
**Mechanical vibration — Measurement
and evaluation of machine
vibration —**

**Part 3:
Industrial machinery with a power
rating above 15 kW and operating
speeds between 120 r/min
and 30 000 r/min**

*Vibrations mécaniques — Mesurage et évaluation des vibrations de
machines —*

*Partie 3: Machines industrielles avec une puissance nominale
supérieure à 15 kW et une vitesse de fonctionnement comprise entre
120 r/min et 30 000 r/min*



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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.

The procedures used to develop this document and those intended for its further maintenance are specified in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 108, *Mechanical vibration, shock and condition monitoring*, Subcommittee SC 2, *Measurement and evaluation of mechanical vibration and shock as applied to machines, vehicles and structures*.

This first edition of ISO 20816-3 cancels and replaces ISO 7919-3:2009, ISO 7919-3:2009/Amd 1:2017, ISO 10816-3:2009 and ISO 10816-3:2009/Amd 1:2017, which have been merged and editorially revised. A list of all parts in the ISO 20816 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document provides specific guidance for assessing

- a) the severity of vibration measured on bearings, bearing pedestals, or housings of industrial machines when measurements are made in-situ, and
- b) the severity of radial shaft vibration on coupled industrial machines.

Evaluation criteria, based on previous experience, are given for use as guidelines for assessing the vibratory conditions of such machines. One criterion considers the magnitude of the observed broad-band vibration; the second considers the changes in the magnitude of the observed broad-band vibration. It should be recognized, however, that these criteria do not form the only basis for judging the severity of vibration.

Mechanical vibration — Measurement and evaluation of machine vibration —

Part 3:

Industrial machinery with a power rating above 15 kW and operating speeds between 120 r/min and 30 000 r/min

1 Scope

This document specifies the general requirements for evaluating the vibration of various coupled industrial machine types with a power above 15 kW and operating speeds between 120 r/min and 30 000 r/min when measurements are made in-situ. Guidelines for applying evaluation criteria are provided for measurements taken on non-rotating and rotating parts under normal operating conditions. The guidelines are presented in terms of both steady running vibration values and in terms of changes to vibration magnitude, which can occur in these steady values. The numerical values presented are intended to serve as guidelines based on worldwide machine experience, but shall be applied with due regard to specific machine features which can cause these values to be inappropriate. In general, the condition of a machine is assessed by consideration of both the shaft vibration and the associated structural vibration, as well as specific frequency components, which do not always relate to the broadband severity values presented.

The machine types covered by this document include:

- a) steam turbines and generators with outputs less than or equal to 40 MW (see Note 1 and Note 2);
- b) steam turbines and generators with outputs greater than 40 MW which normally operate at speeds other than 1 500 r/min, 1 800 r/min, 3 000 r/min or 3 600 r/min (although generators seldom fall into this category) (see Note 1);
- c) rotary compressors;
- d) industrial gas turbines with outputs less than or equal to 3 MW (see Note 2);
- e) turbofans;
- f) electric motors of any type, if the coupling is flexible. When a motor is rigidly coupled to a machine type covered by any other part of ISO 20816, the motor may be assessed either against that other part or against ISO 20816-3;
- g) rolls and mills;
- h) conveyors;
- i) variable speed couplings; and
- j) blowers or fans (see Note 3).

NOTE 1 Land based steam turbines, gas turbines and generators of greater than 40 MW capacity, which run at 1 500 r/min, 1 800 r/min, 3 000 r/min or 3 600 r/min are covered by the requirements of ISO 20816-2. Generators in hydro-electric plants are covered by ISO 20816-5.

NOTE 2 Gas turbines of power greater than 3 MW are covered by ISO 20816-4.

NOTE 3 The vibration criteria presented in this document are generally only applicable to fans with power ratings greater than 300 kW or fans which are not flexibly supported. As and when circumstances permit, recommendations for other types of fans, including those of lightweight sheet-metal construction, will be prepared. Until these recommendations are available, classifications can be agreed between the manufacturer and the customer; using results of previous operational experience (see also ISO 14694).

Machinery including a geared stage can fall under the scope of this document. For performing acceptance tests of gearboxes please refer to ISO 20816-9.

The following types of industrial machine are not covered by this document:

- k) land-based gas turbines, steam turbines and generators with power outputs greater than 40 MW and speeds of 1 500 r/min, 1 800 r/min, 3 000 r/min or 3 600 r/min (see ISO 20816-2);
- l) gas turbine sets with power outputs greater than 3 MW (see ISO 20816-4);
- m) machine sets in hydraulic power generating and pumping plants (see ISO 20816-5);
- n) reciprocating machines and machines solidly coupled to reciprocating machines (see ISO 10816-6);
- o) rotordynamic pumps and any integrated or solidly coupled electric motors where the impeller is mounted directly on the motor shaft or is rigidly attached to it (see ISO 10816-7);
- p) reciprocating compressor systems (see ISO 20816-8);
- q) rotary positive displacement compressors (e. g. screw compressors);
- r) submerged motor-pumps; and
- s) wind turbines (see ISO 10816-21).

The requirements of this document apply to in-situ broad-band vibration measurements taken on the shafts, bearings, bearing pedestals, or housings of machines under steady-state operating conditions within their nominal operating speed range. The requirements relate to both acceptance testing and operational monitoring. The evaluation criteria included in this document can be applied to both continuous and non-continuous monitoring situations.

The requirements of this document cover machines which can have gears or rolling element bearings, but do not address the diagnostic evaluation of the condition of those gears or bearings.

The requirements in this document are applicable only for the vibration produced by the machine set itself and not for vibration that is transmitted to the machine set from external sources.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 2041, *Mechanical vibration, shock and condition monitoring — Vocabulary*

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

ISO 10817-1, *Rotating shaft vibration measuring systems — Part 1: Relative and absolute sensing of radial vibration*

ISO 20816-1, *Mechanical vibration — Measurement and evaluation of machine vibration — Part 1: General guidelines*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 2041 apply. It provides a range of vocabulary and definitions specific to mechanical vibration, shock and condition monitoring used in this document.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org/>

4 Measurement procedures

4.1 General

The measurement procedures to be followed and the instrumentation which shall be used are specified in ISO 20816-1, subject to the recommendations given in this clause.

Care shall be taken to ensure that the measuring system is not influenced by environmental factors such as:

- a) temperature variations;
- b) magnetic fields, including magnetisation of the shaft;
- c) sound fields;
- d) power source variations;
- e) transducer cable length (some designs of shaft vibration probe require matched cable lengths);
- f) transducer cable faults;
- g) transducer orientation.

Particular attention shall be paid to ensure that the vibration transducers are correctly mounted and that such mountings do not degrade the accuracy of the measurements taken.

4.2 Measurement location

It is common practice to measure vibration on non-rotating parts, or rotating parts (shaft relative vibration), or both. Unless stated otherwise, this document refers to shaft relative vibration when referring to displacement measurements taken on rotating parts. On rotating parts, measurement methods using non-contacting transducers are most commonly used and are preferred. The transducers are usually mounted as an orthogonal pair so that an orbit can be visualised. In some machines it is not possible to access the shaft directly adjacent to the bearing. Ensure that measurements reasonably represent the shaft vibration at the bearing and do not include any amplification due to local resonances of the supporting bracket, or due to a non-homogeneous shaft surface. See ISO 10817-1 for further details of instrumentation for radial vibration measurement on rotating parts.

Measurements taken on non-rotating parts shall be taken on the bearings, bearing support housing or other structural parts which significantly respond to the dynamic forces transmitted from the rotating elements at the bearing locations and characterize the overall vibration of the machine. In some machines it is not possible to access the bearing housings directly. In such cases, care shall be taken to ensure that measurements reasonably represent the vibration of the bearing housing and do not include any local resonances or amplification. Thin or otherwise flexible surfaces, such as fan covers or cowlings, should be avoided. It can be necessary to confirm the repeatability and validity of such measurement locations (e.g. by taking measurements at several locations and comparing the results).

The chosen locations and directions of vibration measurements shall be such, that they provide adequate sensitivity to the machine dynamic forces. Typically, this requires two orthogonal radial measurement locations on each bearing cap or pedestal. The transducers may be placed at any angular position on the bearing housings or pedestals. Vertical and transverse directions are usually preferred for horizontally mounted machines. For vertical or inclined machines, the location that gives the maximum vibration reading shall be one of those used. In some cases, it is also recommended to measure in the axial direction (see 6.2.1). The specific measurement locations and directions used shall be recorded along with the measurement result.

A single transducer may be used on a bearing cap or pedestal in place of the more typical pair of orthogonal transducers, if it is known to provide adequate information on the severity of the machine vibration. However, caution shall be exercised when evaluating vibration from a single transducer at a measurement plane, since it may not provide a reasonable approximation to the maximum value at that plane.

Figures showing recommended measurement positions for both shaft vibration and housing vibration can be found in ISO 20816-1, which are reproduced in [Figure 1](#) to [Figure 6](#) for convenience.

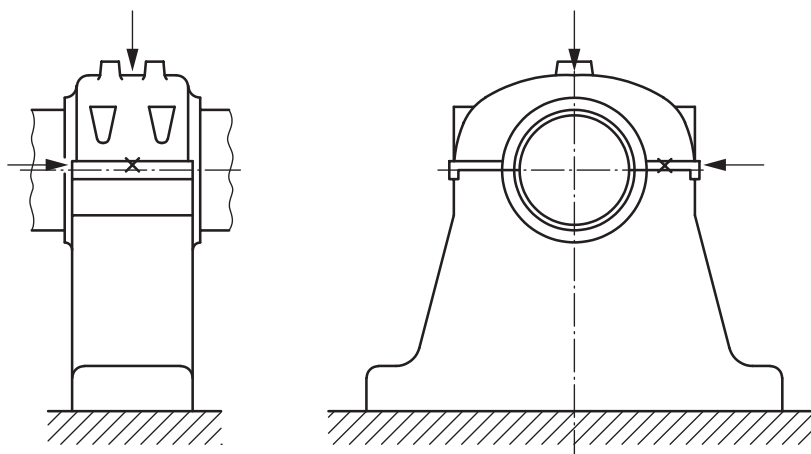


Figure 1 — Measuring points for pedestal bearings

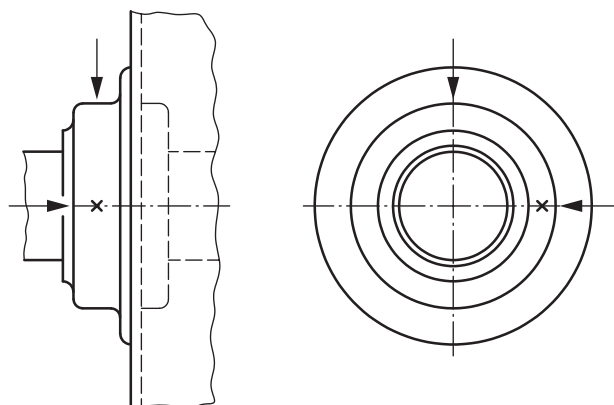


Figure 2 — Measuring points for housing-type bearings

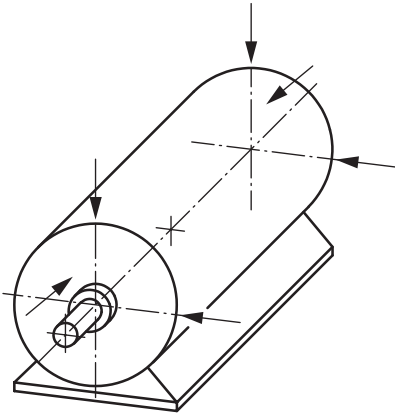


Figure 3 — Measuring points for small electrical machines

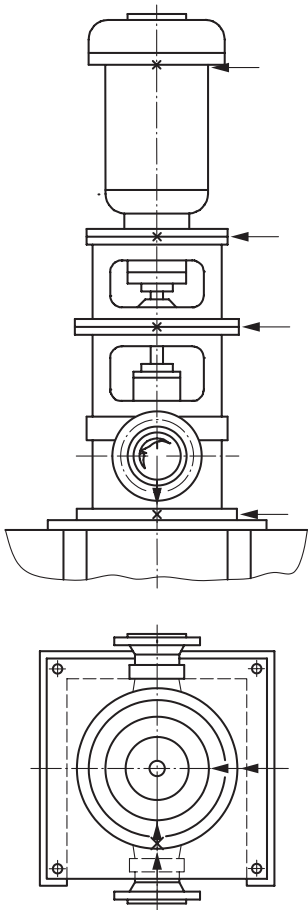
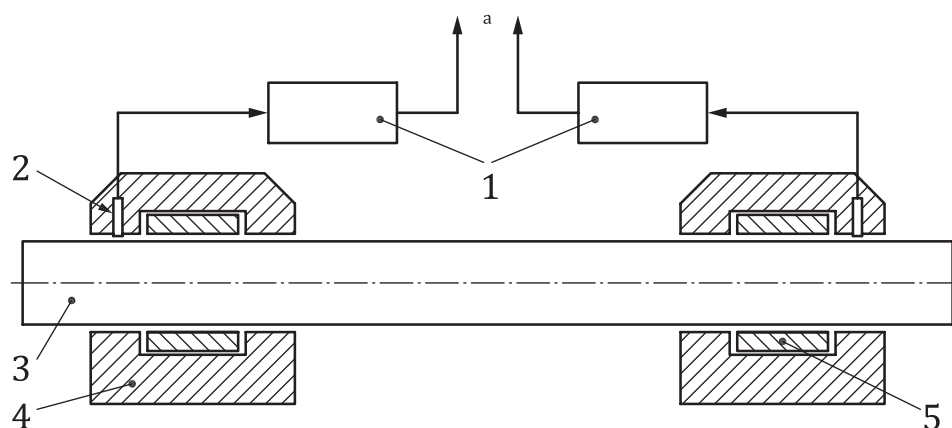


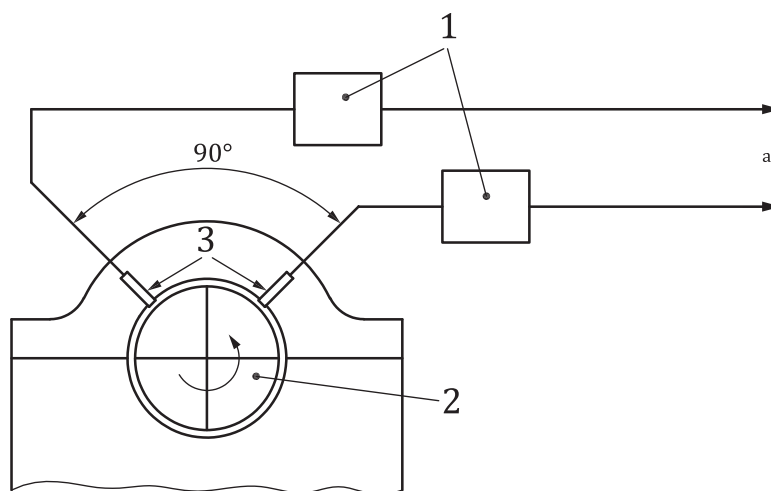
Figure 4 — Measuring points for vertical machine sets



Key

- 1 signal conditioning units
- 2 non-contacting transducers
- 3 shaft
- 4 bearing housings
- 5 bearings
- a To signal processing.

Figure 5 — Measuring points for measurements on rotating shafts



Key

- 1 signal conditioning units
- 2 shaft
- 3 non-contacting transducers
- a To signal processing.

Figure 6 — Mounting of non-contacting probes for the measurement of shaft relative vibration

4.3 Measurement equipment

For monitoring purposes, the equipment used shall be capable of measuring broad-band root-mean-square (r.m.s.) vibration with flat response over a frequency range of at least 10 Hz to 1 000 Hz. For machines with speeds approaching or below 600 r/min, the lower limit of the flat response frequency range shall not be greater than 2 Hz.

For measurements taken on rotating parts, the equipment used shall be capable of measuring overall vibration up to at least a frequency equivalent to 3,5 times the maximum service speed. The measurement equipment used shall meet the requirements of ISO 10817-1.

For measurements taken on non-rotating parts, the measurement equipment used shall meet the requirements of ISO 2954. Depending on the vibration criteria, this requires measurements of displacement or velocity or a combination of them (see ISO 20816-1). Where accelerometers are mounted on stationary parts of the machine (as is common practice), their output shall be integrated to provide a velocity signal. Double integration of acceleration to provide a displacement signal may be used to generate displacement signals, but caution shall be exercised due to the possibility of introducing high noise levels. High pass filtering and/or alternative digital computation of the displacement value can provide more accurate values.

For diagnostic purposes, the linear frequency range of the system should generally cover frequencies from 0,2 times the lowest rotational frequency to 2,5 times the highest excitation frequency of interest (generally not exceeding 10 kHz). Further information can be found in ISO 13373-1, ISO 13373-2 and ISO 13373-3.

4.4 Continuous and non-continuous monitoring

It is common practice on large or critical machinery to have installed instrumentation for continuous on-line monitoring of vibration values at key measurement points for both condition monitoring and protection purposes. In some cases, such instrumentation provides an input to the control system.

For many machines, continuous monitoring of the vibration parameters is not carried out. Changes in machinery condition (e.g. unbalance, bearing performance, structural looseness, alignment) can be detected with sufficient reliability by taking periodic measurements. The guideline vibration values given in this document can be applied to periodic measurements provided that the measurement position, frequency response and mounting arrangements are in accordance with the requirements of this document.

Instruments for measuring the vibration of rotating parts are usually a permanent installation, but in some cases their output may only be measured periodically.

Measurements of vibration taken on non-rotating parts can be achieved with temporary attachment of transducers; however, inaccessible machines may have permanently installed vibration transducers wired back to an accessible location or have a non-continuous logging system installed.

4.5 Operational conditions

Vibration measurements shall be made when the rotor and the bearings have reached their normal steady-state operating temperatures and with the machine running under specified conditions, such as running at rated speed, voltage, flow, pressure and load.

For machines with varying speeds or loads, vibration measurements shall be made at all conditions at which the machine is expected to operate for prolonged periods. The maximum measured value under these conditions shall be considered representative of vibration severity.

It is not always possible to wait for the desired operating conditions before taking a vibration measurement. In such cases the influences of operating conditions shall be considered in the assessment of vibration severity. Operating conditions, which can affect vibration, include, among others:

- a) machine load;
- b) process temperature;
- c) valve positions;
- d) flows;
- e) ambient temperature;

- f) fluid levels;
- g) filter differential pressure.

When operating conditions vary from measurement to measurement, those with the most significant influence on the machine shall be recorded. For best repeatability, newly acquired measurements shall be judged against those taken previously under similar conditions.

4.6 Background vibration

If the measured vibration magnitude is greater than the allowed acceptance criteria and excessive background vibration is suspected, measurements shall be made with the machine shut down to determine the extent of any external influence. Corrective action can be necessary to reduce the effect of background vibration if the measured vibration magnitude with the machine stationary exceeds the smaller of

- a) 25 % of the value measured when the machine is running, or
- b) 25 % of the Zone B/C boundary (see [6.2.2](#)) appropriate to the machine type.

4.7 Choice of measurement type

In this document, guidelines are provided for measurement on both rotating and non-rotating parts. The choice of which measurement type to use depends upon the characteristics of the machine to be measured and the faults which need to be detected.

The following shall be considered, if only one type of measurement is to be chosen:

- a) Machine speed:

Measurements taken on non-rotating parts are more sensitive to higher frequencies than measurements taken on rotating parts;

- b) Bearing type:

Rolling element bearings have very small clearances and transmit shaft vibration effectively into the housings. Therefore, measurements taken on non-rotating parts are usually sufficient to allow effective vibration monitoring and machine assessment. Journal bearings provide high damping and larger clearances, so shaft vibration is often a useful additional parameter to measure;

- c) Machine type:

Machines with internal clearances comparable to the vibration magnitude can require the measurement of shaft relative vibration for protection purposes (see [Annex C](#)). Monitoring of components that generate multiples of rotor speed (e.g. vanes, gear teeth (including gear pumps), blades, rotor bars, etc.) benefit from the higher frequency range available with measurements taken on non-rotating parts;

- d) Ratio of shaft mass to pedestal mass:

Light shafts in heavy pedestals transmit little vibration into the casing, so shaft relative vibration measurements provide a better indication of machine behaviour;

- e) Shaft flexibility:

Shaft relative vibration measurements provide a more sensitive indication of vibration severity in machines with flexible shafts;

- f) Support structure flexibility:

Flexible support structures lead to a higher vibration response on non-rotating parts; and

g) Experience:

Where a large body of experience exists relating to one particular measurement type, it is useful to continue to use that measurement type in similar situations.

More detailed information on the choice of the appropriate measurement method is given in ISO 13373-1. Considerations relating to ease of access, longevity of sensors and cost of installation are also relevant to the final decision (see ISO 17359).

5 Machine classification

5.1 General

In this document, the vibration severity is classified according to the following parameters:

- a) machine type;
- b) rated power or shaft height (see also ISO 496);
- c) support system flexibility.

5.2 Classification according to machine type, rated power or shaft height

Significant differences in design, type of bearings and support structures require a separation into two different machine groups with regard to either the rated power or the shaft height H (see Note 1).

Machines of these two groups can have horizontal, vertical or inclined shafts and can be mounted on rigid or flexible supports.

Group 1: Large machines with rated power above 300 kW; electrical machines with shaft height $H \geq 315$ mm.

These machines normally have journal bearings. The range of operating or nominal speeds is relatively broad and ranges from 120 r/min to 30 000 r/min.

Group 2: Medium-sized machines with a rated power above 15 kW up to and including 300 kW; electrical machines with shaft height $160 \text{ mm} \leq H < 315$ mm.

These machines normally have rolling element bearings and operating speeds above 600 r/min.

NOTE 1 The shaft height H of a machine is defined in accordance with ISO 496 as the distance, measured on the machine ready for delivery, between the centreline of the shaft and the base plane of the machine.

5.3 Classification according to support flexibility

Two classifications are used to denote the support assembly flexibility in specified directions:

- a) rigid;
- b) flexible.

These support conditions are determined by the relationship between the machine and foundation flexibilities. If the lowest natural frequency of the combined machine and support system in the direction of measurement is higher than its main excitation frequency (this is in most cases the rotational frequency) by at least 25 %, then the support system may be considered rigid in that direction. All other support systems may be considered flexible.

As typical examples: large and medium-sized electric motors, mainly with low speeds, normally have rigid supports; whereas turbo-generators or compressors, with power greater than 10 MW, and vertical machine sets usually have flexible supports.

In some cases, a support assembly can be rigid in one measuring direction and flexible in the other direction. For example, the lowest natural frequency in the vertical plane can be well above the main excitation frequency, while the horizontal plane natural frequency can be considerably less. Such a system is stiff in the vertical plane but flexible in the horizontal. In such cases, the vibration shall be evaluated in accordance with the support classification that corresponds to the measurement direction.

If the class of the machine-support system cannot be readily determined from drawings and calculation, it may be determined by testing.

6 Evaluation criteria

6.1 General

ISO 20816-1 provides a general description of the two evaluation criteria used to assess vibration severity on various classes of industrial machines. The first considers the magnitude of the observed broad-band vibration; the second considers changes (both increases and decreases) in the magnitude of the observed broad-band vibration.

For many industrial machines the r.m.s. vibration velocity measured on non-rotating parts is used as the basis for assessing vibration severity, due to the ease of access for taking measurements. However, for some machines it is also prudent to measure the peak-to-peak shaft relative vibration and where these values are available they shall also be used for assessing vibration severity.

6.2 Criterion I: Vibration magnitude

6.2.1 General

For measurements taken on rotating parts, the vibration severity is the higher value of the broad-band peak-to-peak displacement, measured in the two selected orthogonal measurement directions.

For measurements taken on non-rotating parts, the vibration severity is the highest r.m.s. value of the broad-band velocity measured at or near a bearing.

This criterion is concerned with defining limits for vibration magnitude consistent with acceptable dynamic loads on the bearings and acceptable vibration transmission into the environment through the support structure and foundation. The maximum vibration magnitude observed at each bearing or pedestal is assessed against the evaluation zones for the support class. The evaluation zones have been established from experience with machinery of this type and, if due regard is paid to them, acceptable machine operation can be expected. If only one measuring direction is used, ensure that it provides adequate information (for further information refer to ISO 20816-1).

The evaluation zone boundary values are presented for the specified steady-state operating conditions at the rated speed and load ranges. They apply for normal slow changes in load but do not apply when different conditions exist or during transient changes (e.g. during start-up and shut-down and when passing through resonance ranges). See [6.4](#) for further guidance in this respect.

Overall judgement of the vibratory state of a machine is often made based on vibration measurements taken on both rotating parts and non-rotating parts.

It is not common practice to measure axial vibration on main radial load-carrying bearings during continuous operational monitoring. Such measurements are primarily used during periodic vibration surveys or for diagnostic purposes. Certain faults are more easily detected in the axial direction. Specific axial vibration criteria only apply in the case of thrust bearings where axial vibration correlates with axial pulsations, which can cause damage to the axial load-carrying surfaces.

The evaluation zone boundary values shown in [Table A.1](#) and [Table A.2](#) apply to radial vibration on all bearings and to axial vibration on thrust bearings.

6.2.2 Evaluation zones

6.2.2.1 General

The following evaluation zones are specified to permit a qualitative assessment of the vibration severity of a given machine to be made and provide guidelines on possible actions.

Zone A: The vibration of newly commissioned machines normally falls within this zone.

NOTE The effort required to achieve vibration within Zone A can be disproportionate and unnecessary.

Zone B: Machines with vibration within this zone are normally considered acceptable for unrestricted long-term operation.

Zone C: Machines with vibration within this zone are normally considered unsatisfactory for long-term continuous operation. Generally, the machine may be operated for a limited period in this condition until a suitable opportunity arises for remedial action.

Zone D: Vibration values within this zone are normally considered to be of sufficient severity to cause damage to the machine.

6.2.2.2 Evaluation zone boundaries

Numerical values assigned to the zone boundaries are not intended to serve as acceptance specifications, which shall be subject to agreement between the machine manufacturer and the customer. However, these values provide guidelines for ensuring that gross deficiencies or unrealistic requirements are avoided. In certain cases, there can be specific features associated with a particular machine, which justify the use of different zone boundary values (higher or lower). In such cases, it is common for the manufacturer to explain the reasons for this and, in particular, to confirm that the machine will not be endangered by operating with higher vibration values.

6.2.3 Acceptance criteria

Acceptance criteria shall always be subject to agreement between the machine supplier and purchaser either prior to or at the time of purchase. Prior negotiation is encouraged. The evaluation zones provide a basis for defining acceptance criteria for new or refurbished machines, but the numerical values assigned to the zone boundaries are not themselves intended to serve as acceptance specifications.

Historically, for new machines, acceptance criteria have been specified in Zone A or Zone B, but normally do not exceed 1,25 times the Zone A/B boundary. Different acceptance criteria can be agreed upon, based on specific design characteristics and/or fleet experience with similar machines.

Contractual acceptance tests shall be carried out under clearly specified duration and operating parameters (e.g. duty, speed, flow, temperature and/or pressure). After major component replacement, maintenance or service activities, acceptance criteria shall take into account the scope of activity and the vibration of the machine prior to servicing.

6.2.4 Evaluation zone limits

The evaluation criteria for vibration severity, changes in vibration magnitude and operational limits are given in [Annex A](#) for measurements on non-rotating parts and in [Annex B](#) for measurements taken on rotating parts.

6.3 Criterion II: Change in vibration magnitude

This criterion provides an assessment of a change in vibration magnitude from a previously established reference value. A significant change in broad-band vibration magnitude can occur, which requires some action even though Zone C of Criterion I has not been reached. Such changes can be instantaneous or progressive over time and can indicate incipient damage or some other irregularity. Criterion II

is specified based on the change in broad-band vibration magnitude occurring under steady-state operating conditions. Steady-state operating conditions shall be interpreted to include small changes in the machine power or operational conditions.

When Criterion II is applied, the vibration measurements being compared shall be taken at the same transducer location and orientation and under approximately the same machine operating conditions. Obvious changes in the normal vibration magnitudes, regardless of their total amount, shall be investigated so that a dangerous situation can be avoided. When an increase or decrease in vibration magnitude exceeds 25 % of the Zone B/C boundary, as specified in [Annex A](#) and [Annex B](#), it shall be considered significant, particularly if it is sudden. Diagnostic investigations shall then be initiated to ascertain the reason for the change and to determine what further actions are appropriate.

NOTE 1 The 25 % value is provided as a guideline for a significant change in vibration magnitude, but other values can be used based on experience with a specific machine.

NOTE 2 The 25 % value can also be applied to vibration vector information based on a specific frequency of interest, where available. This approach can provide a more sensitive test for identifying changes in vibration magnitude (see ISO 20816-1:2016, Annex D).

NOTE 3 Where a machine shows variability in vibration behaviour, further statistical measures can be applied to the results before this criterion is applied to avoid excessive “false positive” results.

6.4 Evaluation during transient operation

The criteria specified in [Annex A](#) and [Annex B](#) are intended for use under steady-state conditions. In general, higher vibration magnitudes can occur during transient machine states. In particular, when a machine with a flexible support structure runs up to speed or coasts down from normal operation, high values of vibration magnitude can be measured as the rotor passes through its critical speed. In addition, machines can experience transient higher vibration magnitude due to alignment changes or shaft distortions during initial warming through. The response of the machine to operating and external ambient conditions shall be considered when making evaluations of vibration severity. Whilst the criteria given here are not intended for machine supervision during such conditions, as a general rule operation up to the upper limit of Zone C can be considered acceptable for limited periods of transient operation. In the case of run-up, run-down or overspeed, the appropriate values for acceptable vibration are shown in [Table 1](#).

Table 1 — Guidelines for maximum vibration severity during run-up, run-down or overspeed

Speed range (in relation to rated speed) %	Vibration measured on non-rotating parts (see Table A.1 and Table A.2)	Vibration measured on rotating parts (see Formula B.1 to Formula B.3)
<20	n/a (see Note)	1,5 × C/D boundary
20 to 90	1,0 × C/D boundary	1,5 × C/D boundary
>90	1,0 × C/D boundary	1,0 × C/D boundary

NOTE The ratio of vibration displacement to velocity is inversely proportional to frequency. Hence, for measurements made on non-rotating parts, there are drawbacks in using a constant velocity criterion at speeds below 20 % of rated speed.

6.5 Operational limits

6.5.1 General

For long-term operation, it is common practice to establish operational vibration limits. These limits take the form of ALARMS and TRIPS.

ALARMS provide a warning that a specified value of vibration has been reached or a significant change has occurred, upon which remedial action can be necessary. In general, if an ALARM situation occurs,

operation can continue for a period whilst investigations are carried out to identify the reason for the change in vibration and specify any remedial action.

TRIPS specify the magnitude of vibration beyond which further operation of the machine can cause damage. If the TRIP limit is exceeded, immediate action shall be taken to reduce the vibration or shut down the machine.

Different operational limits, reflecting differences in dynamic loading and support stiffness, may be specified for different measurement positions and directions.

6.5.2 Setting ALARM values

ALARM limits can vary considerably, up or down, for different machines. The values chosen shall be set relative to a baseline value determined from experience for the measurement position or direction for that particular machine.

It is recommended that the ALARM limit be set higher than the baseline by an amount equal to 25 % of the upper limit of Zone B. If the baseline is low, the ALARM limit can be below the Zone B/C boundary.

Where there is no established baseline (e.g. with a new machine), the initial ALARM setting shall be based either on experience with other similar machines or relative to agreed acceptance values. After a period of time, the steady-state baseline value will be established and the ALARM setting shall be adjusted accordingly.

It is recommended that the ALARM limit does not normally exceed 1,25 times the upper limit of Zone B.

If the steady-state baseline changes (e.g. after a machine overhaul), the ALARM setting shall be revised accordingly.

6.5.3 Setting TRIP values

TRIP limits relate to the mechanical integrity of the machine and are dependent on specific design features, which have been introduced to enable the machine to withstand abnormal dynamic forces. Therefore, the values used are generally the same for all machines of a similar design and are not normally related to the steady-state baseline value used for setting ALARMS.

There can, however, be differences for machines of different design and it is not possible to give clear guideline values for absolute TRIP limits. In general, the TRIP limit will be within Zone C or Zone D, but it is recommended that the TRIP limit does not exceed 1,25 times the upper limit of Zone C.

6.6 Supplementary procedures/criteria

It is important to recognize that there is no simple way to relate bearing housing vibration to shaft vibration, or vice versa. The difference between the absolute shaft and shaft relative measurements is related vectorially to the bearing housing vibration. Thus, when the requirements of this document - relating to both measurements taken on non-rotating parts and measurements taken on rotating parts - are applied in the assessment of machine vibration, independent shaft and bearing housing (or pedestal) vibration measurements shall be made. If the application of the different criteria leads to different assessments of vibration severity, the more restrictive zone classification shall apply.

6.7 Evaluation based on changes in vibration amplitude of specified frequency components and vibration vector information

Significant changes of vibration amplitude can occur in individual frequency components, which are not necessarily reflected in the broad-band vibration signal. For example, the propagation of a crack in a rotor can introduce a progressive change in vibration components at multiples of its rotational frequency, but their amplitude can be small relative to the amplitude of the once-per-revolution rotational frequency component. Consequently, it can be difficult to identify the effects of the crack propagation by only looking at the change in the broad-band vibration.

Monitoring the change in broad-band vibration can give an indication of potential problems. In certain applications, it can be necessary to use measuring and analysis equipment, which is capable of determining the trends of the amplitude changes that occur in individual frequency components of the vibration signal, in order to support diagnosis. This equipment can be more sophisticated than that used for normal supervisory monitoring and its use and application requires specialist knowledge (see ISO 18436-2).

The evaluation considered in this document is limited to broad-band vibration without reference to frequency components or phase. In most cases, this is adequate for acceptance testing and for operational protection purposes. However, for long-term condition monitoring purposes and for diagnostics, the use of vibration amplitude of different frequency components and vector information (especially of 1 time and 2 times rotational speed) is particularly useful for detecting and defining changes in the dynamic state of the machine. In some cases, these changes can go undetected when using only broad-band vibration measurements. Phase- and frequency-related vibration information is being used increasingly for monitoring and diagnostic purposes. Specifying criteria for evaluating individual frequency components, is beyond the current scope of the ISO 20816 series. For further details, consult the ISO 13373 series of standards, which address vibration monitoring (see also ISO 20816-1).

Annex A (normative)

Evaluation criteria for vibration measured on non-rotating parts of coupled industrial machines under specified operating conditions

It has been found that vibration velocity is sufficient to characterize the zone boundary values of vibration over a wide range of machine types and machine operating speeds. The main evaluation quantity is therefore the overall r.m.s. value of vibration velocity.

It is recognized that the use of a single value of vibration velocity, regardless of frequency, can lead to unacceptably large vibration displacements. This is particularly so for machines with low machine operating rotational speeds (less than 600 r/min) when the once-per-revolution vibration component is dominant (see [Annex D](#)). Similarly, constant velocity criteria for machines operating at high rotational speeds (>10 000 r/min), or with a significant vibration energy concentrated in a high-frequency range, can lead to unacceptably high acceleration values. Acceptance criteria can be provided in terms of displacement, velocity and acceleration, depending on the speed range and type of machine.

Vibration zone boundaries are presented in [Table A.1](#) and [Table A.2](#) for the machine groups covered by the requirements of this document. At present, these are given only in terms of velocity and displacement. It is emphasised that the displacements are derived from measurements taken on non-rotating parts.

NOTE 1 Acceleration measurements have greater sensitivity at higher frequencies and are therefore widely used for diagnostic purposes.

The limits apply to the broad-band r.m.s. values of vibration velocity and displacement in the frequency range from 10 Hz to 1 000 Hz. For machines with speeds below 600 r/min the relevant frequency range is from 2 Hz to 1 000 Hz. In most cases, it is sufficient to measure only vibration velocity. If the vibration spectrum is expected to contain low-frequency components, the evaluation shall be based on broad-band measurements of both velocity and displacement.

Machines of all groups can be installed on rigid or flexible supports. For both types of support, different evaluation zone values are provided in [Table A.1](#) and [Table A.2](#). Guidelines for the support classification are given in [Clause 5](#).

Table A.1 — Classification of vibration severity zones for machines of Group 1: Large machines with rated power above 300 kW; electrical machines with shaft height $H \geq 315$ mm (see [5.2](#))

Support class	Zone boundary	r.m.s. displacement	r.m.s. velocity
		μm	mm/s
Rigid	A/B	29	2,3
	B/C	57	4,5
	C/D	90	7,1
NOTE The r.m.s. displacement is calculated from the velocity value assuming a dominant frequency of 12,5 Hz. Displacement values are provided to give an upper limit of acceptable displacement values (when measured directly via signal integration), and to prevent excessive displacement of non-rotating parts at acceptable vibration velocities on machine with speeds less than 600 r/min (see also Annex D).			

Table A.1 (continued)

Support class	Zone boundary	r.m.s. displacement	r.m.s. velocity
		μm	mm/s
Flexible	A/B	45	3,5
	B/C	90	7,1
	C/D	140	11,0
NOTE The r.m.s. displacement is calculated from the velocity value assuming a dominant frequency of 12,5 Hz. Displacement values are provided to give an upper limit of acceptable displacement values (when measured directly via signal integration), and to prevent excessive displacement of non-rotating parts at acceptable vibration velocities on machine with speeds less than 600 r/min (see also Annex D).			

Table A.2 — Classification of vibration severity zones for machines of Group 2: Medium-sized machines with a rated power above 15 kW up to and including 300 kW; electrical machines with shaft height $160 \text{ mm} \leq H < 315 \text{ mm}$ (see [5.2](#))

Support class	Zone boundary	r.m.s. displacement	r.m.s. velocity
		μm	mm/s
Rigid	A/B	22	1,4
	B/C	45	2,8
	C/D	71	4,5
Flexible	A/B	37	2,3
	B/C	71	4,5
	C/D	113	7,1
NOTE The r.m.s. displacement is calculated from the velocity value assuming a dominant frequency of 10 Hz. Displacement values are provided to give an upper limit of acceptable displacement values (when measured directly via signal integration), and to prevent excessive displacement of non-rotating parts at acceptable vibration velocities on machine with speeds less than 600 r/min (see also Annex D).			

The values shown in [Table A.1](#) and [Table A.2](#) apply to radial vibration measurements taken on all bearings, bearing pedestals, or housings of machines and to axial vibration measurements taken on thrust bearings under steady-state operating conditions at rated speed or within the specified speed range, but do not apply when the machine is undergoing a transient condition (e.g. changing speed or load).

In certain cases, there can be specific features associated with a particular machine which justify the use of different zone boundary values (higher or lower). In such cases, it is common for the manufacturer to explain the reasons for this and, in particular, to confirm that the machine will not be endangered by operating with higher vibration values. All such values are subject to agreement between the manufacturer and the customer.

Annex B (normative)

Evaluation criteria for shaft relative vibration of coupled industrial machines under specified operating conditions

B.1 General

Evaluation zone boundaries are given for machines, based on experience with a range of plant types. This shows that for shaft-relative vibration the allowable values decrease with increasing shaft speed. In addition, caution shall be exercised when using the criteria presented in this annex to ensure that no contact occurs between the rotating shaft and stationary parts. For machines with journal bearings, the clearance within the bearings, if known, shall also be taken into account when setting the zone boundary limits (see [Annex C](#)).

B.2 Vibration magnitude at rated speed under steady-state operating conditions

B.2.1 General

Criterion I is concerned with defining limits for:

- a) shaft vibration magnitude consistent with acceptable dynamic loads on the bearings;
- b) adequate margins on the radial clearance envelope of the machine; and
- c) acceptable vibration transmission into the support structure and foundation.

The maximum shaft vibration magnitude observed at each bearing is assessed against four evaluation zones (see [Figure B.1](#)) which have been established from experience.

B.2.2 Evaluation zone limits

In accordance with the accumulated experience of shaft vibration measurements in this field, the recommended values for the zone boundaries are inversely proportional to the square root of the maximum operating speed of the shaft. The recommended values illustrated in [Figure B.1](#) are derived from [Formula B.1](#), [Formula B.2](#) and [Formula B.3](#):

Zone A/B boundary limit:

$$S_{(p-p)} = 4\,800 / \sqrt{n} \quad (\text{B.1})$$

Zone B/C boundary limit:

$$S_{(p-p)} = 9\,000 / \sqrt{n} \quad (\text{B.2})$$

Zone C/D boundary limit is:

$$S_{(p-p)} = 13\,200 / \sqrt{n} \quad (\text{B.3})$$

where:

n is the maximum operating speed of the shaft in revolutions per minute (r/min);

$S_{(p-p)}$ is the measured peak-to-peak shaft displacement in micrometers (μm);

numerical constants have the unit $\mu\text{m} \cdot \sqrt{\text{r/min}}$ to fit the formulae.

NOTE 1 For a definition of $S_{(p-p)}$ see ISO 20816-1.

NOTE 2 For some applications, in particular machines running below 600 r/min or in machines running above 10 000 r/min, the [Formula B.1](#) to [Formula B.3](#) can result in zone boundary limits which exceed the design clearance of the bearing. In this case an adjustment should be made to ensure the limits used adequately reflect the bearing clearance. For this reason, the acceptance criteria graph is plotted only down to 1 000 r/min. It is suggested that using 600 r/min as the minimum value for n will result in better zone boundary values for machines with lower rotational speeds.

These zone boundary values are not intended to serve as acceptance specifications, which shall be subject to agreement between the machine manufacturer and the customer. However, they provide guidelines for ensuring that gross deficiencies or unrealistic requirements are avoided. In certain cases, there can be specific features associated with a particular machine, which require different zone boundary values (lower or higher) to be used. For example, with a tilting pad bearing it can be necessary to specify alternative vibration limits, whilst in the case of an elliptical bearing different vibration criteria can apply for the directions of maximum and minimum bearing clearance. In particular, the allowable vibration can be related to the journal diameter since, generally, running clearances are greater for larger diameter bearings. Consequently, different values can apply for measurements taken at different bearings on the same rotor line. In such cases, it is necessary to explain the reasons for this and, in particular, to confirm that the machine is not endangered by operating with higher vibration values.

Higher magnitudes of vibration can occur at other measuring positions and under transient conditions, such as start-up and run-down (including passage through critical speed ranges).

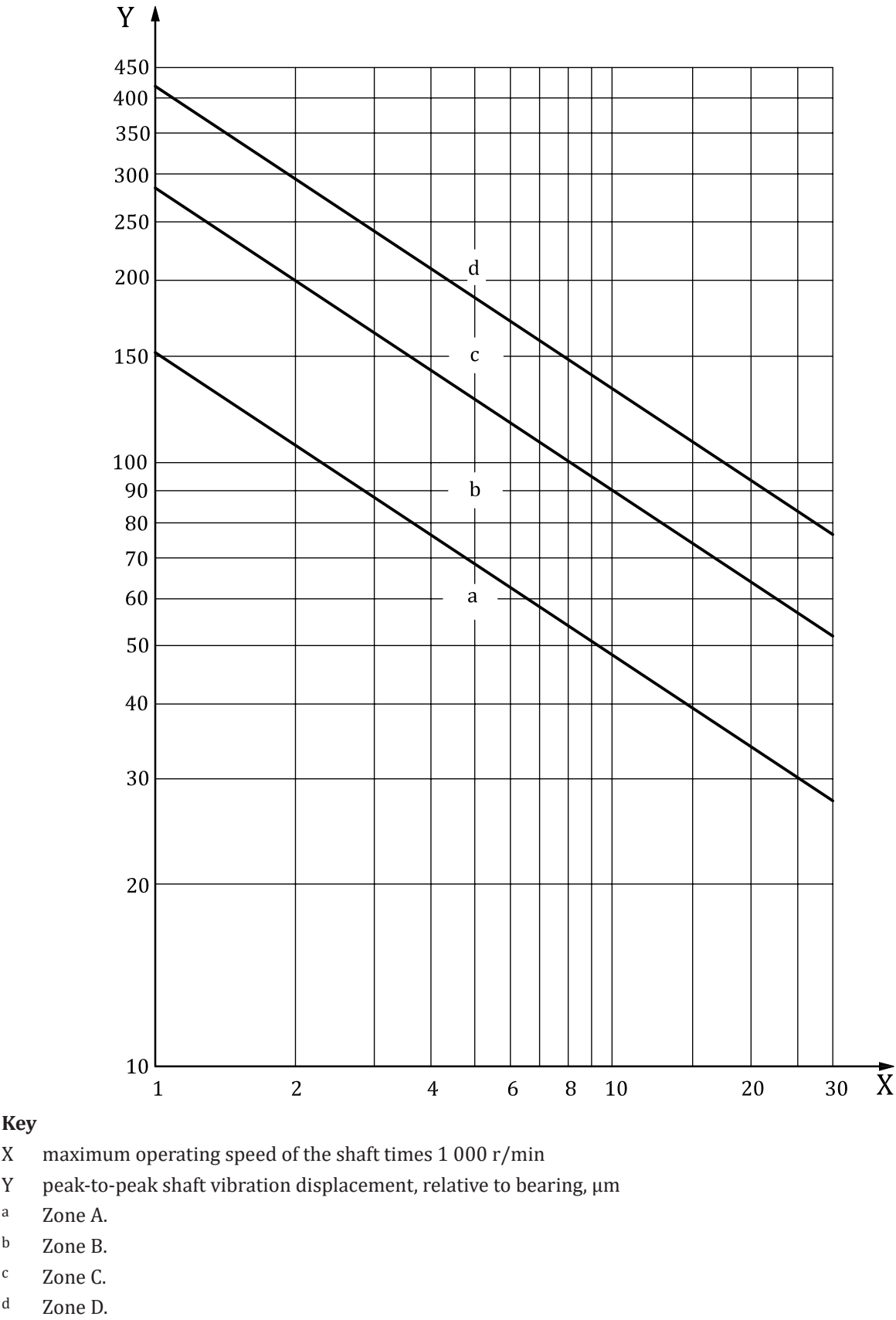


Figure B.1 — Recommended values for maximum shaft relative displacement as a function of the maximum service speed for coupled industrial machines

For some machines – particularly those that run at either very low speed (<10 Hz (<600 r/min)) or very high speed (>200 Hz ($>10\,000$ r/min)) – zone boundaries related to bearing clearance can be applied. For this reason the zone boundaries shown do not extend below 1 000 r/min (see [Annex C](#)).

For vertical machines with journal bearings, the limits can also take into account the bearing clearance when setting the limits, as the bearing clearance has an influence on the possible shaft vibration, where there is no stabilizing force from the weight of the rotor.

Annex C

(informative)

Guidelines for considering the bearing clearance for the specification of evaluation criteria for shaft relative vibration of coupled industrial machines under specified operating conditions

For machines supported by journal bearings, the basic assumption for safe operation is that the shaft relative vibration displacement within the bearing oil film should be such that contact with the bearing is avoided. It should, therefore, be ensured that the shaft relative vibration limits for the evaluation zone boundaries given in [Annex B](#) are consistent with this assumption. In particular, where bearings with clearances comparable to the vibration magnitude are used, it can be necessary to reduce the evaluation zone boundary values. The extent to which this is necessary is dependent on the type of bearing being used and the relationship between the measurement direction and the minimum clearance. In cases where the C/D zone boundary value is in excess of the bearing diametral clearance, it is recommended that the zone boundary limits be reduced, for example:

A/B: 0,4 times bearing clearance;

B/C: 0,6 times bearing clearance; and

C/D: 0,7 times bearing clearance.

The factors 0,4, 0,6 and 0,7 have been chosen to illustrate the principle. Different factors, which should be agreed upon between the supplier and purchaser, apply for different bearing types.

The above example applies to the case where the shaft relative vibration is measured at, or very close to, the bearing oil film. At other measurement positions, where the radial clearances are greater, the limit values specified in [Annex B](#) should be applied.

Annex D

(informative)

Cautionary notes about the use of vibration velocity criteria at low rotational speeds

For the reasons explained in [Annex D](#), it is recommended that the velocity criteria provided in this document should not be applied for frequencies below 2 Hz (120 r/min). For monitoring the vibration at lower speeds, more specialized instrumentation can be required to allow evaluation against other criteria (e.g. constant displacement) which are outside the scope of this document.

The rationale for using vibration velocity measured on non-rotating parts as a basis for characterizing the severity of machine vibration has been derived from field experience (e.g. the pioneering work of Rathbone^[16] in the 1930s), together with an understanding of fundamental mechanics. Based on this, it has been accepted for many years that vibration with the same r.m.s. velocity in the frequency range 10 Hz to 1 000 Hz can generally be considered to be of equal severity. A particular advantage of adopting this approach is that, if vibration velocity is used as an evaluation parameter, the same assessment criteria can be used regardless of the frequency of vibration or the operating speed of the machine. Conversely, if displacement or acceleration were used for evaluation, the assessment criteria would vary with frequency because the relationship between vibration displacement and velocity is inversely proportional to frequency and that between acceleration and velocity is directly proportional to frequency.

The use of a constant-velocity criterion alone becomes impractical at low and high frequencies where the influence of displacement and acceleration, respectively, becomes significant. The ratio of vibration acceleration to velocity is directly proportional to frequency so that at high frequencies, the acceleration corresponding to a constant velocity increases linearly and becomes unacceptably large. However, for the majority of machines, which are the subject of this document, the vibration frequencies are normally not high enough for acceleration to be of concern. Vibration associated with rolling element bearings or gear meshing fall into the category where criteria based on vibration acceleration are needed.

Conversely, the ratio of vibration displacement to velocity is inversely proportional to frequency so that at low frequencies, the displacement corresponding to a constant velocity increases rapidly. This is demonstrated in [Figure D.1](#), which shows how the vibration displacement corresponding to a constant r.m.s. velocity of 4,5 mm/s varies with speed for a once-per-revolution vibration frequency component (e.g. due to unbalance) during run down from 3 600 r/min.

[Figure D.1](#) is simply a mathematical relationship that shows how a constant velocity transposes to displacement at different speeds and demonstrates how a constant velocity criterion can lead to a progressively increasing displacement of the bearing housing as the speed reduces. In such cases, although the dynamic forces transmitted to the bearing housing are acceptable, the vibration displacements can be of concern at lower speeds for ancillary equipment attached to the bearing housing (e.g. oil pipes).

[Figure D.1](#) should not be confused with a normal run-up or run-down response curve for which, apart from when passing through resonance speeds, the vibration velocity normally reduces as the speed is reduced. In practice, if the vibration velocity at rated speed is acceptable, it usually reduces at lower speeds and the corresponding vibration displacements at lower speeds is acceptable. It follows that, if significant vibration velocities are recorded at low speed during run up, even if they are below the values specified in this document and especially if they are significantly outside the range normally experienced at the same speed for that particular machine, action should be taken to understand the reasons for the higher vibration values and to establish whether it is safe to continue to higher speeds.

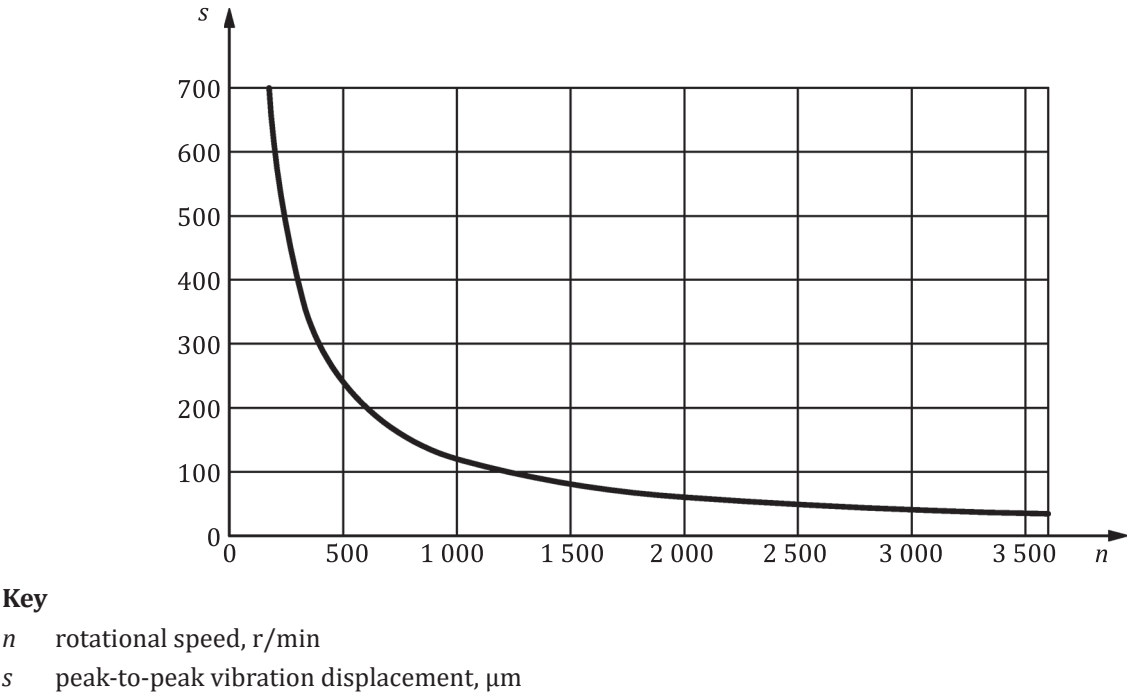


Figure D.1 — Variation of once-per-revolution vibration displacement component with speed for constant r.m.s. vibration velocity of 4,5 mm/s

NOTE When measurements below 10 Hz are taken using a velocity transducer, it is important to linearize the velocity signal (see ISO 2954).

Bibliography

- [1] ISO 496, *Driving and driven machines — Shaft heights*
- [2] ISO 10816-6, *Mechanical vibration — Evaluation of machine vibration by measurements on non-rotating parts — Part 6: Reciprocating machines with power ratings above 100 kW*
- [3] ISO 10816-7, *Mechanical vibration — Evaluation of machine vibration by measurements on non-rotating parts — Part 7: Rotodynamic pumps for industrial applications, including measurements on rotating shafts*
- [4] ISO 10816-21¹⁾, *Mechanical vibration — Evaluation of machine vibration by measurements on non-rotating parts — Part 21: Horizontal axis wind turbines with gearbox*
- [5] ISO 13373-1, *Condition monitoring and diagnostics of machines — Vibration condition monitoring — Part 1: General procedures*
- [6] ISO 13373-2, *Condition monitoring and diagnostics of machines — Vibration condition monitoring — Part 2: Processing, analysis and presentation of vibration data*
- [7] ISO 13373-3, *Condition monitoring and diagnostics of machines — Vibration condition monitoring — Part 3: Guidelines for vibration diagnosis*
- [8] ISO 14694, *Industrial fans — Specifications for balance quality and vibration levels*
- [9] ISO 18436-2, *Condition monitoring and diagnostics of machines — Requirements for qualification and assessment of personnel — Part 2: Vibration condition monitoring and diagnostics*
- [10] ISO 17359, *Condition monitoring and diagnostics of machines — General guidelines*
- [11] ISO 20816-2, *Mechanical vibration — Measurement and evaluation of machine vibration — Part 2: Land-based gas turbines, steam turbines and generators in excess of 40 MW, with fluid-film bearings and rated speeds of 1 500 r/min, 1 800 r/min, 3 000 r/min and 3 600 r/min*
- [12] ISO 20816-4, *Mechanical vibration — Measurement and evaluation of machine vibration — Part 4: Gas turbines in excess of 3 MW, with fluid-film bearings*
- [13] ISO 20816-5, *Mechanical vibration — Measurement and evaluation of machine vibration — Part 5: Machine sets in hydraulic power generating and pump-storage plants*
- [14] ISO 20816-8, *Mechanical vibration — Measurement and evaluation of machine vibration — Part 8: Reciprocating compressor systems*
- [15] ISO 20816-9, *Mechanical vibration — Measurement and evaluation of machine vibration — Part 9: Gear units*
- [16] RATHBONE TC Vibration Tolerances, Power Plant Engineering, 1939

1) To be replaced by ISO 20816-21.

