sensor positions:

Measurement directions: (defined according to a reference direction illustrated by sketch)

A.4 Results

For each set of engine operating parameters at which measurements are made, the following information shall be presented.

Table of engine operating parameters

Power: (kW)

Speed: (r/min)

Flexible coupling model: (if different from A.2.2)

Table of structure-borne noise levels according to A.3.3 at all points for which measurements were recorded; state whether: dB 10^{-9} m/s or 5×10^{-8} m/s was measured.

One graph per measuring point with the velocity spectra according to A.3.3 and A.3.4, corresponding to the directions in which measurement was made, all overlaid on the same sheet.

One graph for each measuring direction, over all of the feet measured, displaying the mean translational velocity level $\overline{L}_{vx}$, $\overline{L}_{vy}$ and $\overline{L}_{vz}$ in decibels for the particular directions:

$$\overline{L}_{vx} = 10 \log \left(\frac{1}{n} \sum_{i=1}^{n} 10^{\frac{Lvxi}{10}} \right)$$

$$\overline{L}_{vy} = 10 \log \left(\frac{1}{n} \sum_{i=1}^{n} 10^{\frac{Lvyi}{10}} \right)$$

$$\overline{L}_{vz} = 10 \log \left(\frac{1}{n} \sum_{i=1}^{n} 10^{\frac{Lvzi}{10}} \right)$$

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