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Mechanical vibration — Methodology for selecting appropriate machinery vibration standards

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National foreword

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Vibrations mécaniques — Méthodologie pour la sélection des normes appropriées relatives aux vibrations des machines

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Contents

Page

Foreword .... **iv**
1 Scope **1**
2 International Standards **1**
2.1 Basic machinery vibration standards 1
2.2 Related machinery vibration standards 2
2.3 Additional machinery vibration standards 2
3 Terms and definitions **3**
4 Evaluation of machine vibration **3**
4.1 General 3
4.2 Machinery vibration standards and criteria 3
4.3 Classification of severity of machine vibration 4
4.4 Measurement procedures and instrumentation 4
4.5 Vibration standards summaries 4
5 Measurements made on non-rotating parts **5**
6 Measurements made on rotating parts **8**
7 Related standards **9**
8 Analytical guidelines for selecting the appropriate vibration standard for specific machinery **11**
8.1 General 11
8.2 Basic relations for rotating shaft and pedestal vibration 14
Annex A (informative) **Bearing dynamics** **16**
Annex B (informative) **Pedestal dynamic stiffness** **19**
Annex C (informative) **Examples of typical values of dynamic stiffness for bearings and pedestals** **20**
Annex D (informative) **Dynamic stiffness of the bearing part combined with the pedestal** **22**
Annex E (informative) **International machinery vibration standards shown by application area** **24**
Bibliography **28**

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 described 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, www.iso.org/directives.

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The committee responsible for this document is 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*.

Mechanical vibration — Methodology for selecting appropriate machinery vibration standards

1 Scope

This Technical Report provides guidance for selecting appropriate vibration standards for specific machine types, and thus selecting the appropriate vibration measurement and evaluation method. Synopses are given of ISO 10816 (evaluation of machine vibration on non-rotating parts) and ISO 7919 (evaluation of machine vibration on rotating parts), together with further International Standards related to machinery.

This Technical Report provides an overview of the relevant International Standards, giving a summary of their scopes. It also provides a theoretical, analytical basis for establishing whether vibration measurements should be carried out on non-rotating parts, rotating shafts or both for those machines where no previous experience exists. It is not intended to supersede established manufacturers' or users' practical experience with specific machine types since there can be specific features associated with a particular machine which lead to a different selection of the most relevant measurement procedure.

The aim of this Technical Report is not to equip the reader with all the technical details provided in the International Standards necessary to carry out a measurement or evaluation task on a particular machine; rather it guides the reader to the appropriate International Standards. It is these International Standards that provide the necessary details; and then, with suitable training, the reader is in a position to carry out the measurement or evaluation task.

2 International Standards

NOTE 1 The International Standards referred to in this Technical Report are periodically reviewed. Care needs to be taken when using the International Standards presented to ensure that the latest edition (including any Amendments and Corrigenda) is used.

NOTE 2 Many of the International Standards discussed in this Technical Report together with additional International Standards are summarized by their application area in Table E.1.

NOTE 3 This Technical Report provides a snapshot of current relevant standards. It is inevitable, however, that as time passes new standards will be developed. Furthermore, there may be other standards available for specific machine types which have not been referred to. The absence of any such reference should not be interpreted as meaning that such standards are not valid.

2.1 Basic machinery vibration standards

ISO 7919-1, *Mechanical vibration of non-reciprocating machines — Measurements on rotating shafts and evaluation criteria — Part 1: General guidelines*

ISO 7919-2, *Mechanical vibration — Evaluation of machine vibration by measurements on rotating shafts — Part 2: Land-based steam turbines and generators in excess of 50 MW with normal operating speeds of 1 500 r/min, 1 800 r/min, 3 000 r/min and 3 600 r/min*

ISO 7919-3, *Mechanical vibration — Evaluation of machine vibration by measurements on rotating shafts — Part 3: Coupled industrial machines*

ISO 7919-4, *Mechanical vibration — Evaluation of machine vibration by measurements on rotating shafts — Part 4: Gas turbine sets with fluid-film bearings*

ISO 7919-5, *Mechanical vibration — Evaluation of machine vibration by measurements on rotating shafts — Part 5: Machine sets in hydraulic power generating and pumping plants*

ISO 10816-1, *Mechanical vibration — Evaluation of machine vibration by measurements on non-rotating parts — Part 1: General guidelines*

ISO 10816-2, *Mechanical vibration — Evaluation of machine vibration by measurements on non-rotating parts — Part 2: Land-based steam turbines and generators in excess of 50 MW with normal operating speeds of 1 500 r/min, 1 800 r/min, 3 000 r/min and 3 600 r/min*

ISO 10816-3, *Mechanical vibration — Evaluation of machine vibration by measurements on non-rotating parts — Part 3: Industrial machines with nominal power above 15 kW and nominal speeds between 120 r/min and 15 000 r/min when measured in situ*

ISO 10816-4, *Mechanical vibration — Evaluation of machine vibration by measurements on non-rotating parts — Part 4: Gas turbine sets with fluid-film bearings*

ISO 10816-5, *Mechanical vibration — Evaluation of machine vibration by measurements on non-rotating parts — Part 5: Machine sets in hydraulic power generating and pumping plants*

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*

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*

ISO 10816-8, *Mechanical vibration — Evaluation of machine vibration by measurements on non-rotating parts — Part 8: Reciprocating compressor systems*

2.2 Related machinery vibration standards

ISO 3046-5, *Reciprocating internal combustion engines — Performance — Part 5: Torsional vibrations*

ISO 8579-2, *Acceptance code for gears — Part 2: Determination of mechanical vibrations of gear units during acceptance testing*

ISO 13373-1, *Condition monitoring and diagnostics of machines — Vibration condition monitoring — Part 1: General procedures*

ISO 13373-2, *Condition monitoring and diagnostics of machines — Vibration condition monitoring — Part 2: Processing, analysis and presentation of vibration data*

ISO 13373-3,[1] *Condition monitoring and diagnostics of machines — Vibration condition monitoring — Part 3: Guidelines for vibration diagnosis*

ISO 14694, *Industrial fans — Specifications for balance quality and vibration levels*

ISO 14695, *Industrial fans — Method of measurement of fan vibration*

2.3 Additional machinery vibration standards

ISO 1925, *Mechanical vibration — Balancing — Vocabulary*[2]

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 5348, *Mechanical vibration and shock — Mechanical mounting of accelerometers*

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

1) Planned.

2) To become ISO 21940-2 when revised.

ISO 21940-31, *Mechanical vibration — Rotor balancing — Part 31: Susceptibility and sensitivity of machines to unbalance*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 1925 and ISO 2041, and the following apply.

3.1
shaft absolute vibration
vibration of the shaft measured from the absolute coordinate

3.2
shaft relative vibration
vibration of the shaft measured from the transducer support (e.g. bearing housing)

3.3
pedestal vibration
bearing support structure vibration

3.4
dynamic stiffness of bearing
stiffness of the bearing part including damping and mass effects

3.5
dynamic stiffness of pedestal
stiffness of the bearing support structure including damping and mass effects

4 Evaluation of machine vibration

4.1 General

ISO 10816 provides guidelines for the measurement and evaluation of vibration for different machine types based on measurements made on non-rotating parts of the machines.

ISO 7919 provides guidelines for the measurement and evaluation of vibration based on measurements made on rotating shafts of the machines.

Further guidance is provided in the related and additional machinery vibration standards listed in 2.2 and 2.3.

4.2 Machinery vibration standards and criteria

Machinery can be subdivided into four categories for the purposes of vibration measurement and evaluation.

a) *Reciprocating machinery having both rotating and reciprocation components*, such as diesel engines and certain types of compressors and pumps. The vibration is usually measured on the main structure of the machine at low frequencies, typically in the range 2 Hz to 1 000 Hz.

b) *Rotating machinery having rotors with rigid behaviour*, such as certain types of electric motors, single-stage pumps and low rotational speed pumps. The vibration is usually measured on the main structure (such as on the bearing caps or pedestals) where the vibration magnitudes are indicative of the excitation forces generated by the rotor because of unbalance, thermal bows, rubs and other sources of excitation.

c) *Rotating machinery having rotors with flexible behaviour*, such as large steam and gas turbine generator sets, multi-stage pumps and compressors. The machine may be set into different modes of vibration as it accelerates through one or more resonance rotational speeds to reach its service rotational speed. On such a machine, the vibration magnitude measured on a structural member may not be totally indicative of the vibration of the rotor. For example, a flexible rotor may experience very large displacements resulting in failure of the machine, even though the vibration magnitude measured on the bearing cap is low. Therefore, it can be necessary to measure the vibration of the shaft directly.

d) *Rotating machinery having rotors with quasi-rigid behaviour*, such as some steam turbine rotors, axial-flow compressors, and fans. Such machinery contains a special class of flexible rotor where vibration magnitudes measured on the bearing cap are indicative of the shaft vibration.

An analytical approach to determine the most beneficial vibration measurement method (or International Standard) to use on a particular machine, based on the physical and structural characteristics of the machine, is included in detail in Clause 8.

4.3 Classification of severity of machine vibration

In the classification of severity of machine vibration, the motion variable that is used (displacement, velocity or acceleration) depends on the applicable International Standard, the frequency range and other factors. In classifying machinery vibration in a range, e.g. 10 Hz to 1 000 Hz, vibration velocity is normally used because it yields a simple measure of the vibration severity of a machine. For lower- and higher-frequency vibration, the preferred measurement quantities are displacement and acceleration, respectively.

For simple harmonic motion, either peak or root mean square (r.m.s.) values of the motion variable may be used. However, for machines whose motion is complex, the use of these two metrics provides distinctly different results, mainly because of particular waveforms such as pulse-like waves or higher-frequency harmonics and are given different weights. For rotating machinery whose rotational speed is in the range 600 r/min to 12 000 r/min, the r.m.s. values of vibration velocity correspond most closely with vibration severity. Therefore, there is a special measure, vibration severity, which has been defined in the past as the highest value of the broadband r.m.s. value of the velocity magnitude in the frequency range 10 Hz to 1 000 Hz, as evaluated on the structure at prescribed points as defined in the relevant standard for that machine type (e.g. ISO 10816-2).

NOTE Nowadays vibration severity is a general term for the maximum measured vibration value on non-rotating parts of a machine, irrespective of whether it is displacement, velocity or acceleration (see ISO 2954).

4.4 Measurement procedures and instrumentation

Included in the referenced International Standards are procedures for measuring relative shaft-to-housing signals, absolute measurements and seismic applications.

The transducers recommended and described include displacement, velocity and acceleration; their mounted and unmounted ranges and limits of application, magnitudes and frequencies are included. ISO 2954 provides specifications of instruments measuring vibration of machinery housings. ISO 5348 provides recommendations for mounting accelerometers to the machinery housing, which in most cases are also applicable to velocity transducers. ISO 10817-1 describes the sensing device (transducer), signal conditioning, attachment methods and calibration procedures for instrumentation to measure shaft vibration.

4.5 Vibration standards summaries

Clauses 5 and 6 contain brief descriptions of the most prominent machinery vibration standards, either issued or under development. They contain broadband measurement procedures and limit values and zones. Clause 5 includes: measurements on non-rotating parts; reciprocating machines; measurements on non-reciprocating rotating shafts; and machines having gear units. Clause 6 includes similar measurement procedures, limit values and zones on rotating shafts. Also considered are measurements on machines with rotors with rigid or flexible behaviour. Consult each individual International Standard for details regarding machinery type and size and vibration limits for zones of operation, from acceptable to critical.

Clause 7 includes brief summaries of related International Standards besides ISO 7919 and ISO 10816.

5 Measurements made on non-rotating parts

5.1 ISO 10816-1 provides general guidelines that describe procedures for the measurement and evaluation of vibration based on measurements made on non-rotating parts of the machine. This is the first part of a series of International Standards that provide individual criteria for each general class of machine covered, which are unique to those machines. These criteria, which are presented in terms of both vibration magnitude and change of vibration, relate to operational monitoring and acceptance testing.

ISO 10816 accomplishes the following:

a) coverage of the broadband frequency range of both low and high rotational speed machines;

b) setting of vibration criteria to include various operational zones;

c) incorporation of vibration criteria derived from a worldwide survey;

d) inclusion of unique criteria and measurement procedures for specific types of machines.

General guidelines for establishing evaluation zones under steady-state operating and transient conditions are described. These provide the basis for the machine-specific evaluation criteria in the subsequent parts of ISO 10816. The zones are defined as follows.

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

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.

The vibration limits for the zone boundaries provide guidelines for ensuring that gross deficiencies or unrealistic requirements are avoided. Acceptance criteria shall always be subject to agreement between the machine supplier and purchaser prior to installation. The evaluation zones provide a basis for defining acceptance criteria for new or refurbished machines. Historically, acceptance criteria have been specified in zone A or zone B but would normally not exceed 1,25 times the zone boundary A/B.

The measure of vibration is broadband and the frequency range is sufficient to ensure that the particular machine is adequately covered, which depends on the type of machine under consideration, e.g. the frequency range necessary to assess the integrity of a machine with rolling element bearings should include frequencies higher than those on machines with fluid-film bearings. In addition to vibration velocity measurements, which were the primary criteria in earlier International Standards because they related to vibration energy, ISO 10816 also includes alternative criteria such as displacement, acceleration and peak values instead of r.m.s., as these criteria may be preferred for machines designed for extra low or high rotational speed operation.

5.2 ISO 10816-2 provides specific guidance for assigning the severity of vibration measured on the bearings or pedestals of large steam turbine generator sets. Measurements at such specified locations reasonably characterize the overall state of vibration of these machines.

The vibration measurement system should be capable of measuring broadband r.m.s. vibration over a frequency range from at least 10 Hz to 500 Hz. If, however, the instrumentation is also to be used for diagnostic purposes, or for monitoring during machine run-up or run-down, or overspeed, a wider frequency range may be required.

ISO 10816-2 includes the vibration criteria that are based on bearing housing or pedestal r.m.s. vibration velocity for steam turbine generator sets exceeding 50 MW, and with nominal rotational speeds of 1 500 r/min, 1 800 r/min, 3 000 r/min and 3 600 r/min. The values apply to *in situ* application under steady-state conditions and they address various zones of operation. The zone descriptions are the same as in ISO 10816-1. Transient operating conditions, such as load and rotational speed changes, are also covered.

5.3 ISO 10816-3 provides specific guidance for assessing the severity of vibration on bearings, bearing pedestals or the housings of coupled industrial machines when measured *in situ*. ISO 10816-3 covers steam turbines up to 50 MW and steam turbine sets with power greater than 50 MW and rotational speeds below 1 500 r/min or above 3 600 r/min. Also included are compressors, industrial gas turbines with power up to 3 MW, generators (other than those covered by ISO 10816-2), electric motors of any type, and all blowers and fans with power greater than 300 kW and other fans that are not too flexibly mounted. It also covers those pumps which are not dealt with by ISO 10816-7.

Significant differences in design, type of bearings and type of support structures require a division in ISO 10816-3 into two machinery groups, namely:

a) group 1: large machines with rated power above 300 kW or electrical machines with shaft heights equal to or above 315 mm;

b) group 2: medium-sized machines with a rated power above 15 kW up to and including 300 kW or electrical machines with shaft heights from 160 mm up to less than 315 mm.

The larger machines normally have sleeve bearings and the range of operating or nominal rotational speeds is relatively broad, ranging from 120 r/min to 15 000 r/min.

Classifications of the vibration severity zones for large industrial machines with rated power from 300 kW to 50 MW (group 1) are included. Classifications of the vibration severity zones for medium-sized industrial machines with rated power from 15 kW to 300 kW (group 2) are also included. The zone descriptions are the same as in ISO 10816-1.

5.4 ISO 10816-4 provides specific guidance for assessing the severity of vibration measured on the bearing housings or pedestals of gas turbine sets with fluid-film bearings.

ISO 10816-4 applies to heavy-duty gas turbines used in electrical and mechanical drive applications covering the power range above 3 MW and a rotational speed range under load between 3 000 r/min and 30 000 r/min. Generally, the criteria apply to both the gas turbine and the driven equipment. For generators above 50 MW, the criteria of ISO 10816-2 are used for assessing the vibration severity and ISO 10816-3 for generators rated up to and including 50 MW.

The evaluation of zone boundaries based on bearing housing or pedestal vibration for industrial gas turbines is included. These criteria assume that the gas turbines incorporate fluid-film bearings and the vibration measurements are broadband values taken *in situ* under normal steady-state operating conditions. Transient operating conditions, such as load changes and rotational speed changes, are also covered. ISO 10816-4 encompasses machines which may have gears, but does not address the evaluation of the condition of those gears. The zone descriptions are the same as in ISO 10816-1.

5.5 ISO 10816-5 provides specific guidance for assessing the severity of vibration measured on bearings, bearing pedestals or housings of hydraulic machines when measured *in situ*. ISO 10816-5 applies to machine sets in hydraulic power generation and pumping plants where the hydraulic machines have rotational speeds from 120 r/min to 1 800 r/min, shell or shoe type sleeve bearings and main engine power of 1 MW or more. The position of the shaft line may be vertical, horizontal or at an arbitrary angle between these two directions.

ISO 10816-5 includes: turbines and generators, pumps and electrical machines operating as motors, pump-turbines and motor generators, including auxiliary equipment (e.g. starting turbines or exciters in line with the main shaft). ISO 10816-5 also includes single turbines or pumps connected to generators or electric motors through gears and/or flexible couplings.

Recommended r.m.s. vibration criteria as a function of shaft rotational speed for hydraulic machines with nominal power above 1 MW and nominal rotational speeds between 120 r/min and 1 800 r/min are included.

5.6 ISO 10816-6 establishes procedures and guidelines for the measurement and classification of mechanical vibration of reciprocating machines. In general, ISO 10816-6 refers to vibration measurements made on the main structure of the machine and the limit values are defined primarily to secure a reliable and safe operation of the machine, and to avoid problems with the auxiliary equipment mounted on the machine structure.

In the case of reciprocating machines, the vibration measured on the machine main structure, and qualified according to ISO 10816-6, may only give a rough idea of the stresses and vibratory states of the components within the machine itself, e.g. torsional vibration of rotating parts cannot generally be determined by measurements on the structural parts of the machine. Based on experience with similar machines, the damage that can occur when exceeding the limit values is sustained predominately by the machine-mounted components (e.g. turbochargers, heat exchangers, governors, pumps, filters) connecting elements of the machine with peripherals (e.g. pipelines) or monitoring instruments (e.g. pressure gauges, thermometers).

ISO 10816-6 generally applies to reciprocating piston machines mounted either rigidly or resiliently with power ratings above 100 kW. Typical examples of application are: marine propulsion engines, marine auxiliary engines, engines operating in diesel generating sets, gas compressors, and diesel locomotives. Maximum magnitudes of vibration displacement, velocity and acceleration are given, and a vibration severity nomograph is included.

5.7 ISO 10816-7 provides guidance for the evaluation of vibration on rotodynamic pumps for industrial applications with nominal power above 1 kW. ISO 10816-7 describes the requirements for evaluation of vibration measurements on non-rotating parts. ISO 10816-7 also provides guidance for assessing the severity of vibration measured on the bearings, both *in situ* or at the manufacturer's test facility, or in the plant. Zones and limits are provided for acceptance tests at the manufacturer's test facility, if specified, and special criteria are given. The included zone limits are for the vibration of horizontal and vertical pumps, irrespective of their support flexibility.

For long-term operation, two additional criteria are provided. One criterion considers the magnitude of the observed vibration and the second considers changes in magnitude. The criteria are applicable for the vibration produced by the machine itself, and not for vibration transmitted to the machine from external sources. Therefore, vibration velocity limits are provided for the two categories, with both zone and test acceptance values given for pumps ≤200 kW and >200 kW. Zone and test acceptance limit values of displacement are also provided.

5.8 ISO 10816-8 establishes procedures and guidelines for the measurement and classification of mechanical vibration of reciprocating compressor systems. The vibration values are defined primarily to classify the vibration of the compressor system and to avoid fatigue problems with parts in the reciprocating compressor system, i.e. foundation, compressor, dampers, piping and auxiliary equipment mounted on the compressor system. The guidelines are not intended for condition monitoring purposes.

ISO 10816-8 applies to reciprocating compressors mounted rigidly with typical rotational speed ratings greater than 120 r/min and up to and including 1 800 r/min. Guidance values for acceptable overall vibration displacement, velocity and acceleration for horizontal and vertical compressor systems are given. The general evaluation criteria relate to operational measurements. The criteria are also used to ensure that machine vibration does not adversely affect the equipment directly mounted on the machine, e.g. pulsation dampers and the pipe system.

It is recognized that the evaluation criteria might only have limited application when considering the effects of internal machine components, e.g. problems associated with valves, pistons or piston rings might be unlikely to be detected in the measurements. Identification of such problems can require investigative diagnostic techniques which are outside the scope of ISO 10816-8.

ISO 10816-8 does not apply to hyper compressors. Noise is also outside the scope of ISO 10816-8. The zone descriptions are different from ISO 10816-1.

6 Measurements made on rotating parts

6.1 ISO 7919-1 provides specific guidelines for vibration measurements on the rotating shafts of machines. Such machines generally contain flexible rotor-shaft systems and changes in the vibration condition can be detected more decisively and more sensitively by measurements on these rotating elements. Also, machines having relatively stiff and/or heavy casings, in comparison to the rotor mass, are typical of those classes of machines for which shaft vibration measurements are frequently preferred.

Machines such as industrial steam turbines, gas turbines, and turbocompressors, all of which have several modes of vibration in their service rotational speed range and their responses due to unbalance, misalignments, thermal bows, rubs, and the unloading of bearings, can be better observed by measurements on the shafts.

There are three principal factors by which the vibration magnitude of a machine is judged:

— bearing kinetic load;

— absolute motion of the rotor;

— rotor clearance relative to the bearing.

If the bearing kinetic load is of concern to ensure against bearing damage, the vibration of the shaft relative to the bearing structure should be monitored as the overriding criteria. If the absolute motions of the shaft (a measure of rotor bending stress) or rotor-bearing clearance are of concern, the type of measurement used depends on the vibration magnitude of the structure which supports the relative-motion transducer. Hence, if the vibration magnitude of this support structure is significant, the absolute shaft vibration is the more valid measurement. The rotor clearance to the bearing needs to be monitored to ensure against rotor seal and blading rubs which can cause rotor or blading failures.

The shaft vibration of machines, measured close to the bearings, is evaluated on the basis of two criteria.

a) Criterion I. The reliable and safe running of a machine under normal operating conditions requires that the shaft vibration displacement remains below certain limits consistent with, for example, acceptable kinetic loads and adequate margins on the radial clearance envelope for the machine. The maximum shaft vibration is assessed against evaluation zones.

b) Criterion II. Changes in shaft vibration displacement, even though the limits in a) are not exceeded, can point to incipient damage or some other irregularity. Consequently, such changes relative to a reference value should not be allowed to exceed certain limits. If this reference value changes by a significant amount, steps should be taken to ascertain the reasons for the change and, if necessary, appropriate action taken. In this context, a decision on what action to take, if any, should be made after consideration of the maximum magnitude of the vibration, and whether the machine has stabilized at a new condition.

General guidelines for establishing evaluation zones under steady-state operating conditions are described which provide the basis for the machine-specific evaluation criteria in the subsequent parts of ISO 7919. The definition and application of the different zones are the same as those adopted for ISO 10816 (see Clause 5).

6.2 ISO 7919-2 provides the special features required for measuring shaft vibration on the coupled rotor systems of steam turbine generator sets for power stations, having rated rotational speeds in the range 1 500 r/min to 3 600 r/min, and power outputs greater than 50 MW. Evaluation criteria, based on experience, are presented which can be used as guidelines for assessing the vibratory conditions of such machines.

The vibration magnitudes specified are for both relative and absolute shaft vibration measured at, or close to, the main load carrying bearings, at rated rotational speed and under steady-state conditions. Higher magnitudes of vibration can be permitted at other measuring positions and under transient conditions, such as start-up and run-down (including passing through resonance rotational speed ranges).

The recommended shaft vibration values for large steam turbine generator sets measured relative to the bearings are included for relative shaft-to-bearing vibration and for absolute shaft vibration. These limit values are graphically shown as severity zones. The definition of these zones is the same as that in ISO 7919-1. Also included are the bearing clearance effects on the zone boundaries.

6.3 ISO 7919-3 gives guidelines for application of evaluation criteria for shaft vibration measured close to the bearings under normal operating conditions. These guidelines are presented in terms of both steady-state conditions and any changes that can occur in these steady values. ISO 7919-3 applies to coupled industrial machines with fluid-film bearings, comprising: turbocompressors, turbines, turbine generators and electric drives, all having maximum rated rotational speeds in the range 1 000 r/min to 30 000 r/min, and powers between 30 kW and 50 MW.

The numerical values specified are not intended to serve as the only basis for acceptance specifications. In general, the vibratory condition of these machines is usually assessed by consideration of both the shaft vibration and the associated casing vibration. As a result, ISO 7919-3 should be used in conjunction with ISO 10816-3. The zone descriptions are the same as those in ISO 7919-1.

6.4 ISO 7919-4 applies to industrial gas turbine sets (including those with gears) with fluid-film bearings, power outputs greater than 3 MW and shaft rotational speeds from 3 000 r/min to 30 000 r/min. Aircraft type gas turbines are excluded, since they differ fundamentally from industrial gas turbines, both in the type of bearings (rolling element) and in the stiffness and mass ratios of the rotors and support structures. Depending on the construction and mode of operation, there are three types of industrial gas turbines:

a) single-shaft constant rotational speed;

b) single-shaft variable rotational speed;

c) gas turbines having separate shafts for hot-gas generation and power delivery.

Guidelines are given for the application of criteria for shaft vibration measured close to the bearings of industrial gas turbines under normal operating conditions. The zone descriptions are the same as those in ISO 7919-1. Transient operating conditions, such as load and rotational speed changes, are also covered. For gas turbine driven generators above 50 MW, the criteria of ISO 7919-2 are used for assessing the vibration severity and ISO 7919-3 for generators rated up to and including 50 MW.

6.5 ISO 7919-5 lists the special features required for measuring shaft vibration on coupled hydraulic machine sets. ISO 7919-5 applies to all types of hydraulic machines having nominal rotational speeds between 60 r/min and 3 600 r/min, with fluid-film bearings and rated powers of 1 MW or more. These machines may consist of turbines, pumps, pump turbines, generators, motors and motor generators, including couplings, gears or auxiliary equipment in the shaft line. The position of the shaft may be vertical, horizontal or at an arbitrary angle between these two directions.

The guidelines are given for the application of criteria for shaft vibration measured close to the bearings of coupled hydraulic machine sets, under normal operating and steady-state conditions, and any changes that can occur in these steady values. The numerical values specified present rotor displacements relative to the bearings as a function of shaft rotational speed.

7 Related standards

7.1 ISO 3046-5 includes the establishment of general requirements and definitions for the torsional vibration in shaft systems driven by reciprocating internal combustion (RIC) engines. ISO 3046-5 covers machine sets driven by internal combustion engines for land, rail-traction and marine use, excluding sets used to propel road construction and earth-moving machines, agricultural tractors, industrial types of tractors, automobiles and trucks, and aircraft.

ISO 3046-5 defines the methods used to analyse free vibration and forced vibration, and the calculation results determine, amongst others, the following:

a) the natural frequencies, natural vectors and resonance rotational speeds;

b) the torsional stresses in the shaft system;

c) the vibratory techniques in elastic couplings and other items influenced by these techniques;

d) the vibratory magnitudes at given points of the shaft line;

e) the thermal power generated in couplings and the other damping sources.

The results can also be used, if necessary, to obtain the vibratory accelerations in gears.

7.2 ISO 8579-2 specifies the methods for determining mechanical vibration of individually housed, enclosed, rotational speed-increasing and speed-reducing gear units. The methods include measuring housing and shaft vibrations, and the types of instrumentation, measurement methods and testing procedures for determining vibration magnitudes. Vibration grades for acceptance are included.

ISO 8579-2 applies only to gear units under test and operating within their design rotational speeds, loads, temperature ranges and lubrication for acceptance testing at the manufacturer's facility. Other specifications can be required for measuring gear unit vibration in field service. In addition, ISO 8579-2 does not apply to special or auxiliary drive trains such as integrated gear-driven compressors, pumps, turbines and power take-off gears.

7.3 ISO 13373-1 includes general guidelines for the measurement and data collection functions necessary for the assessment of machinery vibration for condition monitoring and diagnostics. ISO 13373-1 is applicable to all kinds of rotating machines. ISO 13373-1 describes the various transducer types and their ranges, and the narrowband analysis procedures and techniques recommended to perform discrete frequency analyses of the vibration signals. Also taken into consideration are transducer resonance frequency characteristics and mounted frequency concerns.

Data collection techniques include continuous, periodic and intermittent, and procedures recommended for trending the vibration data are described. It contains a table of machine types (turbines, generators, motors, pumps, etc.), and their recommended transducer locations and types to achieve the best results, and additionally includes a comprehensive list of the most common causes of vibration-related machine problems.

7.4 ISO 13373-2 provides guidelines for processing vibration data, the time and frequency domains, analysing the vibration signatures, displaying the data and applying the results of the analyses to machinery condition and then to diagnostics. Analogue and digital equipment and analysis techniques and filtering types are described.

Various signature characteristics are displayed and brief descriptions are given to identify what they represent. The windows and the descriptions included are some of the most commonly used machinery analysis tools used by analytical engineers and technicians when investigating a machinery problem; the tools comprise waveform characteristics, beating and modulation, Bode and polar plots, time and frequency domain averaging, cascade (waterfall) diagrams.

7.5 ISO 13373-3[1)] is to be used by vibration practitioners, engineers and technicians as it provides a framework for the selection and application of vibration diagnostic techniques for a range of machine and component types and their associated fault symptoms.

The systematic approach to diagnostics starts with a series of pertinent questions that establishes the information base on the machine's operating characteristics. This procedure is followed by a series of flow charts that delineate logical diagnostic step-by-step procedures for various machine and component types.

7.6 ISO 14694 gives the specifications for vibration and balance limits of fans for all applications except those designed solely for air circulation, e.g. ceiling fans and table fans. However, it is limited to fans of all types installed with power of less than 300 kW, or to a commercially available standard electric motor with a maximum power of 355 kW (following an R20 series). For fans of greater power than this, the applicable limits are those given in ISO 10816-3.

ISO 14694 recognizes that vibrational measurements can be recorded as velocity, acceleration or displacement, either in absolute units or in decibels above a given reference value. The magnitude of the vibration measurements can be affected by assembly practices at balancing machines. The preferred parameter is vibration velocity for which both r.m.s. and peak-to-peak, or peak, values are given.

Factory tests are usually conducted with the fan unconnected to a ducting system, such that its aerodynamic duty can be different from the installed conditions. It might also be supported on foundations of different mass and stiffness values to those *in situ*. Accordingly, such tests are specified with vibration measured "filter-in". *In situ* tests are specified "filter-out" and as such represent a measure of overall severity. ISO 14694 does not include the final installed conditions such as foundation characteristics, aerodynamics, cleanliness and maintenance.

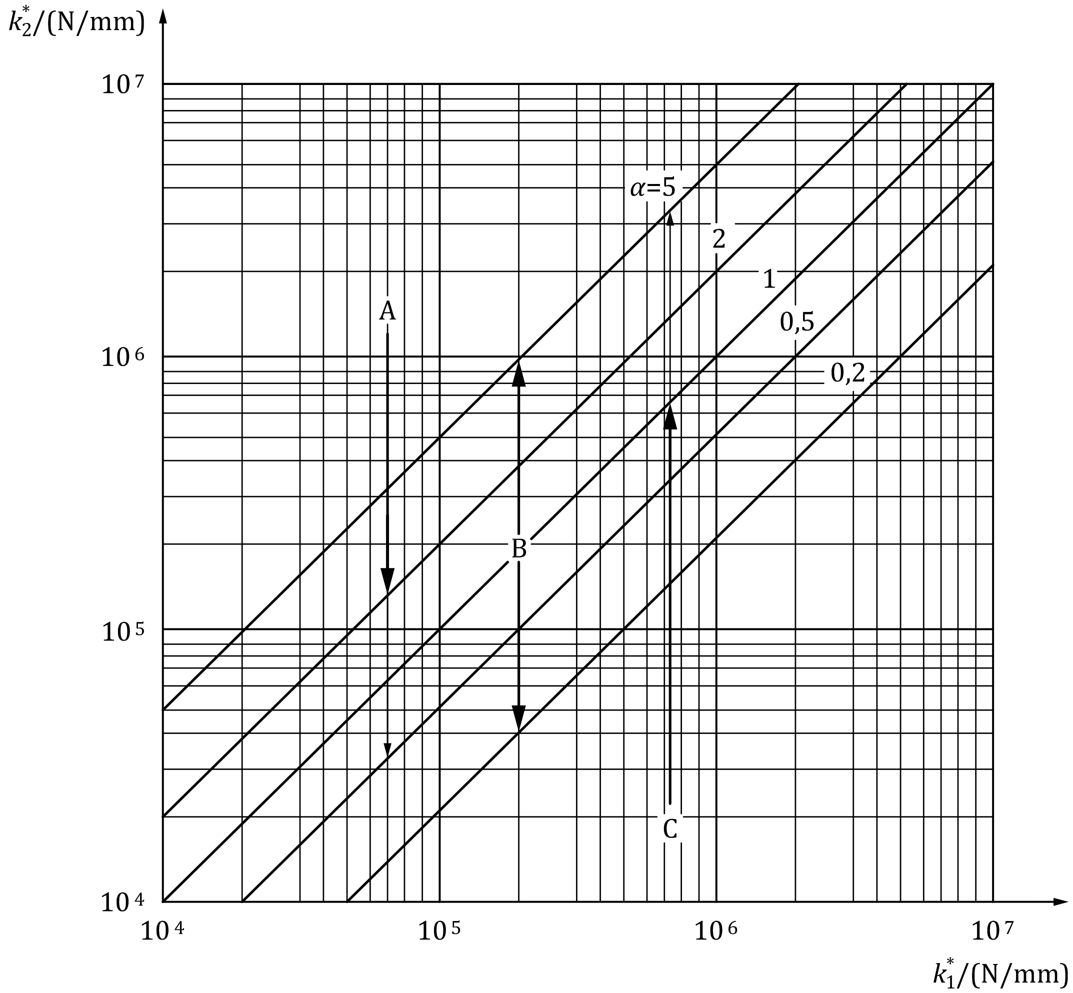
7.7 ISO 14695 contains a method of measuring the vibrational characteristics of fans of all types, except as in ISO 14694 those designed solely for air circulation, and all types installed with a power of less than 300 kW. For fans of greater power than this, the methods described in ISO 10816-1 and the applicable limits in ISO 10816-3 may be used. ISO 14695 gives a general method only and does not give criteria for the interpretation of data (for that aim, see ISO 14694).

ISO 14695 specifies the measurement of vibration that may be recorded as overall r.m.s. velocity, acceleration or displacement, or in terms of a frequency spectrum, within the appropriate frequency range. Methods of testing when suspended on elastic ropes or when installed on resilient mountings are included. Also, it is recognized that the oscillatory forces at mounting points can be a useful measurement for analysing the effects on support structures, but such measurements are outside the scope of ISO 14695.

8 Analytical guidelines for selecting the appropriate vibration standard for specific machinery

8.1 General

The following describes an analytical method that can be used when selecting a vibration measurement method, based on the dynamics of a given machine, characterized by the dynamic stiffness ratio, α, which is the dynamic stiffness of the pedestal divided by the dynamic stiffness of the bearing (additional information can be found in Annexes A and B). Actual example stiffness values are given in Annex C. Figure 1 is used to determine the vibration measurement method from α.



Key

k_2^*	dynamic stiffness of pedestal modulus	A	range for shaft relative vibration measurements
k_1^*	dynamic stiffness of bearing modulus	B	range for shaft absolute vibration measurements
α	dynamic stifffness ratio	C	range for pedestal vibration measurements
	typical		applicable

Figure 1 — Determination of the vibration measurement method from the dynamic stiffness ratio α

EXAMPLE If α = 2 either shaft relative vibration (A) or shaft absolute vibration (B) are typically measured while pedestal vibration (C) is measured only in exceptional cases.

The analytical method for selecting an appropriate International Standard is particularly applicable to ISO 7919 and ISO 10816. The guideline for this approach is shown in Figure 2. This flow chart is convenient for the engineers and designers of rotating machinery; however, most field engineers might not know the dynamic characteristics of the bearing and the pedestal. However, field engineers do have access to the actual machines.

NOTE There may be circumstances when shaft measurements can be required in addition to those taken at the pedestal (e.g. condition monitoring, orbits and bearing lifts), see ISO 13373-1.

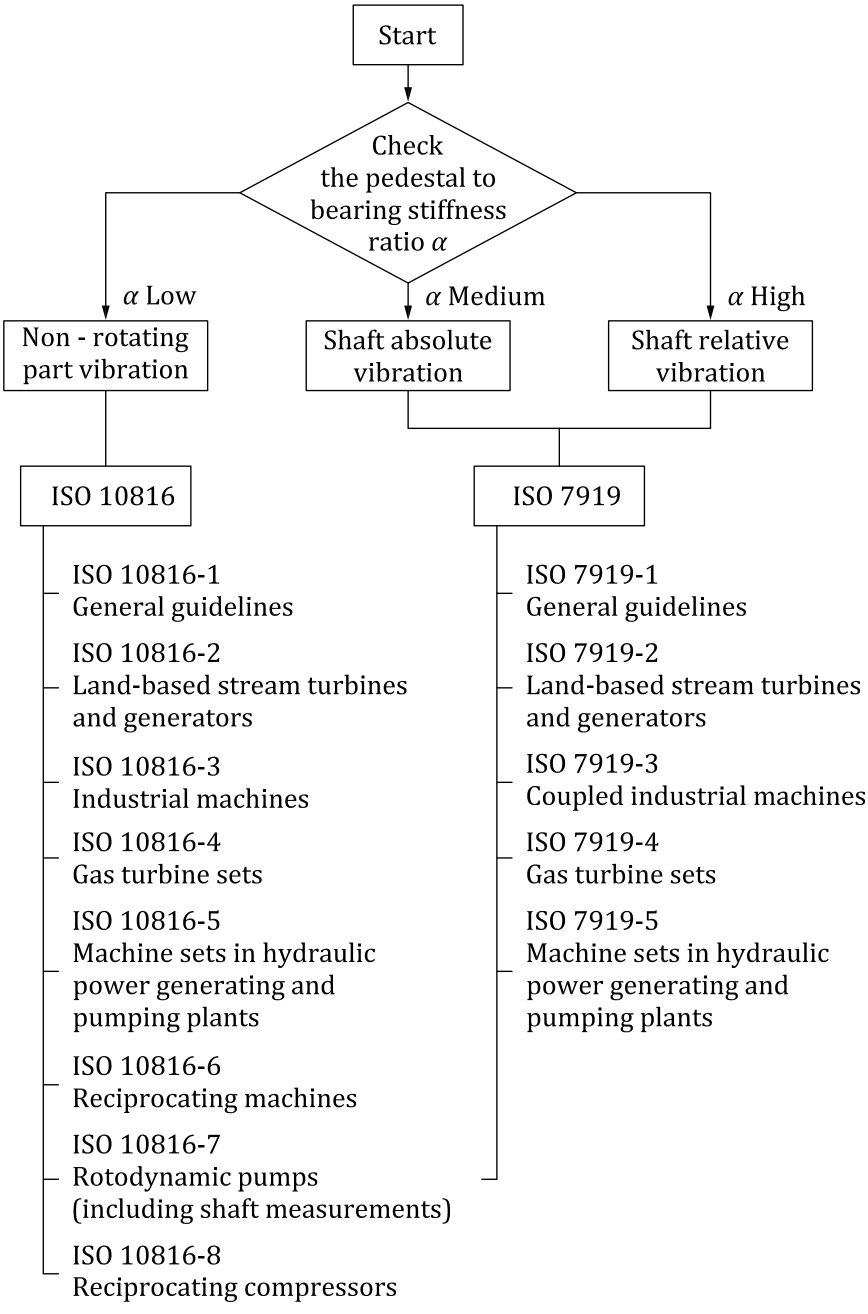


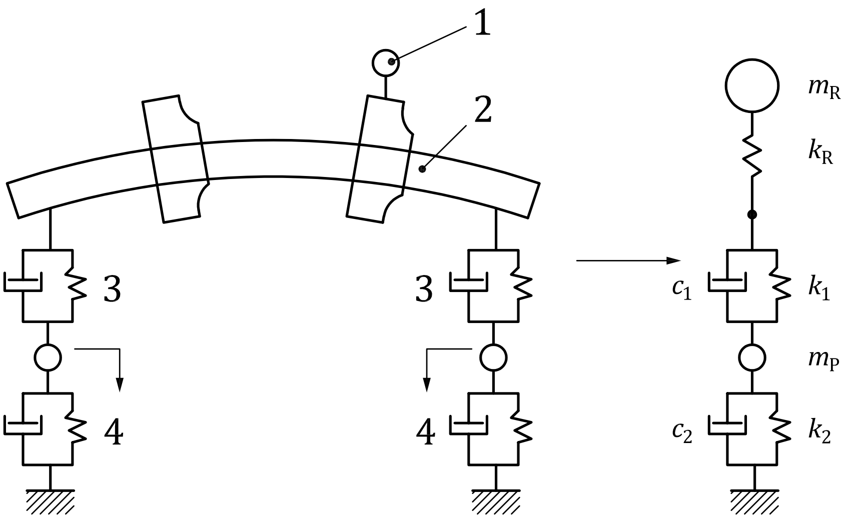
Figure 2 — Flow chart for selecting the appropriate International Standard to evaluate machine vibration

8.2 Basic relations for rotating shaft and pedestal vibration

8.2.1 Basic components to be considered for vibration evaluation

The basic components to determine the vibration characteristics of the rotor-bearing-pedestal system and a simplified dynamic model are illustrated in Figure 3.

NOTE The simplified model of Figure 3 is based on Formulae (A.3) and (A.4)



Key

1	unbalance	c_1	damping of bearing	k_R	stiffness of rotor
2	rotor	c_2	damping of pedestal	m_P	mass of pedestal
3	bearing	k_1	stiffness of bearing	m_R	mass of rotor
4	pedestal (bearing support)	k_2	stiffness of pedestal		

Figure 3 — Basic components of a rotor-bearing-pedestal system

8.2.2 Basic relation of component characteristics for vibration response

The following three component characteristics play an important role in determining the vibration response of the rotor-bearing system:

a) rotor flexibility,

b) bearing dynamic stiffness,

c) pedestal dynamic stiffness.

The basic points need to be considered for evaluating rotating shaft vibration and pedestal vibration. The evaluation of machine vibration is performed based on the following two points:

— dynamic force transmitted to the bearing,

— relative displacement to evaluate the clearance between the rotor and a non-rotating part.

The dynamic force for evaluating bearing reliability is measured by two methods. The first is the pedestal vibration, x_P, which is calculated using Formula (1):

$$x_P = \frac{F}{k_2^*} \tag{1}$$

where

F is the force;

k_2^* is the pedestal dynamic stiffness.

This factor is evaluated using ISO 10816 as the vibration of a non-rotating part.

The second factor is the shaft relative vibration, x_B which is calculated using Formula (2):

$$x_B = \frac{F}{k_1^*} \tag{2}$$

where k_1^* is the bearing dynamic stiffness.

The shaft absolute vibration x_{SA} is the sum of the pedestal vibration x_P and shaft relative vibration x_B, and is given by Formula (3):

$$x_{SA} = x_P + x_B = \frac{F}{k_2^*} + \frac{F}{k_1^*} = \frac{F}{k_{tot}^*} \tag{3}$$

where

k_{tot}^* is the total dynamic stiffness

$$k_{tot}^* = \frac{k_1^* k_2^*}{k_1^* + k_2^*}$$

NOTE The total dynamic stiffness, i.e. the dynamic stiffness of the bearing part combined with the pedestal, is presented in more detail in Annex D.

The only error in Formulae (2) and (3) is in the shaft displacement in the measurement plane, which has an additional displacement from the bearing centre because of shaft bending deformation, and the distance between measurement plane and the bearing centre plane. It is found that this error is negligible for relatively stiff rotors.

However, for rotors with flexible behaviour, a small value x_f which represents the shaft deformation effect needs to be added to Formulae (2) and (3).

These various vibrations are summarized in Table 1.

Table 1 — Relation of vibrations

	Rotors with rigid behaviour	Rotors with flexible behaviour
Pedestal vibration	x_P	x_P
Shaft relative vibration	x_B	$x_B + x_f$
Shaft absolute vibration	$x_P + x_B$	$x_P + x_B + x_f$

Annex A
(informative)

Bearing dynamics

A.1 Symbols

In order to understand the relationships in the following analytical formulae, the symbol definitions are listed in the following.

x, y	relative displacement of the journal to the bearing
$\dot{x}, \dot{y}$	relative velocity of the journal to the bearing
$\ddot{x}, \ddot{y}$	relative acceleration of the journal to the bearing
F_x	bearing force in the x direction
F_y	bearing force in the y direction
m_{xx}, m_{xy}, m_{yx}, m_{yy}	acceleration coefficients of the bearing oil film (mass effect)
c_{xx}, c_{xy}, c_{yx}, c_{yy}	damping coefficients of the bearing oil film
k_{xx}, k_{xy}, k_{yx}, k_{yy}	stiffness coefficients of the bearing oil film
$k^* = k + \mathrm{i}\omega c$	complex representation of the dynamic stiffness of the bearing and the pedestal

Generally, the bearing dynamics are represented as shown in Formula (A.1):

$$\begin{bmatrix} m_{xx} & m_{xy} \\ m_{yx} & m_{yy} \end{bmatrix} \begin{bmatrix} \ddot{x} \\ \ddot{y} \end{bmatrix} + \begin{bmatrix} c_{xx} & c_{xy} \\ c_{yx} & c_{yy} \end{bmatrix} \begin{bmatrix} \dot{x} \\ \dot{y} \end{bmatrix} + \begin{bmatrix} k_{xx} & k_{xy} \\ k_{yx} & k_{yy} \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} F_x \\ F_y \end{bmatrix} \tag{A.1}$$

Except for low-viscosity lubricant bearings, such as water-lubricated bearings, the mass effects can be neglected. The model is then simplified as shown in Formula (A.2):

$$\begin{bmatrix} c_{xx} & c_{xy} \\ c_{yx} & c_{yy} \end{bmatrix} \begin{bmatrix} \dot{x} \\ \dot{y} \end{bmatrix} + \begin{bmatrix} k_{xx} & k_{xy} \\ k_{yx} & k_{yy} \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} F_x \\ F_y \end{bmatrix} \tag{A.2}$$

Except for sleeve type journal bearings, cross-terms can be neglected, then the model takes the simplified form of Formula (A.3). Even for sleeve type journal bearings, a similar simplified presentation is possible for limited applications, such as unbalance response estimations.

$$\begin{bmatrix} c_{xx} & 0 \\ 0 & c_{yy} \end{bmatrix} \begin{bmatrix} \dot{x} \\ \dot{y} \end{bmatrix} + \begin{bmatrix} k_{xx} & 0 \\ 0 & k_{yy} \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} F_x \\ F_y \end{bmatrix} \tag{A.3}$$

The dynamic characteristics of the pedestal are also presented in a similar way. A simplified analysis of the dynamic characteristics of the pedestal can be performed based on Formula (A.4).

$$\begin{bmatrix} m_{xx} & 0 \\ 0 & m_{yy} \end{bmatrix} \begin{bmatrix} \ddot{x} \\ \ddot{y} \end{bmatrix} + \begin{bmatrix} c_{xx} & 0 \\ 0 & c_{yy} \end{bmatrix} \begin{bmatrix} \dot{x} \\ \dot{y} \end{bmatrix} + \begin{bmatrix} k_{xx} & 0 \\ 0 & k_{yy} \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} F_x \\ F_y \end{bmatrix} \tag{A.4}$$

These factors are evaluated using ISO 7919 as shaft relative vibration.

A.2 Characteristics of bearing dynamic stiffness

The dynamic stiffness of the bearing depends on the bearing type. The dynamic stiffness of the bearings need to be evaluated for two characteristics. One is the rotational speed-dependent characteristic, while the other is the excitation frequency-dependent characteristic for the selected rotational speed. The following presents dynamic stiffness considerations for various types of bearings.

a) Rolling element bearing

High stiffness depends on the load, while low damping is a typical characteristic of a rolling element bearing. The stiffness and damping values are almost constant for varying rotational speeds and exciting frequencies, as shown by the horizontal line in Figures A.1 and A.2.

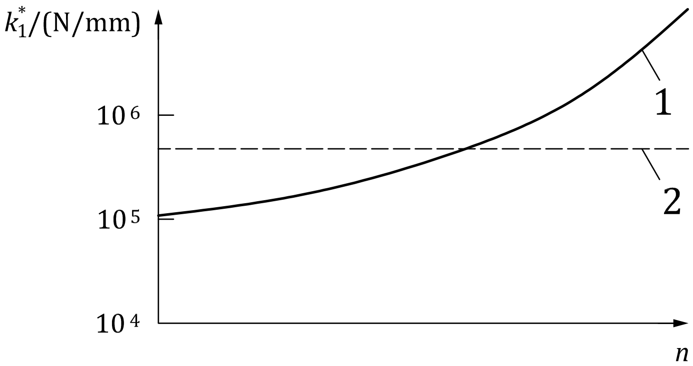
b) Tilting pad type oil film bearing

The tilting pad type oil film bearing has simple characteristics. Speed and load affect the dynamic stiffness and have smooth characteristics as a function of the excitation frequency, as shown in Figures A.1 and A.2.

This type of bearing has stable characteristics and moderately good damping capacity.

c) Sleeve type oil film bearing

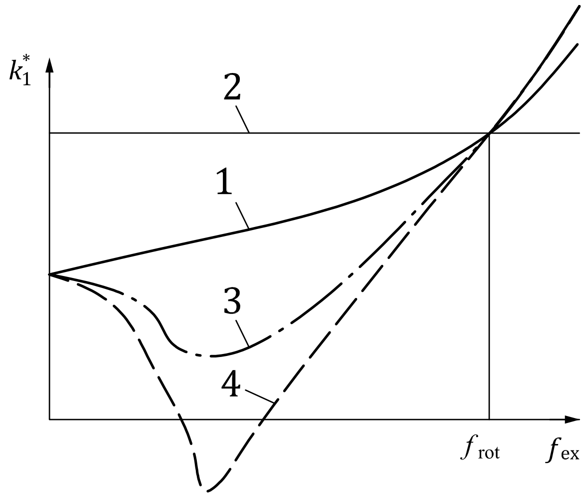
The sleeve type oil film bearing has special complex characteristics. Its rotational speed- and load-dependent dynamics are similar to those of the tilting pad bearing. However, dynamic stiffness for the excitation frequency at a specified rotational speed has complex characteristics, especially for marginal stability limits. It can then be seen that there is very low dynamic stiffness at about half rotational speed, as shown in Figure A.2.



Key

k_1^*	bearing dynamic stiffness (modulus)	1	tilting pad oil film bearing
n	rotational speed	2	rolling element bearing

Figure A.1 — Speed-dependent characteristics of bearing dynamic stiffness



Key

k_1^*	bearing dynamic stiffness (logarithmic representation of the modulus)	1	tilting pad bearing
f_{ex}	excitation frequency	2	rolling element bearing
f_{rot}	rotational frequency	3	stable sleeve bearing
		4	unstable sleeve bearing

Figure A.2 — Frequency-dependent characteristics of bearing dynamic stiffness

In summary, rolling element bearings have high stiffness and very low damping, independent of rotational speed. Tilting pad bearings have moderate stiffness and damping. Sleeve bearings have moderate stiffness and damping for the rotational speed components; however, they have very complex excitation frequency-dependent characteristics. These relationships are summarized as:

— Stiffness:

Rolling element bearing > Tilting pad bearing > Sleeve bearing

— Damping:

Sleeve bearing > Tilting pad bearing > Rolling element bearing

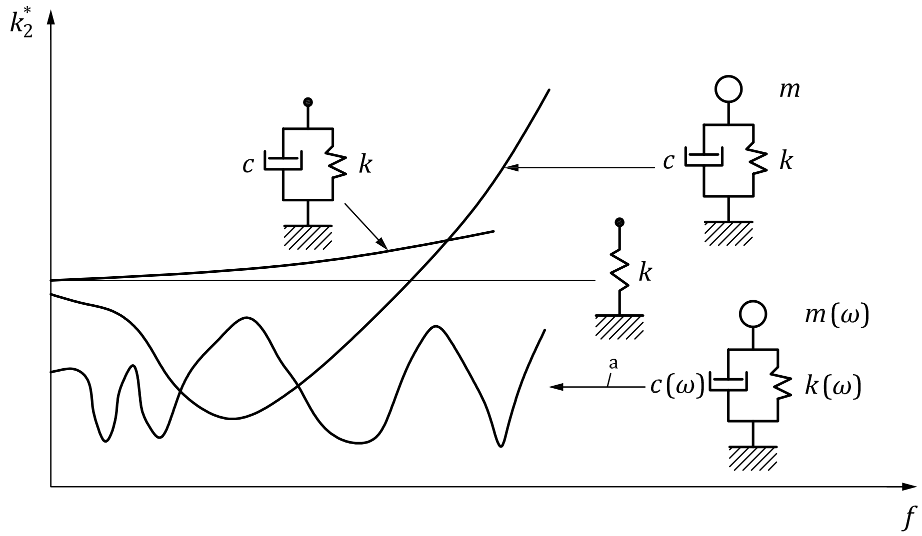
— Complex stiffness at half rotational frequency (or speed):

Rolling element bearing > Tilting pad bearing > Sleeve bearing (almost zero on the stability limit)

Annex B
(informative)

Pedestal dynamic stiffness

The dynamic stiffness of the structure under the bearings is of several types, as shown in Figure B.1.



Key

k_2^* dynamic stiffness of pedestal (logarithmic representation of the modulus)

f frequency ($\omega = 2\pi f$)

a Frequency-dependent characteristics.

Figure B.1 — Dynamic stiffness of pedestal

Factors to consider when evaluating pedestal stiffness characteristics are:

a) the most simple case is the spring effect and small damping;

b) most of the pedestals are represented by mass-spring-damper systems;

c) the complex stiffness supporting the bearing has very complex frequency-dependent characteristics — they have many natural frequencies and mode shapes.

A large bearing vibration can be observed at the resonance of the bearing support. However, the shaft relative vibration is not significantly high, even at pedestal resonance rotational speed.

Annex C
(informative)

Examples of typical values of dynamic stiffness for bearings and pedestals

Table C.1 includes some typical examples of pedestal and bearing stiffness values and pedestal to bearing stiffness ratios for several types of machines.

Table C.1 — Examples of dynamic stiffness values for pedestals and bearings

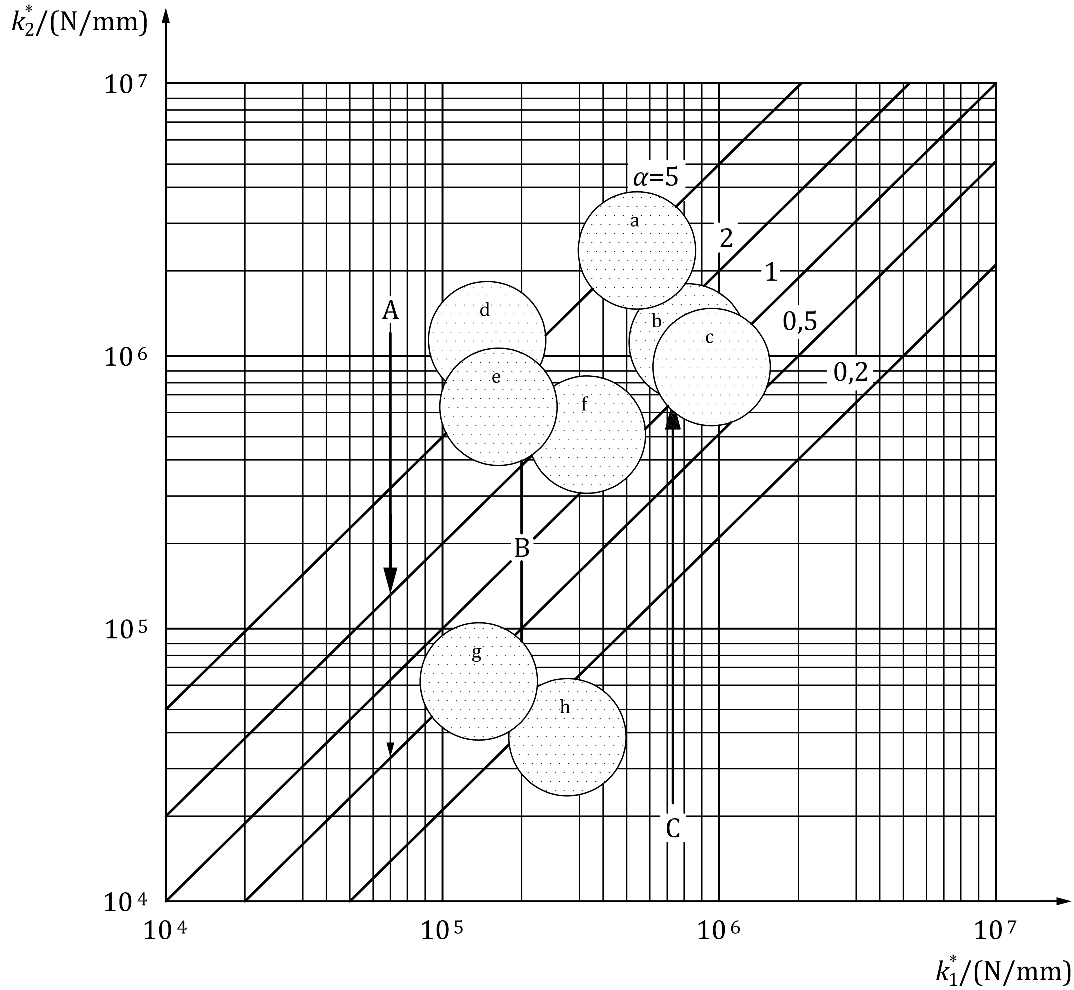
Machine type	**Pedestal stiffness** N/mm	**Bearing stiffness** N/mm	**Pedestal to bearing stiffness ratio**, α
High-pressure steam turbine	3,4E+06	4,7E+05	7,4
Low-pressure steam turbine	5,1E+06	1,7E+06	3
	3,2E+06	1,8E+06	1,8
Generator 100 MW	2,5E+06	4,2E+06	0,6
Gas turbine generator	8,3E+04	2,5E+05	0,3
Large gas turbine	1,4E+05	4,3E+05	0,3
	2,0E+05	8,9E+04	2,3

Table C.2 contains some typical pedestal to bearing dynamic stiffness ratios α for several machine types. Also included are evaluations of the conditions of the pedestal and bearing stiffnesses.

Table C.2 — Selection guideline (typical examples)

Machine	**Pedestal to bearing stiffness ratio**, α	ISO 10816 (pedestal)	ISO 7919 (shaft)
High-pressure turbine	4	moderate	good
Low-pressure turbine	2	moderate/good	good
Large generator	1,5	moderate/good	good
High-pressure centrifugal compressor	5	not good	good
Large fan	0,67	good	moderate
Small fan and pump	0,33	good	moderate
Vertical pump	0,10	good	not good
Large gas turbine	1,0	good	moderate

Figure C.1 shows typical examples of dynamic stiffnesses for various bearings and pedestals, and for different types of machines. Figure C.1 also provides information for selecting a vibration measurement method.



Key

k_2^*	dynamic stiffness of pedestal (modulus)
k_1^*	dynamic stiffness of bearing (modulus)
a	high-pressure turbine
b	large generator
c	low-pressure turbine
d	high-pressure centrifugal compressor
e	moderate-pressure centrifugal compressor
f	large fan
g	small fan and pump
h	vertical pump
A	range for shaft relative vibration measurements
B	range for shaft absolute vibration measurements
C	range for pedestal vibration measurements
↕ (heavy arrow)	typical
↕ (thin arrow)	applicable

Figure C.1 — Typical dynamic stiffness ranges for different types of machines

Annex D
(informative)

Dynamic stiffness of the bearing part combined with the pedestal

The total dynamic stiffness of the model in Figure D.1, $k^*_{tot} = k_{tot} + i\omega c_{tot}$, is represented by Formulae (D.1) and (D.2) and is shown in Figure D.2, together with the vibration ratio, as a function of the dynamic stiffness ratio.

NOTE The symbols are explained in Figure 3.

$$k_{tot} = \frac{(k_1 + k_2')(k_1 k_2' - c_1\omega c_2\omega) + (k_1 c_2\omega + k_2' c_1\omega)(c_1\omega + c_2\omega)}{(k_1 + k_2')^2 + (c_1\omega + c_2\omega)^2} \quad \text{(D.1)}$$

where $k_2' = k_2 - m_P \omega^2$.

$$c_{tot}\omega = \frac{(k_1 + k_2')(k_1 c_2\omega + k_2' c_1\omega) - (c_1\omega + c_2\omega)(k_1 k_2' - c_1\omega c_2\omega)}{(k_1 + k_2')^2 + (c_1\omega + c_2\omega)^2} \quad \text{(D.2)}$$

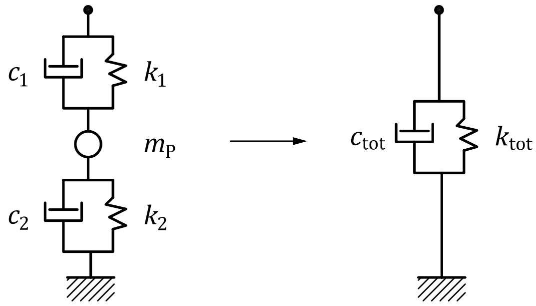
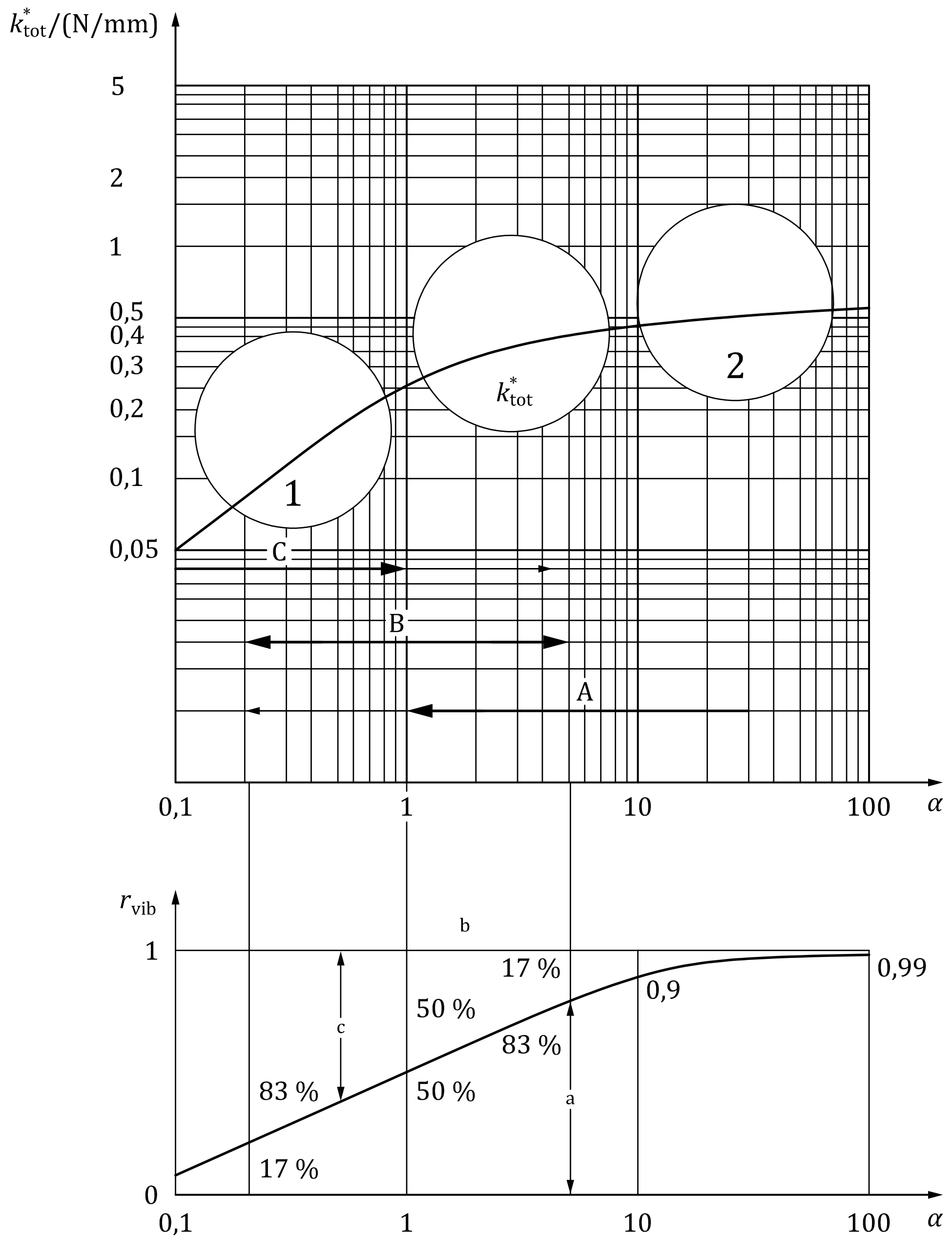


Figure D.1 — Model for the total dynamic stiffness $k^*_{tot} = k_{tot} + i\omega c_{tot}$



Key

k^*_{tot}	total dynamic stiffness $k^*_{tot} = \frac{k^*_1 k^*_2}{k^*_1 + k^*_2}$	r_{vib}	vibration ratio (shaft relative vibration divided by shaft absolute vibration)
α	dynamic stiffness ratio $\alpha = k^*_2 / k^*_1$		
A	range for shaft relative vibration measurements	a	shaft relative vibration
B	range for shaft absolute vibration measurements	b	shaft absolute vibration
C	range for pedestal vibration measurements	c	pedestal vibration
1	soft pedestal	2	rigid pedestal
⟵⟶ (thick)	typical	⟵⟶ (thin)	applicable

Figure D.2 — Total dynamic stiffness and vibration ratio as function of the dynamic stiffness ratio

Annex E
(informative)

International machinery vibration standards shown by application area

Many of the International Standards discussed in this Technical Report together with additional International Standards are summarized by their application area in Table E.1.

Table E.1 — International machinery vibration standards shown by application area

International Standard	Title	Vibration application area					
		Overview, procedure	Casing vibration	Shaft vibration	Rotating machines	Reciprocating machines	Training
ISO 2954:2012	*Mechanical vibration of rotating and reciprocating machinery — Requirements for instruments for measuring vibration severity*		√				
ISO 3046-5:2001	*Reciprocating internal combustion engines — Performance — Part 5: Torsional vibrations*					√	
ISO 7919-1:1996	*Mechanical vibration of non-reciprocating machines — Measurements on rotating shafts and evaluation criteria — Part 1: General guidelines*	√		√	√		
ISO 7919-2:2009	*Mechanical vibration — Evaluation of machine vibration by measurements on rotating shafts — Part 2: Land-based steam turbines and generators in excess of 50 MW with normal operating speeds of 1 500 r/min, 1 800 r/min, 3 000 r/min and 3 600 r/min*			√	√		
ISO 7919-3:2009	*Mechanical vibration — Evaluation of machine vibration by measurements on rotating shafts — Part 3: Coupled industrial machines*			√	√		
ISO 7919-4:2009	*Mechanical vibration — Evaluation of machine vibration by measurements on rotating shafts — Part 4: Gas turbine sets with fluid-film bearings*			√	√		
ISO 7919-5:2005	*Mechanical vibration — Evaluation of machine vibration by measurements on rotating shafts — Part 5: Machine sets in hydraulic power generating and pumping plants*			√	√		
ISO 8528-9:1995	*Reciprocating internal combustion engine driven alternating current generating sets — Part 9: Measurement and evaluation of mechanical vibrations*		√			√	
ISO 10816-1:1995 + Amd.1:2009	*Mechanical vibration — Evaluation of machine vibration by measurements on non-rotating parts — Part 1: General guidelines*	√	√		√		
ISO 10816-2:2009	*Mechanical vibration — Evaluation of machine vibration by measurements on non-rotating parts — Part 2: Land-based steam turbines and generators in excess of 50 MW with normal operating speeds of 1 500 r/min, 1 800 r/min, 3 000 r/min and 3 600 r/min*		√		√		
ISO 10816-3:2009	*Mechanical vibration — Evaluation of machine vibration by measurements on non-rotating parts — Part 3: Industrial machines with nominal power above 15 kW and nominal speeds between 120 r/min and 15 000 r/min when measured in situ*		√		√		

Table E.1 *(continued)*

International Standard	Title	Vibration application area					
		Overview, procedure	Casing vibration	Shaft vibration	Rotating machines	Reciprocating machines	Training
ISO 10816-4:2009	*Mechanical vibration — Evaluation of machine vibration by measurements on non-rotating parts — Part 4: Gas turbine sets with fluid-film bearings*		√		√		
ISO 10816-5:2000	*Mechanical vibration — Evaluation of machine vibration by measurements on non-rotating parts — Part 5: Machine sets in hydraulic power generating and pumping plants*		√		√		
ISO 10816-6:1995	*Mechanical vibration — Evaluation of machine vibration by measurements on non-rotating parts — Part 6: Reciprocating machines with power ratings above 100 kW*		√			√	
ISO 10816-7:2009	*Mechanical vibration — Evaluation of machine vibration by measurements on non-rotating parts — Part 7: Rotodynamic pumps for industrial applications, including measurements on rotating shafts*		√	√	√		
ISO 10816-8:—[a]	*Mechanical vibration — Evaluation of machine vibration by measurements on non-rotating parts — Part 8: Reciprocating compressor systems*		√			√	
ISO 10817-1:1998	*Rotating shaft vibration measuring systems — Part 1: Relative and absolute sensing of radial vibration*			√			
ISO 13373-1:2002	*Condition monitoring and diagnostics of machines — Vibration condition monitoring — Part 1: General procedures*	√	√	√	√		
ISO 13373-2:2005	*Condition monitoring and diagnostics of machines — Vibration condition monitoring — Part 2: Processing, analysis and presentation of vibration data*	√					
ISO 13373-3:—[b]	*Condition monitoring and diagnostics of machines — Vibration condition monitoring — Part 3: Guidelines for vibration diagnosis*	√					
ISO 14694:2003	*Industrial fans — Specifications for balance quality and vibration levels*		√		√		
ISO 14695:2003	*Industrial fans — Method of measurement of fan vibration*		√		√		
ISO 14839-1:2002	*Mechanical vibration — Vibration of rotating machinery equipped with active magnetic bearings — Part 1: Vocabulary*				√		
ISO 14839-2:2004	*Mechanical vibration — Vibration of rotating machinery equipped with active magnetic bearings — Part 2: Evaluation of vibration*				√		

Table E.1 *(continued)*

International Standard	Title	Vibration application area					
		Overview, procedure	Casing vibration	Shaft vibration	Rotating machines	Reciprocating machines	Training
ISO 14839-3:2006	*Mechanical vibration — Vibration of rotating machinery equipped with active magnetic bearings — Part 3: Evaluation of stability margin*				√		
ISO 14839-4:2012	*Mechanical vibration — Vibration of rotating machinery equipped with active magnetic bearings — Part 4: Technical guidelines*				√		
ISO 18436-2:—[c]	*Condition monitoring and diagnostics of machines — Requirements for qualification and assessment of personnel — Part 2: Vibration condition monitoring and diagnostics*						√
ISO 20283-4:2012	*Mechanical vibration — Measurement of vibration on ships — Part 4: Measurement and evaluation of vibration of the ship propulsion machinery*				√	√	
ISO 22266-1:2009	*Mechanical vibration — Torsional vibration of rotating machinery — Part 1: Land-based steam and gas turbine generator sets in excess of 50 MW*				√		
IEC 60034-14:2003 + Amd.1:2007	*Rotating electrical machines — Part 14: Mechanical vibration of certain machines with shaft heights 56 mm and higher — Measurement, evaluation and limits of vibration severity*		√	√	√		

[a] To be published.

[b] Planned.

[c] To be published. (Revision of ISO 18436-2:2003)

Bibliography

[1] ISO 1940-1, *Mechanical vibration — Balance quality requirements for rotors in a constant (rigid) state — Part 1: Specification and verification of balance tolerances*[3)]

[2] ISO 8528-9, *Reciprocating internal combustion engine driven alternating current generating sets — Part 9: Measurement and evaluation of mechanical vibrations*

[3] ISO 11342, *Mechanical vibration — Methods and criteria for the mechanical balancing of flexible rotors*[4)]

[4] ISO 13381-1, *Condition monitoring and diagnostics of machines — Prognostics — Part 1: General guidelines*

[5] ISO 14839-1, *Mechanical vibration — Vibration of rotating machinery equipped with active magnetic bearings — Part 1: Vocabulary*

[6] ISO 14839-2, *Mechanical vibration — Vibration of rotating machinery equipped with active magnetic bearings — Part 2: Evaluation of vibration*

[7] ISO 14839-3, *Mechanical vibration — Vibration of rotating machinery equipped with active magnetic bearings — Part 3: Evaluation of stability margin*

[8] ISO 14839-4, *Mechanical vibration — Vibration of rotating machinery equipped with active magnetic bearings — Part 4: Technical guidelines*

[9] ISO 15242 (all parts), *Rolling bearings — Measuring methods for vibration*

[10] ISO 17359, *Condition monitoring and diagnostics of machines — General guidelines*

[11] ISO 19499, *Mechanical vibration — Balancing — Guidance on the use and application of balancing standards*[5)]

[12] ISO 20283-4, *Mechanical vibration — Measurement of vibration on ships — Part 4: Measurement and evaluation of vibration of the ship propulsion machinery*

[13] ISO 21940-13, *Mechanical vibration — Rotor balancing — Part 13: Criteria and safeguards for the in-situ balancing of medium and large rotors*

[14] ISO 21940-14, *Mechanical vibration — Rotor balancing — Part 14: Procedures for assessing balance errors*

[15] ISO 22266-1, *Mechanical vibration — Torsional vibration of rotating machinery — Part 1: Land-based steam and gas turbine generator sets in excess of 50 MW*

[16] IEC 60034-14, *Rotating electrical machines — Part 14: Mechanical vibration of certain machines with shaft heights 56 mm and higher — Measurement, evaluation and limits of vibration severity*

[17] IEC 60994, *Guide for field measurement of vibrations and pulsations in hydraulic machines (turbines, storage pumps and pump-turbines)*

[18] IEC 81400-4, *Wind turbines — Part 4: Design requirements for wind turbine gearboxes*

[19] VDI 3836, *Measurement and evaluation of mechanical vibration of screw-type compressors and Roots blowers — Addition to DIN ISO 10816-3*

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3) To become ISO 21940-11 when revised.

4) To become ISO 21940-12 when revised.

5) To become ISO 21940-1 when revised.

[20] VDI 3838, *Measurement and evaluation of mechanical vibration of reciprocating piston engines and piston compressors with power ratings above 100 kW — Addition to DIN ISO 10816-6*

[21] VDI 3839 (all parts), *Instructions on measuring and interpreting the vibrations of machines*

[22] VDI 3840, *Vibration analysis for machine sets*

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