COMMITTEE DRAFT ISO/CD 10816-7	
Date **2003-01-20**	Reference number **ISO/TC 108 / SC 2** N 395
Supersedes document	

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ISO/TC 108 / SC 2

Title

Measurement and evaluation of mechanical vibration and shock as applied to machines, vehicles and structures

Secretariat **DIN**

Circulated to P- and O-members, and to technical committees and organizations in liaison for:

☐ discussion at [venue/date of meeting] on

☒ comments by **2003-04-22** [date]

☐ approval for registration as a DIS in accordance with 2.5.6 of part 1 of the ISO/IEC Directives, by [date]

(P-members vote only: ballot form attached)

P-members of the technical committee or subcommittee concerned have an obligation to vote.

English title

1st ISO/CD 10816-7 "Mechanical vibration — Evaluation of machine vibration by measurements on non-rotating parts — Part 7: Rotodynamic pumps for industrial application"

French title

Reference language version: ☐ English ☐ French ☐ Russian

Introductory note

Based on SC 2-Resolution 2/1999, a new work item proposal was circualated to SC 2 and ISO/TC 115 "Pumps" and approved in October 1999 as WI 17129. A joint WG 9 was established to deal with this item, which met on 27 October 1999 the first time.
In April 2001, SC 2 confirmed its intention to publish the future standard as a Part 7 of ISO 10816.
By its Resolution 2/2001, SC 2 requested JWG 9 to consider the request of IEC/TC 2 to develop an evaluation procedure for vertical machines mounted on an elastic foundation.
As result of discussions at the SC 2 meeting in Minden, May 2002, Resolution 9/2001 was taken, which was requesting the exclusion of close coupled pumps with integral drives from Part 7, since these pumps shall be dealt with by ISO 10816-3. According to SC 2 Resolution 10/2002, the 1st CD is now circulated to members of ISO/TC 108/SC 2 and ISO/TC 115 for comments only. IEC/TC 2 and CEN/TC 197 are also invited to comment on this draft.
Since this draft has been developed jointly by SC 2 and ISO/TC 115 it is expected that member bodies submit comments which reflect their positions as both members of ISO/TC 108/SC 2 and ISO/TC 115.

ISO /TC 108/SC 2 N

Date: 2003-1-9

ISO/CD 10816-7

ISO /TC 108/SC 2/JWG 9 with ISO/TC 115

Secretariat: DIN

Mechanical vibration — Evaluation of machine vibration by measurements on non-rotating parts —

Part 7:
Rotodynamic pumps for industrial application

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Document type: International Standard
Document subtype:
Document stage: (30) Committee
Document language: E

T:\TG1_2\N A L S\FBC\Normen\10816\7\10816-7CD(E).doc STD Version 2.1a

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Foreword

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

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

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

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

ISO 10816-7 was prepared by Technical Committee ISO/TC 108, *Mechanical vibration and shock*, Subcommittee SC 2, *Measurement and evaluation of mechanical vibration and shock as applied to machines, vehicles and structures*, in collaboration with ISO/TC 115 *Pumps*.

ISO 10816 consists of the following parts, under the general title *Mechanical vibration – Evaluation of machine vibration by measurements on non-rotating parts:*

— Part 1: General guidelines

— Part 2: Land-based steam turbines and generators in excess of 50 MW with normal operating speeds of 1500 r/min, 1800 r/min, 3000 r/min and 3600 r/min

— Part 3: Industrial machines with nominal power above 15 kW and nominal speeds between 120 r/min and 15000 r/min when measured in situ

— Part 4: Gas turbine driven sets excluding aircraft derivatives

— Part 5: Machine sets in hydraulic power generating and pumping plants

— Part 6: Reciprocating machines with power ratings above 100 kW

— Part 7: Rotodynamic pumps for industrial application

Introduction

This part of ISO 10816 describes the special requirements for evaluation of vibration when the vibration measurements are made on non-rotating parts (bearing housing vibration). It provides specific guidance for assessing the severity of vibration measured on bearings of rotodynamic pumps in situ and for the acceptance test[1)] at the manufacturer's test facility or in the plant. It also gives general information for assessing shaft vibration (measured on rotating shafts).

Vibration measurements can be useful for many purposes, e.g. for the operational monitoring, acceptance tests and for diagnostic or analytic investigations.

A general description of the principles to be applied for the measurement and assessment of vibration on coupled industrial machines are given for vibration on non-rotating parts in ISO 10816-1 and for shaft vibration in ISO 7919-1.

This part of ISO 10816 is based on state-of-the-art technology comprising the experiences from pump users and manufacturers as well as vibration measurements of many companies. Vibration data from both shop test and in-situ long-term operation with all types of flow are incorporated in the tables. Statistical evaluation has been made for the preferred operating region, i.e. 70 % to 120 % of the best efficiency point (BEP), as well as evaluation of the flow dependency.

The data which are the basis for the values in the tables come from about 1500 pumps in situ and at test facilities. As it is visible out of this survey, the differences between rigid and flexible supports are not significant as well as those between horizontal and vertical orientations of the pumps. Therefore, considering the experiences and other standards this part of ISO 10816 does not distinguish between those criteria.

It should be taken into account that other standards (e.g. ISO 10816-1, ISO 10816-3, ISO 13709) dealing with vibration measurement make those differences. There is a lack of information about the meantime between failure and operating conditions for the measured values. Due to the large number of measured pumps, it is assumed that they have statistically a sufficient lifetime and do not show other problems.

1) Wherever acceptance test is mentioned in this part of ISO 10816 it should be taken into account that all the details about place, size and form of those test procedures are optional and need to be specified and agreed between both parties of a contract.

Mechanical vibration — Evaluation of machine vibration by measurements on non-rotating parts —

Part 7: **Rotodynamic pumps for industrial application**

1 Scope

This part of ISO 10816 is a guidance for the evaluation of vibration on rotodynamic pumps for industrial application with nominal power above 1 kW. It describes the special requirements for evaluation of vibration when the vibration measurements are made on non-rotating parts (bearing housing vibration). It provides specific guidance for assessing the severity of vibration measured on bearings of rotodynamic pumps in situ and for the acceptance test at the manufacturer’s test facility or in the plant. It also gives general information for assessing shaft vibration (measured on rotating shafts).

This part of ISO 10816 specifies zones and limits for the vibration of horizontal and vertical pumps irrespective of their support flexibility. The general evaluation criteria are valid for operational monitoring of rotodynamic pumps, for acceptance tests in situ or at the manufacturer's test facility if specified. For the acceptance test at the manufacturer's test facility, special criteria are given.

For observing the vibration values during long-term operation, in addition two criteria are provided for assessing the machine vibration. One criterion considers the magnitude of the observed vibration, the second considers changes in magnitude. The criteria are applicable for the vibration produced by the machine itself and not for vibration which is transmitted to the machine from external sources. The criteria mainly serve to ensure a reliable, safe long-term operation of the pump, simultaneously minimising harmful effects on connected devices. Additionally recommendations are given in which way to determine operational limits and setting alarm and trip values.

For pump units with integrated or closed coupled driver (VO-type), the whole coupled unit is covered by this part of ISO 10816.

Torsional vibration is not dealt with by this part of ISO 10816. The evaluation criteria given in this part of ISO 10816 are not applicable to the vibration of driving machines (e.g. electrical motors or turbines). For these machines, ISO 7919-3 and ISO 10816-3 are normally applicable. The following types of pumps are excluded from this part of ISO 10816:

— reciprocating pumps,

— pumps in hydraulic power generating and pumping plants with power above 1 MW (see ISO 7919-5 and ISO 10816-5).

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

ISO 5199, Technical specifications for centrifugal pumps — Class II

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

ISO 9905, Technical specifications for centrifugal pumps — Class I

ISO 9908, Technical specifications for centrifugal pumps — Class III

ISO 10816-1:1995 Mechanical vibration — Evaluation of machine vibration by measurements on non-rotating parts — Part 1: General guidelines

3 Vibration measurement

3.1 Measurement quantity and procedure

The measurement quantity to be used for measuring the vibration of non-rotating parts[2)] of rotodynamic pumps is the root-mean-square (r.m.s.) vibration velocity in mm/s. For speeds below 600 r/min, it is additionally required to measure the peak-to-peak displacement in µm filtered at 0,5 ×, 1 × and 2 × the running speed.

The measurement procedure to be followed is set out in ISO 10816-1.

3.2 Measurement instrumentation and frequency range

3.2.1 General

The measurement instrumentation shall conform to the requirements set out in ISO 10816-1. The instrumentation shall be capable of measuring the r.m.s. vibration velocity in a broad frequency range reaching from at least 10 Hz to 1000 Hz and shall be in accordance with the requirements of ISO 2954.

At machines with speeds below 600 r/min, the measurement instrumentation shall be capable of enclosing frequencies lower than 10 Hz, in which case normally the frequency range 2 Hz to 1000 Hz is used so that the running speed is well within the measured frequency range. The measurement instrumentation is additionally required to measure the peak-to-peak displacement in µm filtered at 0,5 ×, 1 × and 2 × the running speed.

For very high-speed machines or for diagnostic purposes (see e.g. ISO 13373-1 which specifies a more detailed analysis), it may be required to use measurement instrumentation which covers a wider frequency range, usually up to 2,5 times the blade-passing frequency so that the blade-passing frequency components are adequately accounted for.

3.2.2 Precautions

Care shall be taken to ensure that the measurement instrumentation is not influenced by factors such as:

— temperature variations,

— magnetic fields,

— sound fields,

2) For measurements on rotating shafts, see Annex B.

— power source variations,

— transducer cable length,

— transducer orientation.

Particular attention should be given to ensure that the vibration transducers are correctly mounted and that such mountings do not degrade the accuracy of the measurements. If vibration transducers with a magnetic plate are used, the support surface at the measured body should be prepared to avoid measurement errors. Appropriate mounting methods are shown in Figure 1.

NOTE ISO 5348 contains information on the mechanical mounting of accelerometers which is in general also applicable to velocity transducers.

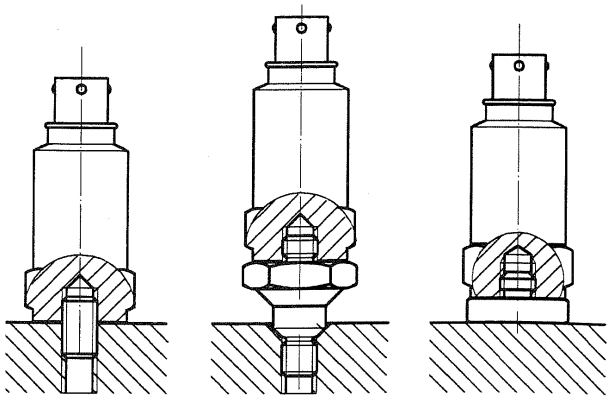


Figure 1 — Mounting methods for vibration transducers

3.2.3 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 at key measurement locations. For many machines, mainly those of small size or power, continuous monitoring of vibration is not necessarily carried out. Changes in unbalance, bearing performance, alignment, etc. can be detected with sufficient reliability from periodic vibration measurements with portable instrumentation.

When performing only periodic measurements on pumps, spontaneous defects will not be detected. This shall be especially taken into account when a pump is safety relevant, in that case permanent monitoring is recommended. The use of computers for trend analysis and warning against malfunctions is also becoming more common. Detailed information about procedures and instrumentation for vibration condition monitoring is given in ISO 13373-1.

3.3 Measurement locations and directions

3.3.1 General radial measurements

The vibration of non-rotating parts of rotodynamic pumps shall be measured at the bearing housing of the pump. Vibration measurements are normally made on exposed parts of the machine that are accessible (see Figures 2 and 3).

It should be confirmed that the measurements represent the bearing housing vibration correctly and are not degraded by any local resonance or amplification. The measurement locations and transducer orientations shall be such that the dynamic forces of the machine are mirrored with sufficient sensitivity, this is normally close to the centreline of the bearings. To ensure this, normally measurements shall be made at each bearing housing in two orthogonal radial directions as shown in Figures 2 and 3.

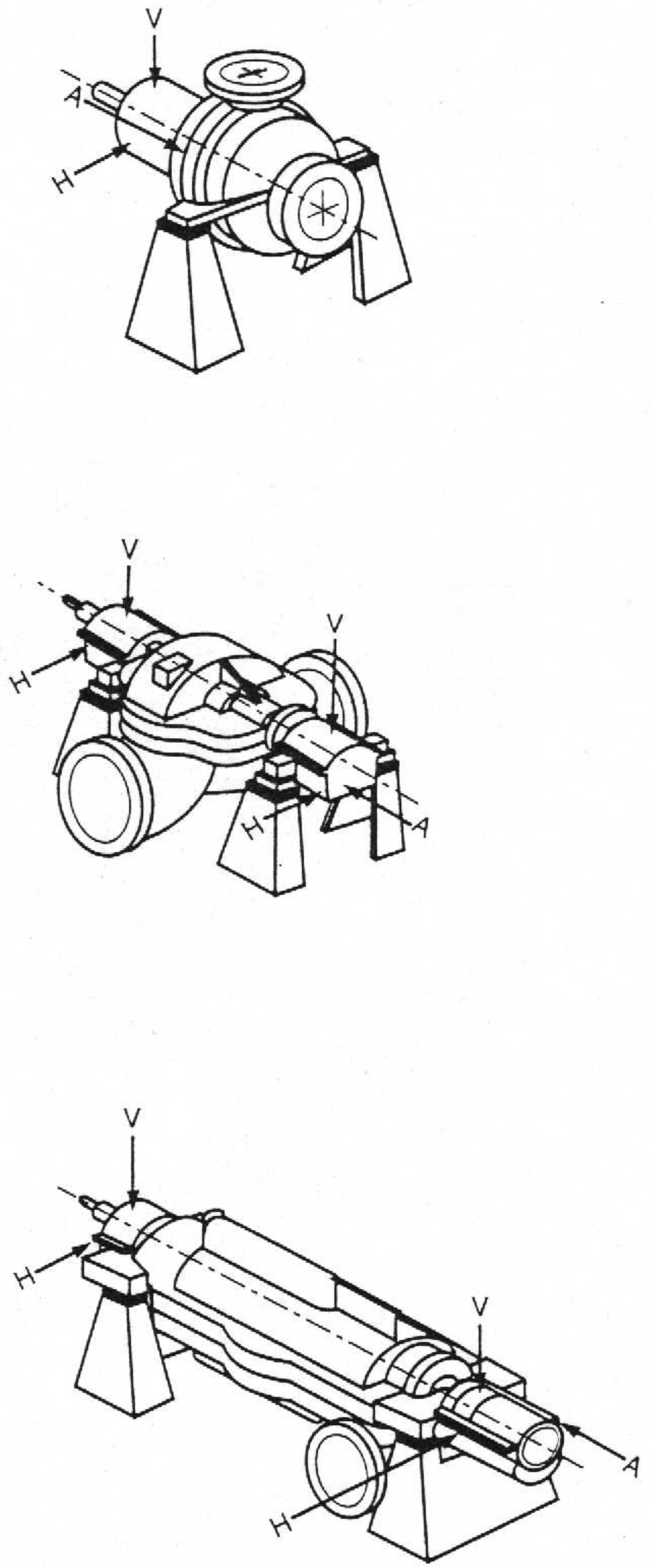


Figure 2 — Measurement locations on horizontal pumps

((Note of the secretariat: New figures will be provided))

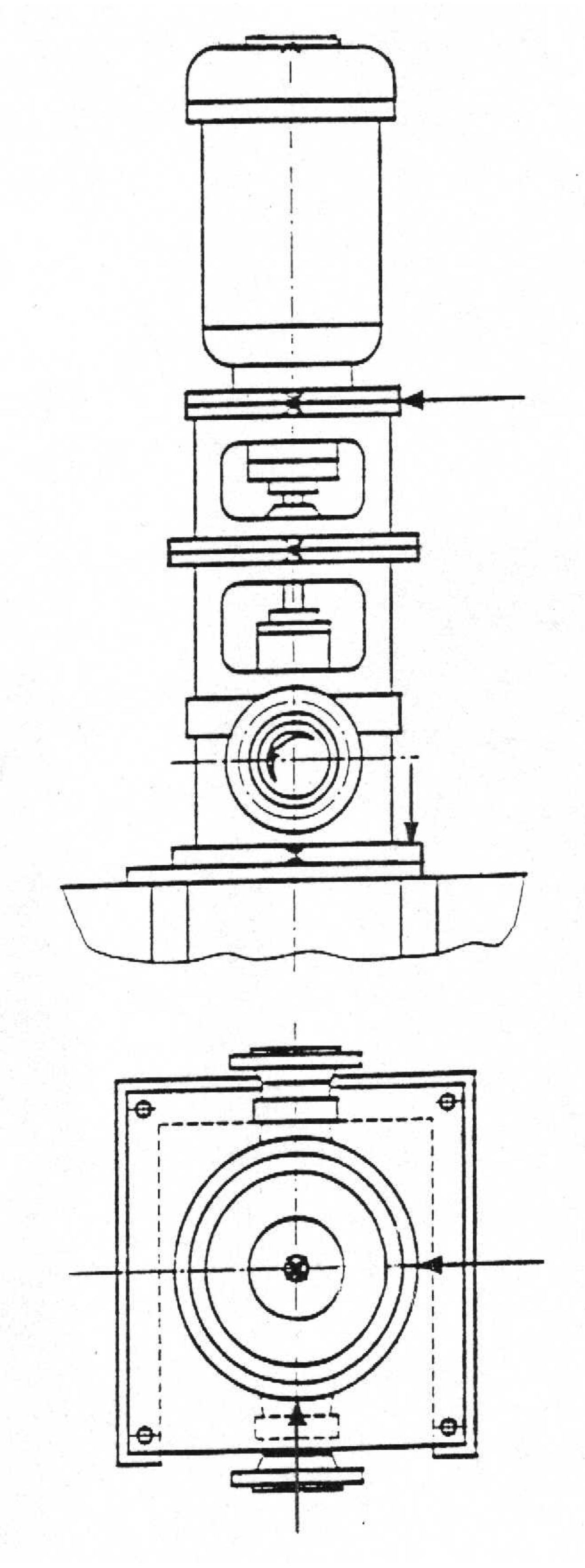


Figure 3 — Measurement locations on vertical pumps

((Note of the secretariat: New figures will be provided))

In case of pumps with horizontal shafts usually the horizontal and vertical directions are preferred and, if possible, also the axial direction. For machines with vertical or inclined shaft arrangements, the measurement locations need to be chosen in such a way as to ensure the maximum reading. In most of the cases it will lie towards the direction of the largest flexibility and 90° towards it.

NOTE If possible it may be agreed to measure directly on the pump bearing or close to it in both directions.

The measurement locations and directions used shall be listed in the measurement report. It may be recommendable to measure also in the axial direction (see 3.3.2).

3.3.2 Special axial measurements

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 are at present only given in the case of thrust bearings where axial vibration correlates with axial pulsation which could cause damage to the axial load-carrying surfaces. The criteria of Tables A.1 and A.2 apply to radial vibration on all bearings and to axial vibration on thrust bearings.

3.4 Installation and operating conditions

For installation of pumps, it is important that special care is taken to avoid resonance in the connected piping systems and foundations with the normal excitation frequencies (e.g. rotating frequency, double rotating frequency or blade-passing frequency) since such resonance can cause excessive vibration.

Measurements shall be carried out when the rotor and the main bearings have reached their normal steady-state operating temperatures. The machine shall be operated under the specified operating conditions, i.e. at the nominal values for rate of flow, delivery head, speed, which should lie within the preferred operating range (see Figure 4).

Special attention has to be drawn to those pumps which operate under different operating conditions. If variable conditions might occur, those have to be marked. On machines with varying speeds or loads, measurements shall be made under all conditions under which the machine would be expected to operate for prolonged periods. The maximum measured value under these conditions shall be considered representative of the vibration severity. When comparing measurements it is important that the operating conditions are mainly the same.

The allowable operating range and the preferred operating range (in general 70 % to 120 % of the BEP) for the rotodynamic pump shall be indicated by the pump manufacturer in accordance with pump user's specifications. Outside the allowable operating range higher vibration values may occur. They are the result of higher dynamic forces during partial-load and overload operation of the rotodynamic pump. These values may be tolerated for short-term operation; for continuous operation, however, damage or premature wear could occur.

If the measured vibration is greater than the acceptance criteria allowed and excessive background vibration is suspected, measurements should be made with the machine shut down to determine the degree of external influence. If the vibration with the machine not running exceeds 25 % of the value measured when the machine is running, corrective action may be necessary to reduce the effect of background vibration.

NOTE In some cases the effect of background vibration can be nullified by spectrum analysis or by eliminating the disturbing external source.

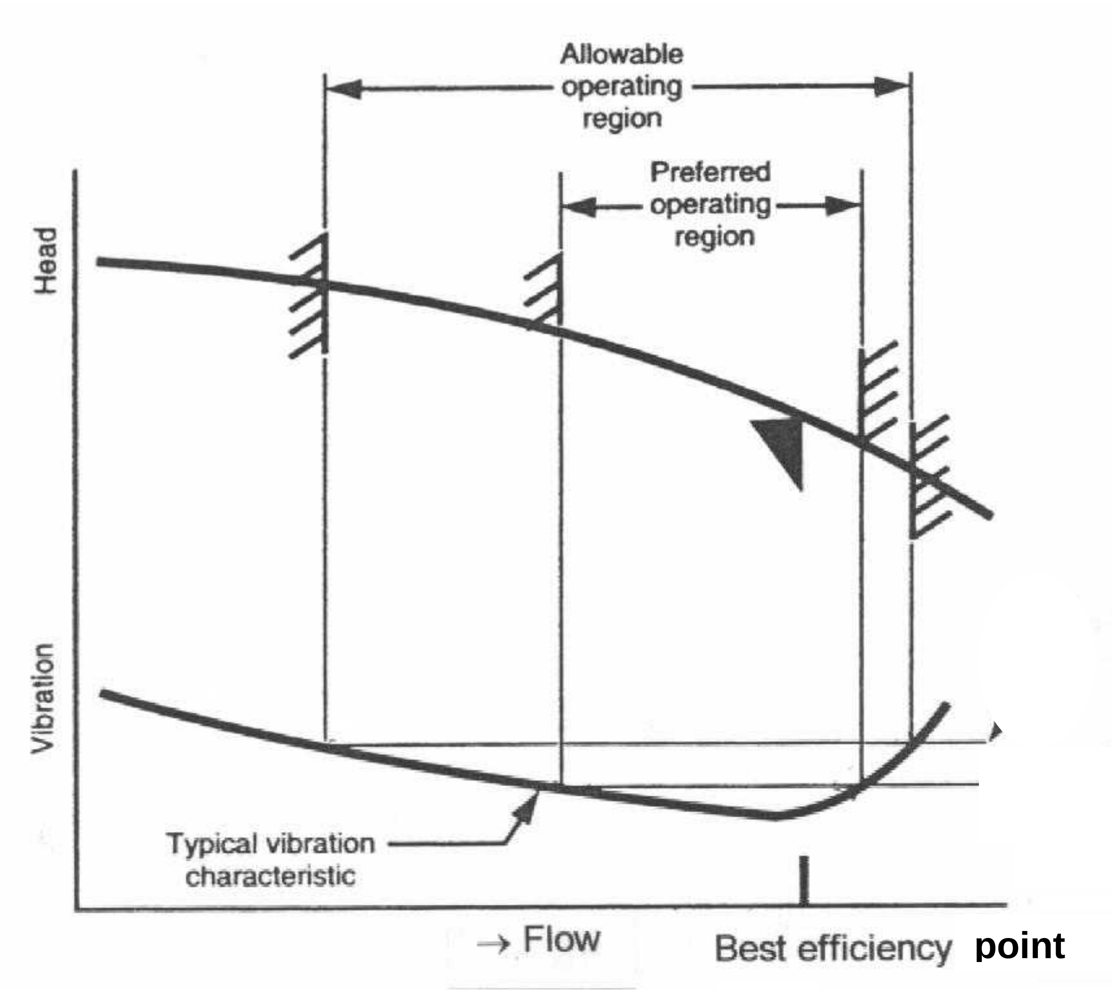


Figure 4 — Operating ranges of rotodynamic pumps

4 Vibration evaluation

4.1 General

ISO 10816-1 provides a general description of the two evaluation criteria used to assess the vibration severity of various classes of machines. One criterion considers the magnitude of observed broad-band vibration; the second considers changes in magnitude, irrespective of whether they are increases or decreases.

The criteria are presented for the specified steady-state operating conditions at the rated speed and load ranges. They do not apply when different conditions exist or during transient operation, for example during start-up and shut-down and when passing through resonance speed ranges. In these cases alternative criteria are necessary, i.e. higher values of vibration can be permitted at other measurement locations and under transient conditions. For transient operations, the vibration has to be limited since the shaft should not be in contact with stationary parts (in bearings or seals), i.e. rubbing should not occur. For bearing vibration, the maximum vibration velocity (and also the maximum shaft vibration, see Annex B) during transient operations should be below the upper boundary of zone C (see Clause 5).

4.2 Evaluation of bearing housing vibration

4.2.1 Criterion I: Vibration magnitude

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. The maximum vibration magnitude observed at each bearing is assessed against the evaluation zone (see 5.2). The permissible limits for each zone have been established from international experience and are given in Tables A.1 and A.2.

4.2.2 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 may occur which requires some action even if the limits of zone C as given in Tables A.1 and A.2 have not been reached. Such changes can be instantaneous or progressive with time and may indicate incipient damage or some other irregularity. Criterion II is specified on the basis of a change in broad-band vibration magnitude occurring under steady-state operating conditions. Steady-state operating conditions should be interpreted to include small changes in the machine power or operating 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, should be investigated so that a dangerous situation can be avoided. When an increase or decrease in vibration magnitude exceeds 25 % of the upper value of zone B, as defined in Tables A.1 and A.2, such changes should be considered significant, particularly if they are sudden. Diagnostic investigations, e.g. using Fast Fourier Transform (FFT) spectrum, should then be initiated to ascertain the reason for the change (unbalance, cavitation, damage at the antifriction bearings, etc.) and to determine what further actions are appropriate.

4.3 Evaluation based on vibration vector information

The evaluation considered in this part of ISO 10816 is limited to broad-band vibration without reference to phase. This will, in most cases, be adequate for acceptance testing and for operational monitoring purposes. However, for long-term condition monitoring purposes and for diagnostics, the use of vibration vector information is particularly useful for detecting and defining changes in the dynamic state of the pump. In some cases, these changes would go undetected when using only broad-band vibration measurements (for more details, see ISO 10816-1:1995, Annex D).

Phase- and frequency-related vibration information is being used increasingly for monitoring and diagnostic purposes. The specification of criteria for this, however, is beyond the present scope of this part of ISO 10816.

5 Evaluation zones and conditions for acceptance tests and operation in situ

5.1 General

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

Numerical values, as given in Annexes A and B, provide guidelines for ensuring that gross deficiencies or unrealistic requirements are avoided. In certain cases, there may be specific features associated with a particular machine which would require different zone boundary values (higher or lower) to be used. In such cases it is normally necessary to explain the reasons for this and, in particular, to confirm that the machine will not be endangered by operating with higher vibration values.

This part of ISO 10816 divides pumps into three classes as follows:

a) Class I pumps in accordance with ISO 9905: mainly foreseen for pumps in critical application (power plants, oil and gas industry or chemical industry, etc.);

b) Class II pumps in accordance with ISO 5199: mainly foreseen for pumps in less critical application (power plants, oil and gas industry or chemical and paper industry, etc.);

c) Class III pumps in accordance with ISO 9908: mainly foreseen for pumps in non-critical application (water application, etc.).

For each of these classes, different vibration limits apply. The classification of a pump has to be agreed upon between the manufacturer and user.

5.2 Evaluation zones

Zone A: The vibration of newly commissioned machines would normally fall 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.

5.3 Evaluation zone limits

The values for the zone boundaries which are given in Annex A are the maximum broad-band values of velocity (see Table A.1) and the filtered displacement (0,5 ×, 1 × and 2 × the running speed) for low-speed machines (see Table A.2) when measurements are taken from two orthogonally oriented radial transducers. Therefore when using these tables, the higher of each of the values measured from the two transducers in each measurement plane should be used.

When both velocity and displacement criteria are given, and the maximum measured values of velocity and displacement are compared to the corresponding values in Tables A.1 and A.2, the evaluation zone which is the most restrictive shall apply.

The criteria in Tables A.1 and A.2 apply to radial vibration on all bearings and to axial vibration on thrust bearings (for axial vibration, see also 3.3.2).

5.4 Conditions for operation in situ

The normal conditions for operation in situ are steady-state operation of the fully installed machine at rated speed and load. The evaluation zones defined in 5.2 are relevant to these conditions.

5.5 Conditions for acceptance tests

5.5.1 General

Wherever acceptance test is mentioned in this part of ISO 10816 it should be taken into account that all the details about place, size and form of those test procedures are optional and need to be specified and agreed between both parties of a contract.

The conditions below shall apply for acceptance tests unless others are specified. Acceptance tests will be carried out if required and specified. The final acceptance test will normally be in situ.

5.5.2 Factory acceptance test

The test will be carried out in a test facility with temporary fixing of pump and piping arrangement and because of that higher vibration may be expected than in situ.

The vibration of newly commissioned machines installed in a test bed would normally fall within zone B in the entire allowable operating range (see the limits given in Table A.1 unless otherwise specified). If the values at the test facility do not fulfil these requirements, additional measurements (e.g. FFT analysis) by the manufacturer to clarify the reason of the deviation are necessary.

5.5.3 Acceptance test in situ

The in-situ conditions apply to machines which are fully installed on site.

The borderline between zone A and zone B is normally considered to be the limit value for acceptance tests in situ when running in the preferred operating range. For the entire allowable operating range, higher vibration is expected but still being within zone B (see Table A.1 for details).

6 Operational limits

6.1 General

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

ALARMS: To provide a warning that a defined value of vibration has been reached or a significant change has occurred, at which remedial action may 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 define any remedial action.

TRIPS: To specify the magnitude of vibration beyond which further operation of the machine may cause damage. If the TRIP value is exceeded, immediate action should be taken to reduce the vibration or the machine should be shut down.

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

6.2 Setting of ALARMS

The ALARM values may vary considerably, up or down, for different machines. The values chosen will normally be set relative to a baseline value determined from experience for the measurement location or direction for that particular machine.

It is recommended that the ALARM value should 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 may be below zone C.

Where there is no established baseline (for example with a new machine), the initial ALARM setting should 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 should be adjusted accordingly.

It is recommended that the ALARM value should normally not exceed 1,25 times the upper limit of zone B.

If the steady-state baseline changes (for example after a machine overhaul), the ALARM setting should be revised accordingly (an example is given in Annex C).

6.3 Setting of TRIPS

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

There may, however, be differences for machines of different design and it is not possible to give clear guidelines for absolute TRIP values. In general, the TRIP value will be within zone C or D, but it is recommended that the TRIP value should not exceed 1,25 times the upper limit of zone C.

Annex A
(normative)

Evaluation zone boundaries for vibration of non-rotating parts

These values apply to radial vibration measurements on all bearings, bearing pedestals or housings of machines and to axial vibration measurements on thrust bearings under steady-state operating conditions at rated speed or within the specified speed range, irrespective of the support flexibility and installation orientation (see Annex D). They do not apply when the machine is undergoing a transient condition (e.g. changing speed or load).

Table A.1 — Zone limits for vibration of non-rotating parts of rotodynamic pumps with power above 1 kW, applicable for impellers with number of vanes $z_2 \geq 3$ [a)]

<table>
<tr><th rowspan="2">Zone</th><th rowspan="2" colspan="2">Description</th><th colspan="3">Vibration limits
r.m.s. value
mm/s</th></tr>
<tr><th>Class I [b)]</th><th>Class II [b)]</th><th>Class III [b)]</th></tr>
<tr><td>A</td><td colspan="2">Newly commissioned machines in preferred operating range</td><td>≤ 3,0</td><td>≤ 3,7</td><td>≤ 5,6</td></tr>
<tr><td>B</td><td colspan="2">Unrestricted long-term operation in allowable operating range</td><td>≤ 4,5</td><td>≤ 5,6</td><td>≤ 9,0</td></tr>
<tr><td>C</td><td colspan="2">Limited operation</td><td>≤ 7,1</td><td>≤ 9</td><td>≤ 11</td></tr>
<tr><td>D</td><td colspan="2">Hazard of damage</td><td>> 7,1</td><td>> 9</td><td>> 11</td></tr>
<tr><td colspan="3">Maximum ALARM[c)]</td><td>5,6</td><td>7</td><td>10</td></tr>
<tr><td colspan="3">Maximum TRIP[c)]</td><td>9</td><td>11</td><td>12,5</td></tr>
<tr><td colspan="3">For all acceptance tests and in the preferred operating range (see 3.4), the filtered values for rotating frequency (f_n) and blade-passing frequency ($f_n \cdot z_2$) should be</td><td>≤ 2</td><td>≤ 3</td><td>≤ 4,5</td></tr>
<tr><td colspan="2" rowspan="2">In-situ acceptance test</td><td>Preferred operating range (see 3.4)</td><td>≤ 3,0</td><td>≤ 3,7</td><td>≤ 5,6</td></tr>
<tr><td>Allowable operating range</td><td>≤ 3,8</td><td>≤ 4,7</td><td>≤ 7,1</td></tr>
<tr><td colspan="2" rowspan="2">Factory acceptance test</td><td>Preferred operating range (see 3.4)</td><td>≤ 3,8</td><td>≤ 4,7</td><td>≤ 7,0</td></tr>
<tr><td>Allowable operating range</td><td>≤ 4,5</td><td>≤ 5,6</td><td>≤ 9,0</td></tr>
<tr><td colspan="6">a) For pumps with special one- and two-vane impeller, the values for class III pumps are applicable. For clogless or similar operation two-phase flow with suspended solids (e.g. rough sewage, potatoes, sugarbeans, fish), a higher vibration of 2 mm/s over Class III can be expected.
b) The classes are in accordance with ISO 9905 (Class I), ISO 5199 (Class II) and ISO 9908 (Class III).
c) Recommended values which must be above set ((that?)) value for a duration of not more than 10 s before alarm respectively trip is released (see also Clause 6).</td></tr>
</table>

It should be noted that there are specific machines or special support and operating conditions as well as some pump designs and impeller shapes for special applications, which require to permit different values (higher or lower) than those given in Tables A.1 and A.2 (see also footnote a) in Table A.1). Different values may therefore be permissible. All such cases should be subject to agreement between the manufacturer and user.

A standby pump may be effected by running machines installed nearby that may cause damage especially at antifriction bearings of the standby pump. The values given in this part of ISO 10816 are only valid for a running pump. If measurements are taken at the standby pump, limits should be much lower. These limits are not subject of this part of ISO 10816.

Table A.2 — Additional criteria for vibration limits on non-rotating parts for pumps with a running speed below 600 r/min and valid filtered values (0,5 ×, 1 × and 2 × the running speed)

Zone	Description	Displacement peak-to-peak value µm
A	Newly commissioned machines in preferred operating range	≤ 50
B	Unrestricted long-term operation in allowable operating range	≤ 80
C	Limited operation	≤ 130
D	Hazard of damage	> 130
Maximum ALARM[a)]		100
Maximum TRIP[a)]		160
In-situ acceptance test	Preferred operating range (see 3.4)	≤ 50
	Allowable operating range	≤ 65
Factory acceptance test	Preferred operating range (see 3.4)	≤ 65
	Allowable operating range	≤ 80

a) Recommended values which must be above set ((that?)) value for a duration of not more than 10 s before alarm respectively trip is released (see also Clause 6).

Annex B
(informative)

Evaluation criteria for relative shaft vibration of rotodynamic pumps with sleeve bearings

B.1 Shaft vibration measurement

Relative shaft vibration measurement can be useful to detect rubbing between the rotating and stationary parts. General information about measurement procedures are given in ISO 7919-1. Shaft vibration measurement is complementary to the bearing housing vibration measurement. It is important to recognise that there is no simple way to relate bearing housing vibration to shaft vibration, or vice versa.

For shaft vibration measurement, the measurement equipment to be used shall conform to the requirements set out in ISO 7919-1 and shall be in accordance with the requirements of ISO 10817-1. The frequency range shall fulfil the specifications given in 3.2. The measurement quantity is the unfiltered peak-to-peak vibration displacement measured in µm. The shaft runout (total electrical and mechanical runout) should be minimized and is recommended to not exceed 25 % of the allowable vibration displacement or 6 µm, whichever is greater.

It is recommended to use two transducers radially mounted in the same radial plane perpendicular to the shaft axis or as close to as practicable, and mounted 90° ± 5° apart on the same bearing half. The measurement should be taken inside or close to the bearing (measurement of peak-to-peak shaft vibration relative to the bearing housing). The shaft vibration of rotodynamic pumps with hydrodynamic bearings shall be measured relative to the bearing shell inside or close to the bearings.

A single transducer instead of the more typical pair of orthogonal transducers may be used at a bearing, if it will provide adequate information on the magnitude of the machine vibration. In general caution should be observed when evaluating values from a single transducer in a measurement plane since it may not be oriented to provide a reasonable approximation of the maximum value in that plane (see ISO 7919-1).

In view of the relatively high rotary frequencies of industrial machines, measurement techniques are widely spread which use contactless transducers. These are preferred with rotating parts with speeds of 3000 r/min and more. In case of mounting of eddy-current probes for measuring relative shaft vibration, care should also be taken in respect to avoid resonances.

B.2 Shaft vibration evaluation

B.2.1 General

The vibration magnitude is the higher value of the peak-to-peak displacement measured in two selected directions orthogonal to each other. The values presented in this annex are the result of experience with machinery of this type and, if due regard is paid to them, acceptable operation can be expected. If only one measurement direction is used care should be taken to ensure that it provides adequate information.

The difference between the shaft absolute and shaft relative measurements is related to the bearing housing vibration but may not be numerically equal to it because of phase angle differences. Thus, when the criteria of this part of ISO 10816 are applied in the assessment of pump vibration on non-rotating parts (bearing housing), and on the rotating shaft, independent shaft and bearing housing vibration measurements shall be made. If application of the different criteria leads to different assessments of vibration severity, the more restrictive is considered to apply.

The basic assumption for a safe operation of a plain bearing is that the shaft in the bearing shell may only be displaced so far that contact between shaft and bearing shell is excluded. The bearing clearance between shaft and bearing shell therefore shall never be completely bridged by the vibration displacement of the shaft movement in relation to the bearing shell (this assumes that the bearing clearance is the smallest clearance compared to other parts as seals or labyrinths). The evaluation of the vibration magnitudes is referred to the diametrical bearing clearance as they were in the new machine. Thus it is presaged to limit the vibration displacement of the shaft movement in relation to the bearing shell as a function of the absolute diametrical bearing clearance.

The bearing clearance of the new pump shall be stated by the pump manufacturer. For axial bearings, the permissible clearance has also to be stated by the manufacturer.

The basic assumption for a safe operation of a sleeve bearing is that no contact occurs between the rotating shaft and the stationary parts such as the bearing shell and also that the limits of vibration on the bearing are not exceeded.

Shaft vibration limits are specified in this annex as a function of both the nominal bearing clearance and the maximum service speed. These limits do not apply to axial shaft vibration on thrust bearings.

If the bearing clearance is known the clearance-related evaluation is decisive and that criterion should be used, see B.2.2.

If the bearing clearance is not known the evaluation should be based on peak-to-peak displacement values taken from ISO 7919-3, see B.2.3.

Due to the fact that the measurement locations are close to the bearing, higher shaft deflections could be experienced at other positions along the shaft and care should be taken that no contact occurs at those positions, for example in a seal area or inside multistage pumps.

For transient conditions, the maximum limit is normally the upper boundary of zone C.

Table B.1 — Recommended values for maximum relative displacement of the shaft as a function of the nominal diametrical clearance for horizontal rotodynamic pumps with hydrodynamic bearings

<table>
<tr><td>Zone</td><td colspan="2">Description</td><td>Limits for peak-to-peak shaft vibration in relation to the total clearance of the hydrodynamic bearing[a) b)]</td></tr>
<tr><td>A</td><td colspan="2">Newly commissioned machines in preferred operating range</td><td>≤ 0,33 × bearing clearance in new state</td></tr>
<tr><td>B</td><td colspan="2">Unrestricted long-term operation in allowable operating range</td><td>≤ 0,5 × bearing clearance in new state</td></tr>
<tr><td>C</td><td colspan="2">Limited operation</td><td>≤ 0,7 × bearing clearance in new state</td></tr>
<tr><td>D</td><td colspan="2">Hazard of damage</td><td>> 0,7 × bearing clearance in new state</td></tr>
<tr><td colspan="3">Maximum ALARM[c)]</td><td>0,7 × bearing clearance in new state</td></tr>
<tr><td colspan="3">Maximum TRIP[c)]</td><td>0,9 × bearing clearance in new state</td></tr>
<tr><td colspan="2" rowspan="2">In-situ acceptance test</td><td>Preferred operating range (see 3.4)</td><td>≤ 0,33 × bearing clearance in new state</td></tr>
<tr><td>Allowable operating range</td><td>≤ 0,5 × bearing clearance in new state</td></tr>
<tr><td colspan="2" rowspan="2">Factory acceptance test</td><td>Preferred operating range (see 3.4)</td><td>≤ 0,33 × bearing clearance in new state</td></tr>
<tr><td>Allowable operating range</td><td>≤ 0,5 × bearing clearance in new state</td></tr>
<tr><td colspan="4">a) The pump manufacturer shall specify the nominal value of the hydrodynamic bearing clearance.
b) The measured shaft runout may be subtracted from the measured vibration.
c) Recommended values which must be above set ((that?)) value for a duration of not more than 10 s before alarm respectively trip is released (see also Clause 6).</td></tr>
</table>

B.2.2 Limits for relative shaft displacement as a function of bearing clearance

The evaluation of the vibration displacement is related to the nominal diametrical bearing clearance if the latter is known. The recommended values given in Table B.1 are for guidance only. They apply to horizontal pumps with oil-lubricated hydrodynamic bearings and speeds above 2900 r/min, they are not applicable to vertical pumps.

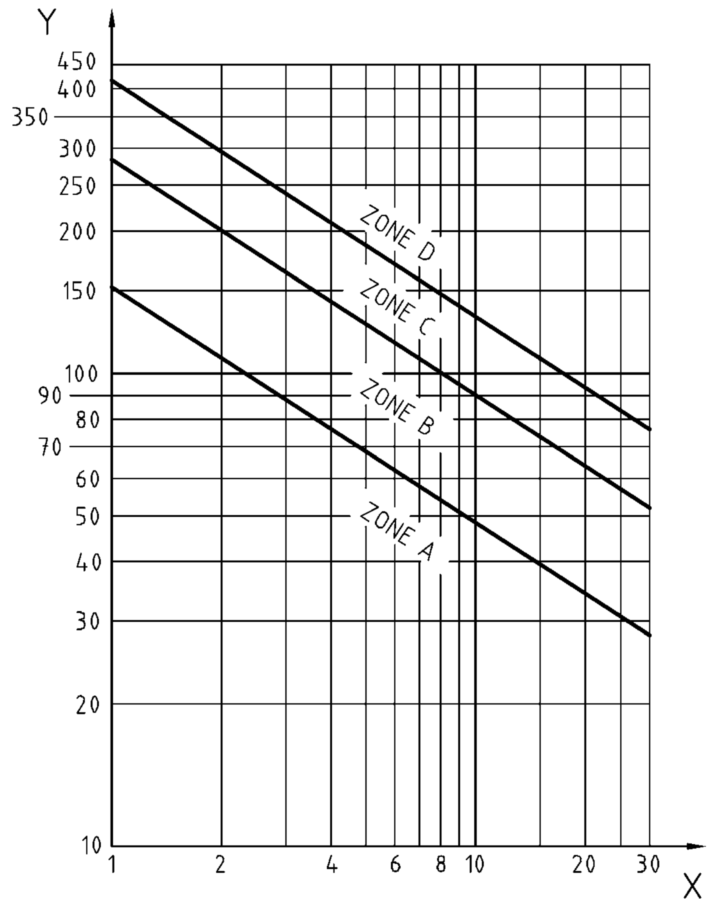
B.2.3 Limits for relative shaft displacement as a function of maximum service speed

If the bearing clearance is not known the evaluation should be based on the peak-to-peak displacement values taken from ISO 7919-3 which gives recommended values for maximum relative displacement of the shaft, S_{p-p}, as a function of the maximum service speed.

NOTE S_{p-p} is the peak-to-peak vibration displacement in the direction of measurement.

For some machines, the recommended maximum displacement values from ISO 7919-3 might be higher than the actual bearing clearance and in those cases care should be taken when applying those values to assure that a certain clearance between rotating and non-rotating parts (bearing housing) is maintained.

Figure B.1 presents the recommended values for maximum relative displacement of the shaft as a function of the maximum service speed as given in ISO 7919-3:1996 for information. However, the latest edition of ISO 7919-3 shall always be used.



Key

X Shaft speed × 1000, r/min

Y Peak-to-peak vibration displacement of the shaft, relative to bearing, µm

Figure B.1 — Recommended values for maximum relative displacement of the shaft as a function of the maximum service speed (taken from ISO 7919-3:1996 for information only)

Annex C
(informative)

Example of setting ALARM and TRIP values

Consider the case of a 1500 r/min centrifugal pump classified as a Class II pump. The operational ALARM setting for a new machine for which there is no prior knowledge of bearing vibration is normally set within zone C. The specific value is often set by mutual agreement between the machine manufacturer and user. For this example, assume it has been set initially near the zone boundary B/C for each bearing, for example to an r.m.s. value of 6 mm/s (the maximum recommended ALARM value for this pump type is 7 mm/s according to Table A.1).

The recommended TRIP value from the manufacturer of the pump in this example is an r.m.s. value of 9 mm/s (the maximum recommended TRIP value for a Class II pump is 11 mm/s).

After a period of machine operation, the user may choose to keep the original ALARM setting (same on all bearings) or consider the option of changing the ALARM setting to reflect the typical steady-state baseline values of vibration at each bearing. Using the procedure described in 6.2 as the basis, the ALARM may be set for each bearing to equal the sum of the typical steady-state value obtained from experience with the specific machine, and 25 % of the upper value of zone B. Hence, if the typical steady-state r.m.s. value at one bearing is 2,5 mm/s, a new ALARM setting of 3,9 mm/s (i.e. 2,5 mm/s + 0,25 × 5,6 mm/s) (see Table A.1) may be used that is within Zone B. If on another bearing the typical value is 4,3 mm/s, application of the procedure of 6.2 for this second bearing would result in a value of 5,7 mm/s (4,3 mm/s + 0,25 × 5,6 mm/s). The difference between this (5,7 mm/s) and the initial alarm value (6 mm/s) is insignificant and therefore the ALARM value would probably remain unchainged at 6 mm/s, within zone C.

For either bearing of the pump, however, the machine TRIP value would be the same and remain at an r.m.s. value of 9 mm/s in accordance with Criterion I (see 4.2.1). The basis for this is that the TRIP value is a fixed value corresponding to the maximum vibration to which the machine should be subjected.

Annex D
(informative)

Consideration of support flexibility and installation orientation

In general two different support situations (type of foundation) exist:

— flexible support where the natural frequency is at least 25 % lower than the lowest exciting frequency of the machine (usually the running speed),

— rigid support where the natural frequency is 25 % higher than the lowest exciting frequency.

On one machine and especially on one bearing in different directions different situations can occur. It is often very difficult to evaluate if the support is rigid or flexible. In any case, resonances of natural frequencies with the running speed or other excitation frequencies should be avoided.

Experience shows also that the permissible vibration limits are not very much affected by the support flexibility. As a result of this fact, this part of ISO 10816 makes no difference between rigid and flexible foundations.

As it is visible out of a survey of about 1500 pumps, the differences between horizontal and vertical installation of a pump are not significant, although the statistical evaluation has in fact shown lower vibration for vertical pumps than horizontal pumps measured on the pump bearings and also lower vibration for low-speed pumps (speed below 600 r/min).

Bibliography

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

ISO 7919-3:1996, Mechanical vibration of non-reciprocating machines — Measurements on rotating shafts and evaluation criteria — Part 3: Coupled industrial machines

ISO 7919-5, Mechanical vibration of non-reciprocating machines — Measurements on rotating shafts and evaluation criteria — Part 5: Machine sets in hydraulic power generating and pumping plants

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

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

ISO 13709, Centrifugal pumps for petroleum, petrochemical and natural gas industries[3)]

ISO 15783, Seal-less rotodynamic pumps — Class II — Technical specification

3) This International Standard corresponds to API 610:1995.

