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Rolling bearings — Measuring methods for vibration —

Part 1: **Fundamentals**

Roulements — Méthodes de mesurage des vibrations —

Partie 1: Principes fondamentaux

Reference number
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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 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.

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 15242-1 was prepared by Technical Committee ISO/TC 4, *Rolling bearings*.

ISO 15242 consists of the following parts, under the general title *Rolling bearings — Measuring methods for vibration*:

— *Part 1: Fundamentals*

— *Part 2: Radial ball bearings with cylindrical bore and outside surface*

— *Part 3: Radial double-row spherical and tapered roller bearings with cylindrical bore and outside surface*

Introduction

Vibration in rotating rolling bearings can be of importance as an operating characteristic of such bearings. The vibration can affect the performance of the mechanical system incorporating the bearing and can result in audible noise when the vibration is transmitted to the environment in which the mechanical system operates.

Vibration of rotating rolling bearings is a complex physical phenomenon dependent on the conditions of operation. Measuring the vibration output of an individual bearing under a certain set of conditions does not necessarily characterize the vibration output under a different set of conditions or when the bearing becomes part of a larger assembly. Assessment of the audible sound generated by the mechanical system incorporating the bearing is complicated further by the influence of the interface conditions, the location and orientation of the sensing device, and the acoustical environment in which the system operates. Assessment of airborne noise, which for the purpose of this document can be defined as any disagreeable and undesired sound, is further complicated by the subjective nature of the terms *disagreeable* and *undesired*. Structure-borne vibration can be considered the driving mechanism that ultimately results in the generation of airborne noise. Only selected methods for the measurement of the structure-borne vibration of rotating rolling bearings are addressed in the current edition of ISO 15242.

This part of ISO 15242 serves to define and specify the physical quantities measured and the general test conditions and environment utilized in the measurement of vibration generated by rolling bearings on a test rig. Based on this part of ISO 15242, parties to the acceptance inspection of rolling bearings may, by agreement, establish acceptance criteria with which to control bearing vibration.

Vibration of rotating rolling bearings can be assessed by any of a number of means using various types of transducers and test conditions. No simple set of values characterizing the vibration of a bearing is adequate for the evaluation of the vibratory performance in all possible applications. Ultimately, a knowledge of the type of bearing, its application and the purpose of the vibration testing (e.g., as a manufacturing process diagnostic or an assessment of product quality) is required to select the most suitable method for testing. The field of application for standards on bearing vibration is, therefore, not universal. However, certain methods have established a wide enough level of application to be considered as standard methods for the purposes of this part of ISO 15242.

This part of ISO 15242 serves to define the general principles involved in vibration measurement. It is intended that further parts will specify in more detail the methods for assessing vibration of different types of bearings with cylindrical bore and outside surface.

Rolling bearings — Measuring methods for vibration —

Part 1: **Fundamentals**

1 Scope

This part of ISO 15242 specifies measuring methods for vibration of rotating rolling bearings under established test conditions, together with calibration of the related measuring systems.

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 286-2, *ISO system of limits and fits — Part 2: Tables of standard tolerance grades and limit deviations for holes and shafts*

ISO 554, *Standard atmospheres for conditioning and/or testing — Specifications*

ISO 558, *Conditioning and testing — Standard atmospheres — Definitions*

ISO 1132-1, *Rolling bearings — Tolerances — Part 1: Terms and definitions*

ISO 2041, *Vibration and shock — Vocabulary*

ISO 3205, *Preferred test temperatures*

ISO 3448, *Industrial liquid lubricants — ISO viscosity classification*

ISO 5593, *Rolling bearings — Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 1132-1, ISO 2041, ISO 5593 and the following apply.

3.1
error motion
undesired radial or axial (translational) motion or tilt (angular) motion of an axis of rotation, excluding motions due to changes of temperature or externally applied load

3.2
stiffness
ratio of change of force (or torque) to the corresponding change in translational (or rotational) displacement of an elastic element

3.3
vibration
variation with time of the magnitude of a quantity which is descriptive of the motion or position of a mechanical system, when the magnitude is alternately greater and smaller than some average value or reference

3.4
transducer
device designed to receive energy from one system and supply energy, of either the same or of a different kind, to another system in such a manner that the desired characteristics of the input energy appear at the output

3.5
electromechanical pickup
transducer which is actuated by energy from a mechanical system (strain, force, motion, etc.), and supplies energy to an electrical system, or vice versa

NOTE The principal types of transducers used in vibration and shock measurement are

a) piezoelectric accelerometer;

b) piezoresistive accelerometer;

c) strain-gauge type accelerometer;

d) variable-resistance transducer;

e) electrostatic (capacitor/condenser) transducer;

f) bonded-wire (foil) strain-gauge;

g) variable-reluctance transducer;

h) magnetostriction transducer;

i) moving-conductor transducer;

j) moving-coil transducer;

k) induction transducer.

3.6
displacement
vector quantity that specifies the change of position of a body, or particle, with respect to a reference frame

3.7
velocity
vector quantity that specifies the time-derivative of displacement

3.8
acceleration
vector quantity that specifies the time-derivative of velocity

3.9
filter
wave filter
device for separating oscillations on the basis of their frequency. It introduces relatively small attenuation to wave oscillations in one or more frequency bands and relatively large attenuation to oscillations of other frequencies

3.10
band-pass filter
filter which has a single transmission band extending from a lower cut-off frequency greater than zero to a finite upper cut-off frequency

3.11
pass-band
⟨band-pass filter⟩ frequency band between the upper and lower cut-off frequencies

3.12
nominal upper and lower cut-off frequencies
cut-off frequency
⟨band-pass filter⟩ frequencies above and below the frequency of maximum response of a filter at which the response to a sinusoidal signal is 3 dB below the maximum response

3.13
root mean square (r.m.s.) velocity
$v_{\text{r.m.s.}}(t)$
square root, over a time interval T, of the average of squared values of the velocity' over the time interval

NOTE Root mean square value can also be used for displacement and acceleration.

3.14
exponential mean effective (e.m.e.) velocity
$v_{\text{e.m.e.}}(t)$
parameter for obtaining a time-average velocity, which is similar to root mean square velocity, but considers exponential decay

NOTE 1 Exponential mean effective value can also be used for displacement and acceleration.

NOTE 2 Exponential mean effective value is also known as exponential average value or time relaxation value.

3.15
period
smallest increment of the independent variable of a periodic quantity for which the function repeats itself

4 Fundamental concepts

4.1 Bearing vibration measurement

The diagram in Figure 1 shows the fundamental elements of bearing vibration measurement and the factors that influence the measurement. The numbers in Figure 1 correspond to clauses of this part of ISO 15242.

4.2 Characteristics of an axis of rotation

A rotating rolling bearing is designed to provide an axis of rotation for rotational motion of one machine element relative to another while supporting radial and/or axial loads. An axis of rotation may exhibit motion in six basic degrees of freedom. These are shown in Figure 2, and are listed below:

— rotational motion, see Figure 2 b);

— translational motion in a radial direction, i.e. in one or both orthogonal planes passing through the axis of rotation, see Figures 2 c) and 2 d);

— translational motion in an axial direction, i.e. in a direction parallel to the axis of rotation, see Figure 2 e);

— tilt motion in an angular direction, i.e. in one or both orthogonal planes passing through the axis of rotation, see Figures 2 f) and 2 g).

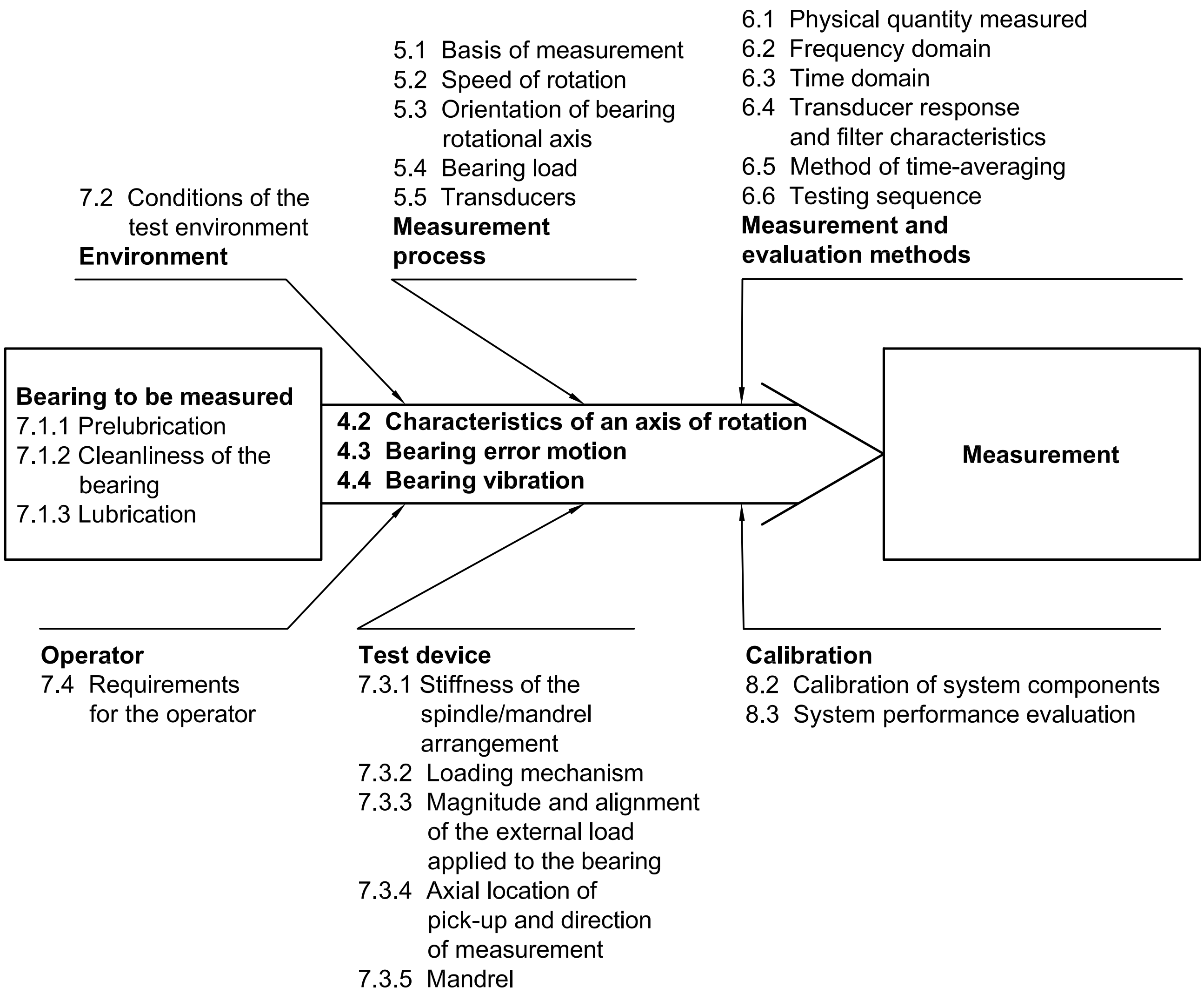
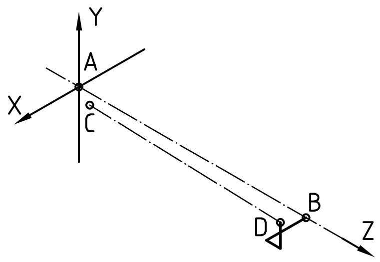


Figure 1 — Fundamental elements of bearing vibration measurement

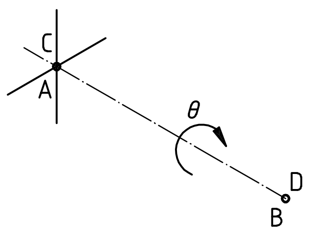
A rotating rolling bearing will, ideally, have no resistance to externally applied forces in the rotational direction, i.e. zero frictional torque. Depending on the type of external loading the bearing is designed to support, the bearing will exhibit stiffness in any or all of the five remaining degrees of freedom. For example, a bearing with self-aligning capabilities may support radial and axial loading, but will, ideally, exhibit no stiffness in the two tilt directions. Other bearings may be designed to allow free axial motion, while exhibiting radial and tilt stiffness.

4.3 Bearing error motion

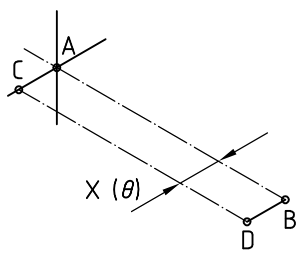
Displacement of the axis of rotation of a rotating bearing in any of the five non-rotational degrees of freedom for which the bearing is designed to support load is known as bearing error motion. This includes any displacements associated with rotation of the bearing, but excludes displacements due to thermal drift or changes in externally applied load. Error motion is reported in terms of displacement and characterizes the deviation from perfection of an axis of rotation. In a rotating rolling bearing, error motion is a consequence of geometric imperfections of the various internal bearing surfaces that undergo relative motion as the bearing rotates. These geometric imperfections may be an intrinsic characteristic of the bearing components (such as form errors in a manufactured surface), or may be the consequence of distortions of the bearing components introduced during mounting or installation.



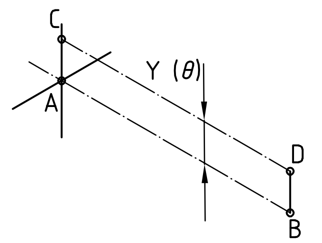
a) General case showing axis designations



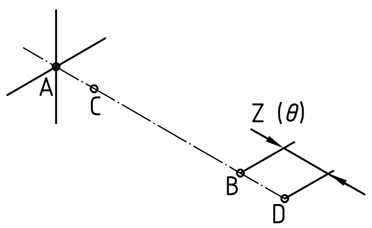
b) Rotational motion coaxial with the Z reference axis



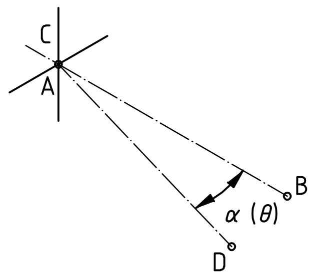
c) Radial translational motion in the X direction



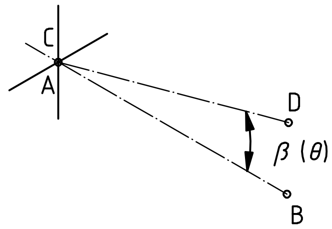
d) Radial translational motion in the Y direction



e) Axial translational motion in the Z direction



f) Tilt motion in the X direction with the origin at A



g) Tilt motion in the Y direction with the origin at A

AB = Z reference axis

CD = Axis of rotation

Figure 2 — Schematic diagrams of the six degrees of freedom of an axis of rotation

4.4 Bearing vibration

The same factors that result in bearing error motion will also result in dynamic vibration of the bearing elements. Vibration is a consequence of the displacements induced by error motion, but with the additional consideration of acceleration-dependent inertial effects and bearing/mounting stiffness characteristics, which will generate internal forces in the bearing. Internal forces will also be generated by time-variable deformations of the bearing parts, several types of non-intended motions of the rolling elements and cages and periodic displacements of the cage with respect to the rolling elements or rings. Vibration is generated by error motion under specific circumstances, such as rotational speed and applied load. Bearing vibration can affect the performance of a mechanical system and contributes, in airborne noise generation, by the system that incorporates the bearing.

5 Measurement process

5.1 Basis of measurement

For the purposes of this part of ISO 15242, the structure-borne vibration of a rotating rolling bearing is evaluated by mounting a transducer (e.g. displacement, velocity, acceleration or force) at a specified point on one of the bearing rings, or on a mechanical element of the test rig that is mechanically coupled to one of the bearing rings. The line of action of the transducer (e.g. axial or radial) must be specified with respect to a reference system. The bearing is rotated at a fixed speed under specified loading conditions and the transducer signal is monitored for a specified period of time. The data thus collected are then analysed to calculate one or more parameters that are used to characterize the level of vibration. These observations yield data on the vibration of the bearing for the selected test conditions. The results may or may not allow conclusions to be drawn regarding vibration and noise under different operating conditions.

The measurement process can be represented schematically as a combination of the elements as shown in Figure 1.

Appropriate clauses of this part of ISO 15242 provide details on each of these separate elements of the measurement process.

5.2 Speed of rotation

Bearings shall be vibration-tested dynamically, with the outer ring being stationary or rotating gradually, and with the inner ring turning at a constant speed dependent on the size and construction of the bearing (see type-specific parts of ISO 15242).

During the test, the actual speed of rotation shall not exceed the nominal speed by more than 1% and shall not fall below it by more than 2 %.

5.3 Orientation of bearing rotational axis

Bearings may be vibration tested with their axis of rotation vertical or horizontal. With the axis horizontal, the change in orientation of the Earth’s gravity with respect to the rotating rolling elements should be taken into consideration. This can lead to additional vibration unless the centrifugal or induced contact forces on the rolling elements are much higher than their mass.

5.4 Bearing load

In order to achieve well-defined kinematic conditions, bearings shall be loaded during the vibration test. Applied loads shall be high enough to prevent slipping of the rolling elements relative to the inner and outer ring raceways without causing distortion which would affect the results.

5.5 Transducers

The quantity measured is the radial or axial vibration of the bearing outer ring. An electromechanical pick-up converts the mechanical movement to an electrical signal. Three main types of transducer have to be considered, giving signals nominally proportional to displacement, velocity or acceleration. Force transducers may also be used, provided their signal can be transformed to a value corresponding to one of these three parameters.

A distinction is drawn between contact-free systems, which are used particularly for displacement measurement, and pick-ups that need to contact the vibrating outer ring of the bearing. When a contact type pick-up is used, care must be taken to ensure that the transducer does not influence the vibrations of the bearing outer ring. Conversely, the contact needs to be sufficiently firm so that all vibrations within the appropriate frequency range are detected. To achieve this, moving masses should be as low as possible. If vibrations are transferred via a transducer tip that touches the bearing outer ring, the occurrence of contact resonance has to be taken into consideration (see Annex A).

The vibrational motion of the outer ring is a complicated superposition of displacements of various amplitudes at different frequencies. Whereas there may be high single amplitudes, even at higher frequencies (especially for defective bearings), in general amplitudes decrease with increasing frequency and decline to nanometre magnitude at a few kilohertz. This makes it hard for some displacement measuring systems to give reliable results in the high frequency range. On the other hand, acceleration type transducers, which are well suited for high frequencies, need to have extremely high dynamics to resolve the lower frequency spectrum. A good compromise is a velocity type pick-up. Signals should be presented in velocity proportional form. If necessary, the primarily gathered signal should be converted electronically using a known calibrated conversion factor.

6 Measurement and evaluation methods

6.1 Physical quantity measured

The default physical quantity to be measured is vibration velocity, $v_{\text{r.m.s.}}$ (µm/s). The measurement direction is to be radial or axial depending on the bearing type.

6.2 Frequency domain

The velocity signal is to be measured in one or more frequency bands within the range 50 Hz to 10 000 Hz. Specific frequency ranges will be suggested for various bearing types.

NOTE For example, radial and angular contact bearings of a certain size range may use 50 Hz to 300 Hz, 300 Hz to 1 800 Hz and 1 800 Hz to 10 000 Hz.

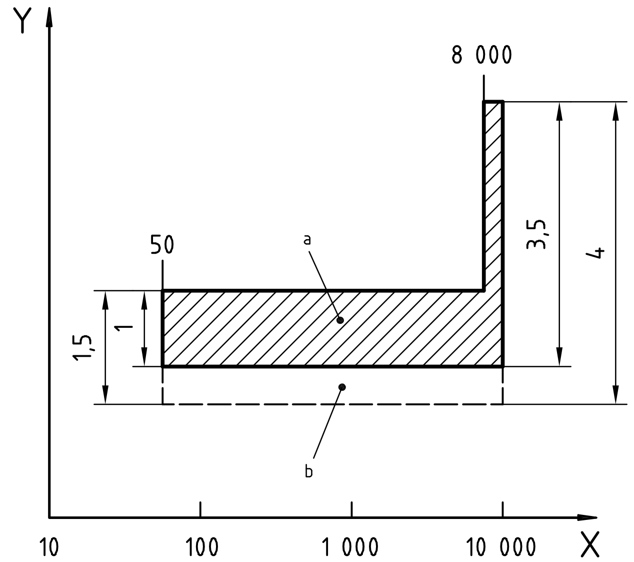
The use of spectral analysis of the vibration signal is an alternative.

6.3 Time domain

Detection of peaks or spikes in the time domain velocity signal, usually due to surface defects and/or contamination in the test bearing, may be considered as a supplementary option by agreement between the manufacturer and the customer. Various evaluation methods exist depending on bearing type and application.

6.4 Transducer response and filter characteristics

Frequency response of the electromechanical transducer shall fall within the limits specified in Figure 3.



Key

X frequency, Hz

Y output signal/vibration velocity, dB

[a] Recommended zone

[b] Maximum permissible zone (includes a)

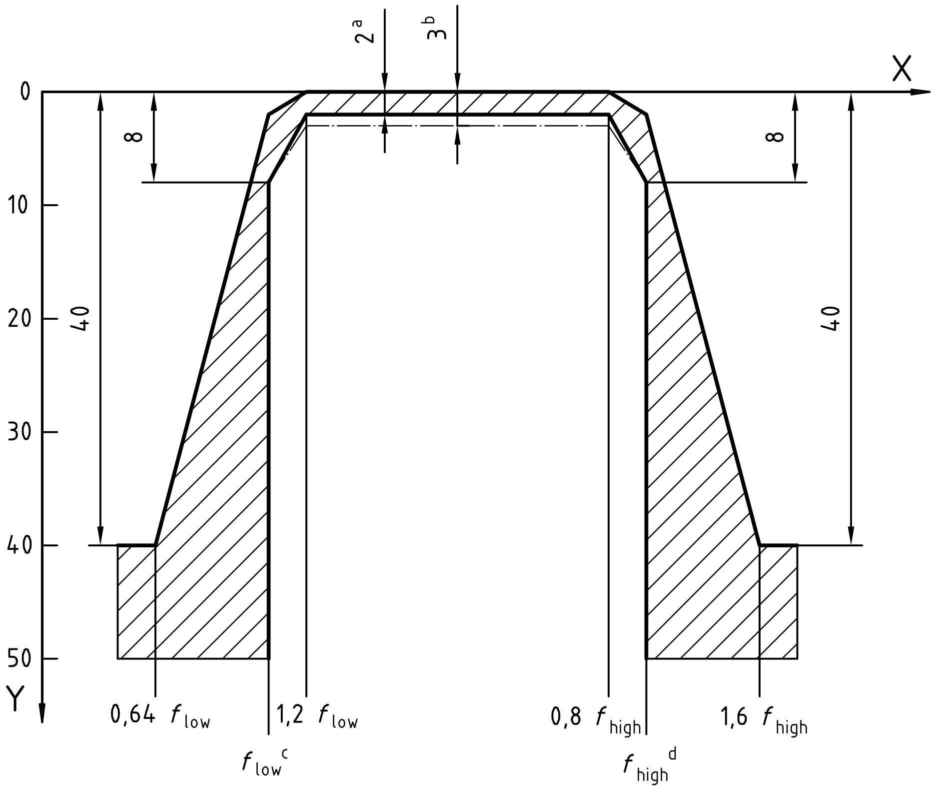
Figure 3 — Transducer response specification

The minimum response requirement of the transducer in Figure 3 should include the compensated output signal of the amplifier.

Amplitude linearity: The maximum deviation from linearity shall be less than 10 % for vibration amplitudes in the velocity range between 10 µm/s and 3 000 µm/s r.m.s.

The sensitivity of the transducer, as matched with the electronic unit, shall be specified within ± 5 %. This sensitivity shall be within specification limits for the operational range of static axial displacement of the transducer. In the case of variation in the sensitivity between individual transducers, adequate compensation must be provided in the electronic unit.

The wave filter characteristics of the electronic unit shall fall within the band-pass filter limits specified in Figure 4. The attenuation of pass-band at all frequencies lower than 64 % of the lower cut-off frequency (f_{low}) and all frequencies greater than 160 % of the upper cut-off frequency (f_{high}) shall not be less than 40 dB.



Key

X cut-off frequency, Hz

Y attenuation, dB

[a] Recommended range

[b] Maximum permissible range

[c] Nominal lower cut-off frequency

[d] Nominal upper cut-off frequency

Figure 4 — Filter specification

6.5 Method of time-averaging

The measurement of the velocity signal in each frequency band should represent a time-average reading over a period of not less than 0,5 s once the vibration has reached a stabilized level, characterized by only an occasional random fluctuation about the average. The selection of a particular time-average formulation shall be by agreement between the manufacturer and the customer. The two typical formulations are root mean square (r.m.s.) and exponential mean effective (e.m.e.) as defined in 3.13 and 3.14, respectively.

$$v_{\text{r.m.s.}}(t) = \sqrt{(1/T) \int_{(t-T)}^{t} v^2(t')\,\mathrm{d}t'} \qquad (1)$$

where

$v(t')$ is the time-dependent vibration velocity;

T is the sampling time, which shall be longer than the period of any of the major frequency components of which $v(t')$ is composed.

Often, $v_{\text{r.m.s.}}(t)$ is taken at time $t = T$.

$$v_{\text{e.m.e.}}(t) = \sqrt{(1/\tau)\int_0^t v^2(t')\,\mathrm{e}^{-(t-t')/\tau}\,\mathrm{d}t'} \tag{2}$$

where

$v(t')$ is the time-dependent vibration velocity;

τ is the relaxation time, which shall be longer than the period of any of the major frequency components of which $v(t')$ is composed.

$v_{\text{e.m.e.}}(t)$ should be taken at time $t \gg \tau$.

Stabilization should be reached within five minutes of starting the evaluation. In the instance where stabilization cannot be reached within five minutes, the manufacturer and the customer shall mutually agree on a suitable test duration.

6.6 Testing sequence

Measurements shall be taken at the required number of positions. Details for specific bearing types are given in other parts of ISO 15242.

For acceptance of the bearing, the highest vibration reading for the appropriate frequency range shall be within the limits mutually agreed between the manufacturer and the customer.

7 Conditions for measurement

7.1 Bearing conditions for measurement

7.1.1 Prelubrication

Prelubricated (greased, oiled or solid lubricated) bearings, including sealed and shielded types, shall be tested in the as-delivered condition.

For bearings that are not prelubricated, the reference condition procedures (7.1.2 and 7.1.3) shall apply.

7.1.2 Cleanliness of the bearing

Since contamination affects vibration levels, bearings must be effectively cleaned, taking care not to introduce contamination or other sources of vibration.

NOTE Some preservatives may meet the lubrication requirements (see 7.1.3) for vibration testing. In this case, it is not necessary to remove the preservative.

7.1.3 Lubrication

Before testing, bearings shall be lubricated with a specified volume of clean, low viscosity oil depending on bearing type and size. Additional information is given in ISO 3448. The lubrication procedure shall include some run-in to achieve homogeneous distribution of the lubricant within the bearings.

7.2 Conditions of the test environment

The bearings shall be tested at room temperature in an environment that does not influence the bearing vibration. Additional information is given in ISO 554, ISO 558 and ISO 3205.

7.3 Conditions for the test device

7.3.1 Stiffness of the spindle/mandrel arrangement

The spindle (including the mandrel) used to hold and drive the bearing inner ring shall be so designed and constructed that, except for transmittal of rotary motion, it represents essentially a rigid reference system for the inner ring axis. The transmission of vibration between the spindle/mandrel arrangement and the bearing inner ring in the frequency band used shall be negligible by comparison to the velocities measured (in cases of dispute, precise values shall be agreed between the manufacturer and the customer).

7.3.2 Loading mechanism

The loading system used to apply load to the bearing outer ring shall, ideally, be designed and constructed so that it leaves the ring essentially free to vibrate in all radial, axial, angular or flexural modes according to the bearing type.

7.3.3 Magnitude and alignment of the external load applied to the bearing

Details for specific bearing types are given in other parts of ISO 15242.

7.3.4 Axial location of pick-up and direction of measurement

Details for specific bearing types are given in other parts of ISO 15242.

7.3.5 Mandrel

The cylindrical surface of the mandrel, on which the inner ring of the bearing is mounted, shall have an outside diameter to tolerance grade f5, according to ISO 286-2, with minimal geometric errors. This will ensure a sliding fit in the bearing bore.

7.4 Requirements for the operator

A competent operator shall ensure that vibration measurements are taken in accordance with this part of ISO 15242 together with the part covering the appropriate bearing type.

8 Calibration and reference evaluation of the measuring system

8.1 General

Documented calibration procedures shall be followed to ensure up to date calibration of the measuring system before measurements are taken.

8.2 Calibration of the system components

The basic elements requiring calibration in the bearing vibration measuring system are the following:

— drive unit to rotate the bearing;

— load unit to apply load to the bearing;

— transducer which converts bearing vibration into an electrical signal;

— electronic unit (amplifier, filter and display device) which processes the signal.

Each part of the measuring system has to be maintained in its originally designed performance condition and adjusted under controlled conditions. The adjustment or calibration should be traceable to international measurement standards or other national measurement standards. The following are the major calibration and confirmation items for each measuring system:

a) drive unit

  1) rotational speed of the spindle,

  2) error motion and residual vibration of the spindle,

  3) condition of the spindle mandrel on which a bearing is mounted (damage, corrosion, deformation, dimensional change, etc.);

b) load unit

  1) load value,

  2) alignment of the loading direction,

  3) position of the loading point;

c) transducer

  1) sensitivity and amplitude linearity,

  2) frequency response,

  3) orientation and position;

d) electronic unit (amplifier, filter and display device)

  1) amplification and linearity,

  2) frequency characteristics,

  3) indication accuracy of the meter or digital display.

8.3 System performance evaluation

If measurements are performed with the bearing components in the same position and using the same measuring equipment and test parameters, the measuring repeatability must be within ± 10 % of the average measured values.

NOTE This measuring system variation does not include the variation of the bearing being tested.

Annex A
(informative)

Contact resonance considerations

A.1 Contact forces

If the transducer is spring loaded, the contact force shall be higher than $m \times a$ (where m is the moving mass and a is the highest acceleration to be measured), in order to prevent the transducer losing contact with the bearing outer ring.

A.2 Contact resonance

Contact resonance is due to the fact that the tip of the transducer behaves like a spring, owing to its modulus of elasticity E. With a ball ended tip the situation becomes more complex because the tip acts like a spring with variable stiffness which increases with load. The higher the value of E and the larger the transducer tip radius r, the higher the value of the resonant frequency f becomes. Table A.1 gives some examples for a hemispherical transducer tip (E = 600 GPa), coupled with a pick-up to a total moving mass m, which is pressed onto the outside surface of the bearing outer ring (E = 200 GPa) with a static force F.

Table A.1 — Frequency of contact resonance

r mm	F N	m g	f kHz
1	1	1	9,6
5	1	1	12,6
1	5	1	12,6
1	1	5	4,3

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