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

Part 7: Rotodynamic pumps for industrial applications, including measurements on rotating shafts

*Vibrations mécaniques — Évaluation des vibrations des machines par
mesurages sur les parties non tournantes —*

*Partie 7: Pompes rotodynamiques pour applications industrielles, y
compris mesurages sur les arbres tournants*



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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, shock and condition monitoring*, 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 1 500 r/min, 1 800 r/min, 3 000 r/min and 3 600 r/min*
- *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*
- *Part 4: Gas turbine sets with fluid-film bearings*
- *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 applications, including measurements on rotating shafts*

Introduction

Vibration measurements on rotodynamic pumps can be useful for many purposes, e.g. for the operational monitoring, acceptance test and for diagnostic or analytic investigation (condition monitoring).

General descriptions 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 vibration data gathered from a survey of about 1 500 pumps operating both *in situ* and at various test facilities. This survey included pumps of different types, speed and power, operating over a wide range of flows. Due to the large number of vibration measurements, these data are considered to be representative of pumps that are operating satisfactorily, though there is a lack of information about the mean time between failure and operating conditions for the measured values.

Statistical evaluation of these data has been made for the preferred operating region, i.e. 70 % to 120 % of the best efficiency point (BEP), as well as evaluations of the flow and power dependency.

This vibration survey showed no significant differences between rigid and flexible supports, or between horizontal and vertical orientations of the pumps when measured at the positions defined in this part of ISO 10816. This is in contrast to other standards dealing with vibration measurements (e.g. ISO 10816-1, ISO 10816-3 and ISO 13709^[10]) which do make these distinctions.

The statistical analysis showed a slight dependency of the vibration values with the power consumption of a pump. Consequently, this part of ISO 10816 distinguishes between pumps up to and above 200 kW.

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

Part 7: Rotodynamic pumps for industrial applications, including measurements on rotating shafts

1 Scope

This part of ISO 10816 gives instructions for the evaluation of vibration on rotodynamic pumps for industrial applications with nominal power above 1 kW. It defines 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 bearing housings of rotodynamic pumps *in situ* and for the acceptance test at the manufacturer's test facility or in the plant. This part of ISO 10816 also gives general information and guidelines for assessing relative shaft vibration of the rotating shaft.

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 and for acceptance tests¹⁾ *in situ* or at the manufacturer's test facility if specified. For the acceptance test at the manufacturer's test facility, special conditions are given.

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

For pump units with integrated electrical motors (impeller directly on the motor shaft or impeller shaft rigidly connected to the motor shaft), this part of ISO 10816 applies to the whole coupled unit.

For flexibly coupled motors, this part of ISO 10816 is applicable for the pump only. Also, separately mounted drivers are not within the scope of this part of ISO 10816. Those drivers are dealt with in ISO 10816-3.

The following types of pumps are excluded from this part of ISO 10816:

- reciprocating and rotating positive displacement pumps;
- reciprocating engine driven pumps;

1) Wherever acceptance tests are 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.

- pumps in hydraulic power generating and pumping plants with power above 1 MW (see ISO 7919-5^[4] and ISO 10816-5);
- solids handling, slurry and submersible pumps.

Torsional vibration is not dealt with in this part of ISO 10816.

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

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 parts²⁾ 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 . The measurement procedure to be followed is specified in ISO 10816-1.

3.2 Measuring instrumentation and frequency range

3.2.1 General

The measuring 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 1 000 Hz and shall be in accordance with the requirements of ISO 2954.

For pumps with operating speeds below 600 r/min, the lower frequency limit of the measuring instrumentation shall normally be 2 Hz so that the frequency of the vibration component at operating speed is well within the measured frequency range. In addition, the measuring instrumentation shall measure both r.m.s. vibration velocity (in millimetres per second) and peak-to-peak displacement (in micrometres).

Owing to the fact that the broad-band peak-to-peak displacement in the low-frequency range can be strongly influenced by stochastic, impulsive excitations due to the fluid flow, sometimes higher than normal values might occur and should then be analysed and explained e.g. by frequency filtering. In accordance with this it is recommended to measure the peak-to-peak displacement for the filtered values at 0,5 times, 1 times and 2 times the operating speed with a bandwidth of 1 Hz or less to evaluate the quality of a pump.

For very high-speed pumps or for diagnostic purposes (see e.g. ISO 13373-1^[8] which specifies a more detailed analysis), it may be required to use measuring 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.

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

3.2.2 Precautions

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

- temperature variations,
- magnetic fields,
- sound fields,
- power source variations,
- earth loops,
- 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 base are used, the support surface at the measurement object should be prepared to avoid measurement errors. Appropriate mounting methods are shown in Figure 1.

NOTE ISO 5348^[2] contains information on the mechanical mounting of accelerometers which is, in general, also applicable to velocity transducers.

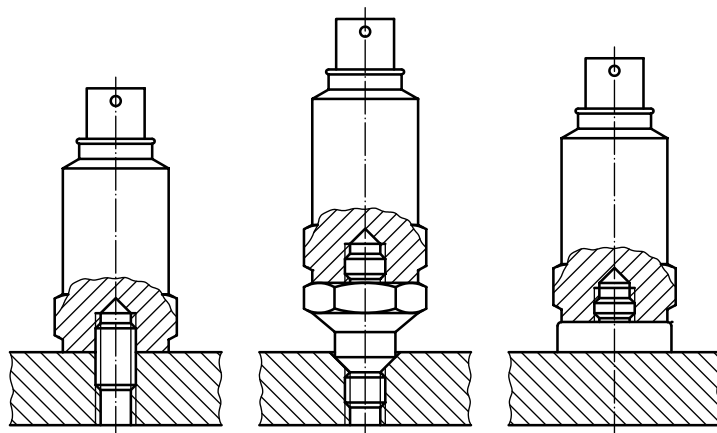


Figure 1 — Mounting methods for vibration transducers

3.2.3 Continuous and periodic monitoring

It is common practice on large or critical pumps to have permanently installed instrumentation for continuous on-line monitoring of vibration at key measurement locations. For many pumps, 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, suddenly occurring defects will not be detected. This shall be especially taken into account when a pump is relevant to safety. In that case continuous on-line 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^[8].

3.3 Measurement locations and directions

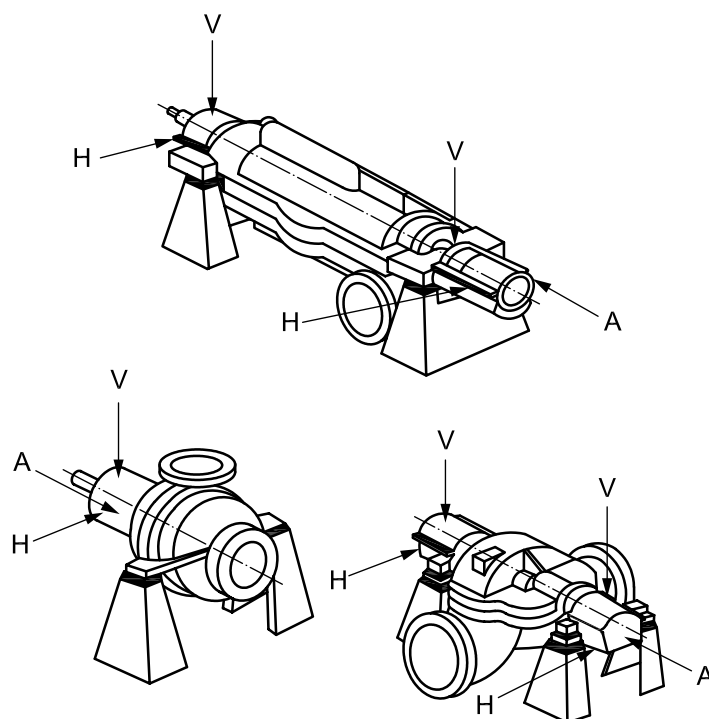
3.3.1 General measurements

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 pump that are accessible (see Figure 2 and Figure 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 pump are represented with sufficient sensitivity. These locations are normally close to the centreline of the bearings. To ensure this, measurements shall normally be made at each bearing housing in two orthogonal radial directions and possibly one axial direction (see 3.3.2) as shown in Figure 2 and Figure 3.

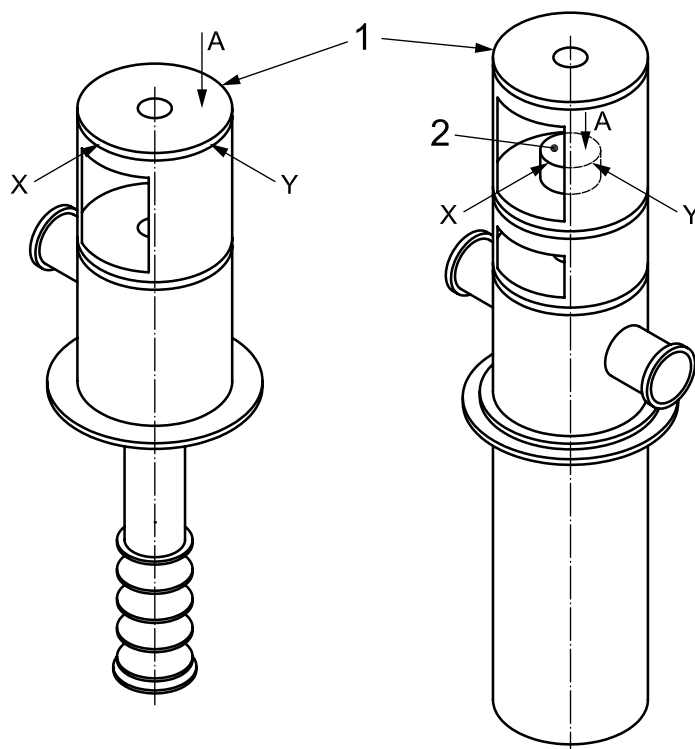
For pumps with horizontal shafts, usually the horizontal and vertical directions are preferred and, if possible, also the axial direction. For pumps with vertical or inclined shaft arrangements, the measurement locations shall be chosen in such a way as to ensure the maximum reading. In most of the cases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

The measurement locations and directions used shall be listed in the measurement report.



NOTE H, V (horizontal, vertical) are the two orthogonal radial measurement directions; A is the axial measurement direction.

Figure 2 — Measurement locations on horizontal pumps



Key

1 driver mounting surface/lower motor bearing

2 pump bearing housing. Preferably this location has to be chosen if within reach, otherwise the lower motor bearing housing can be used.

NOTE X, Y are the two orthogonal radial measurement directions; A is the axial measurement direction.

Figure 3 — Measurement locations on vertical pumps

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 axial measurements are primarily used during periodic vibration surveys or for diagnostic purposes. However, certain faults are more easily detected in the axial direction. Axial vibration criteria are at present only given for thrust bearings where axial vibration correlates with axial pulsation which could cause damage to the axial load-carrying surfaces. The criteria given in Table A.1 and Table A.2 apply to radial vibration on all bearings and to axial vibration on thrust bearings.

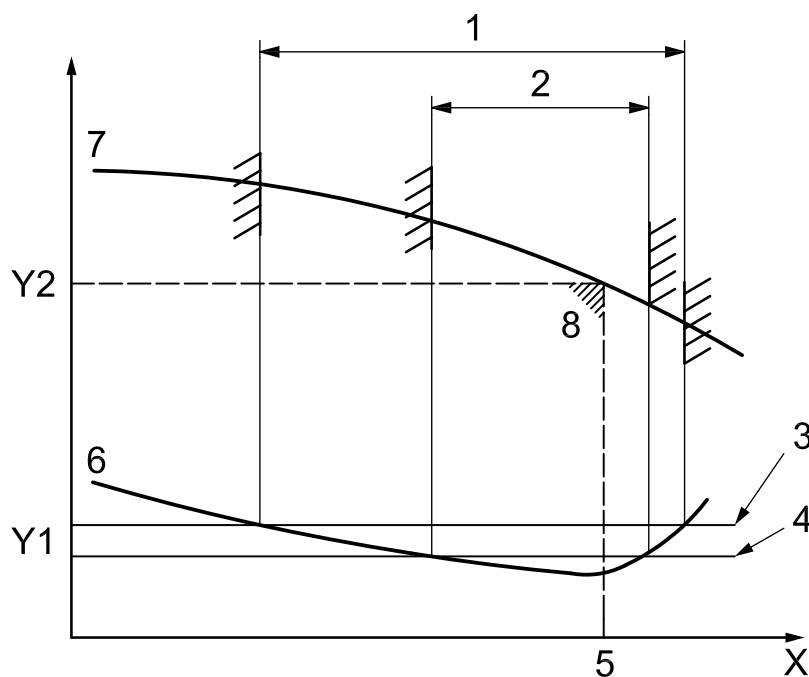
3.4 Installation and operating conditions

For the installation of pumps, it is important that the system designer, pump manufacturer and user take special care to avoid resonance in the connected piping systems and foundations with the main excitation frequencies (e.g. rotational frequency, twice rotational frequency or blade-passing frequency) since such a 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 pump shall be operated under the specified operating conditions, i.e. at the nominal values for rate of flow, delivery head, and speed, which should lie within the preferred operating range (see Figure 4). This part of ISO 10816 also gives guidelines for operating within the whole allowable operating range.

Special attention has to be drawn to those pumps which operate under different operating conditions. If variable conditions might occur, these have to be noted. On pumps with varying speeds or loads, measurements shall be made under all conditions under which the pump 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 the same within the testing tolerances.

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.



Key

X flow
Y1 vibration
Y2 head

- 1 allowable operating region (AOR)
- 2 preferred operating region (POR)
- 3 vibration limit, AOR
- 4 vibration limit, POR
- 5 flow rate of best efficiency point (BEP)
- 6 typical vibration characteristic
- 7 head-flow rate curve
- 8 best efficiency point for head and flow rate

Figure 4 — Operating ranges of rotodynamic pumps

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

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 types of machines. One criterion considers the magnitude of observed broad-band vibration; the other considers changes in magnitude, irrespective of whether they are increasing or decreasing.

These vibration criteria are presented for steady-state conditions at the rated speeds and loads. They do not apply for other conditions or during transient operation (e.g. during start up and shutdown or when passing through resonant speed ranges), when higher values of vibration may be expected. It is, however, necessary to limit the vibration in these transient conditions to avoid potentially damaging contact (i.e. rubbing) between the rotating and stationary parts. Therefore, the maximum bearing vibration (and also the maximum shaft vibration, see Annex B) during transient operations should be below the upper limit 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 zones (see 5.2). The permissible limits for each zone have been established from international experience and are given in Table A.1 and Table 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 can occur which requires some action even though the limits of zone C as given in Table A.1 and Table 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 changes within the range of testing tolerances of 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 pump 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 given in Table A.1 and Table 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 to the 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 frequency components or 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 a 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 are 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 operation *in situ* and acceptance tests

5.1 General

The evaluation zones given in 5.2 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 Annex A and Annex B, provide guidelines for ensuring that gross deficiencies or unrealistic requirements are avoided. In certain cases, however, there may be specific features associated with a particular machine which would require different zone limit 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 pump will not be endangered by operating with higher vibration values.

This part of ISO 10816 divides pumps into two categories as follows:

- a) **Category I:** Pumps required to have a high level of reliability, availability or safety reasons (e.g. pumps for toxic and/or hazardous liquids; for critical application, oil and gas, special chemical, nuclear or power plant application);
- b) **Category II:** Pumps for general or less critical application (e.g. pumps for non hazardous liquids).

NOTE Vertical suspended pumps (pump designations VS 1 to VS 7 according to ISO 13709^[10]) with speeds above 600 r/min are usually within Category II.

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

5.2 Evaluation zones

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.

5.3 Evaluation zone limits

The values for the zone limits which are given in Annex A are the maximum broad-band values of velocity and, for acceptance tests, also the filtered (1 times the running speed and blade-passing frequency, $f_n \cdot z_i$) velocity (see Table A.1). For low-speed pumps, additionally the filtered (0,5 times, 1 times and 2 times the running speed) displacement values are listed (see Table A.2). When measurements are taken from two orthogonally oriented radial transducers (see 3.3) the higher of each of the values measured in each measurement plane should be used.

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

The criteria in Table A.1 and Table 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 pump 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.

5.5.2 Factory acceptance test

The vibration of new pumps installed in a test bed should 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 this requirement, additional measurements (e.g. FFT analysis) by the manufacturer to clarify the reason for the deviation are necessary.

Normally the reason for higher values is that the throttle valve is very near to the pump and this causes vibration at the piping, the pump casing and the bearing housing.

If the values exceed the vibration limits the manufacturer shall demonstrate with additional measurements the root cause for these values, e.g. due to a temporary fixing (supports).

5.5.3 Acceptance test *in situ*

The *in situ* conditions apply to pumps 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 establish operational vibration limits. These limits take the form of ALARM and TRIP.

ALARM: 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.

TRIP: To specify the magnitude of vibration beyond which further operation of the machine may cause damage. If the TRIP limit 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 limits 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 limit be set higher than the baseline by an amount equal to 25 % of the upper limit of zone B. If the baseline is low, the ALARM 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 limit should not normally 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 limits 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 limits. In general, the TRIP limit will be within zone C or zone D, but it is recommended that the TRIP limit not exceed 1,25 times the upper limit of zone C.

Annex A (normative)

Evaluation zone limits for vibration of non-rotating parts

These values apply to radial vibration measurements on all bearings, bearing pedestals or housings of rotodynamic pumps 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 pump is undergoing a transient condition (e.g. changing speed or load). Table A.1 gives vibration velocity limits while Table A.2 gives additionally vibration displacement limits for low-speed pumps.

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

**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 blades $z_i \geq 3$**

Zone	Description (see 5.2 for details of zone definitions)	Vibration velocity limit r.m.s. value mm/s			
		Category ^a I		Category ^a II	
		≤ 200 kW	> 200 kW	≤ 200 kW	> 200 kW
A	Newly commissioned machines in preferred operating range	2,5	3,5	3,2	4,2
B	Unrestricted long-term operation in allowable operating range	4,0	5,0	5,1	6,1
C	Limited operation	6,6	7,6	8,5	9,5
D	Risk of damage	$> 6,6$	$> 7,6$	$> 8,5$	$> 9,5$
Maximum ALARM limit ($\approx 1,25$ times the upper limit of zone B) ^b		5,0	6,3	6,4	7,6
Maximum TRIP limit ($\approx 1,25$ times the upper limit of zone C) ^b		8,3	9,5	10,6	11,9
<i>In situ</i> acceptance test	Preferred operating range	2,5	3,5	3,2	4,2
	Allowable operating range	3,4	4,4	4,2	5,2
Factory acceptance test	Preferred operating range	3,3	4,3	4,2	5,2
	Allowable operating range	4,0	5,0	5,1	6,1
For all acceptance tests in the preferred operating range (see 3.4), each of the filtered values ^c for rotational frequency (f_n) and blade-passing frequency ($f_n \cdot z_i$) should be		≤ 2	≤ 2	≤ 3	≤ 3
^a For definition, see 5.1. ^b Recommended values. The vibration magnitudes should be above these limits for about 10 s before an ALARM or TRIP is released to avoid false alarms and trips. ^c For acceptance tests in the allowable but outside the preferred operating range, the filtered values for rotational frequency (f_n) and blade-passing frequency ($f_n \cdot z_i$) may be expected to be higher (1,3 times) than the values for the preferred operating range.					

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

Zone	Description (see 5.2 for details of zone definitions)	Vibration displacement limit 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	Risk of damage	> 130
Maximum ALARM ^a		100
Maximum TRIP ^a		160
<i>In situ</i> acceptance test	Preferred operating range	50
	Allowable operating range	65
Factory acceptance test	Preferred operating range	65
	Allowable operating range	80
^a Recommended values. The vibration magnitudes should be above these limits for about 10 s before an ALARM or TRIP is released to avoid false alarms and trips.		
NOTE The limits are applicable for each discrete frequency mentioned.		

It should be noted that there are specific pumps or special support and operating conditions as well as some pump designs and impeller shapes for special applications, for which different values (higher or lower) from those given in Table A.1 and Table A.2 may be permissible. All such cases should be subject to agreement between the manufacturer and the user.

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

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 recognize that there is no simple way to relate bearing housing vibration to shaft vibration, or vice versa. The values in Table B.1 are applicable for horizontal pumps with oil lubricated hydrodynamic bearings. Vertical pumps and product lubricated bearings are not covered within this annex.

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^[7]. The frequency range shall fulfil the specifications given in 3.2 of this part of ISO 10816. The measurement quantity is the unfiltered peak-to-peak vibration displacement measured in μm . The shaft runout at the measuring planes (total electrical and mechanical runout) should be minimized and is recommended to not exceed 12,5 % of the diametrical bearing clearance or 6 μm , whichever is greater.

The use of two transducers radially mounted in the same radial plane perpendicular to the shaft axis or as close to as practicable, and mounted $90^\circ \pm 5^\circ$ apart on the same bearing half, is recommended. The measurement of peak-to-peak shaft vibration relative to the bearing housing should be taken inside the bearing housing or as close as possible to the bearing.

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 rotational speed of rotodynamic pumps, measurement techniques using non-contacting transducers are commonly applied. These are preferred with rotating parts with speeds of 3 000 r/min and more. When mounting non-contacting transducers for measuring relative shaft vibration, care should be taken to avoid resonances within the transducer mounting.

B.2 Shaft vibration evaluation

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 rotodynamic pumps 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 hydrodynamic bearing is that the shaft in the bearing shell may only be displaced so far that contact between shaft and bearing shell is avoided. 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 such as seals or labyrinths). The evaluation of the vibration magnitudes is referred to the diametrical bearing clearance as it was in the new pump. Thus it is advisable to limit the vibration displacement of the shaft movement in relation to the bearing shell as a function of the diametrical bearing clearance.

The bearing clearance of a 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 the diametrical bearing clearance only. These limits do not apply to axial shaft vibration on thrust bearings.

NOTE ISO 7919-3^[3] gives shaft vibration limits as a function of maximum service speed. However, for some pumps, the displacement values recommended in ISO 7919-3 might be higher than the actual bearing clearance.

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 limit of zone C.

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

Zone	Description (see 5.2 for details of zone definitions)	Limit for peak-to-peak shaft vibration displacement in relation to the diametrical clearance of oil lubricated hydrodynamic bearing ^a
A	Newly commissioned machines in preferred operating range	$0,33 \times$ bearing clearance in new state
B	Unrestricted long-term operation in allowable operating range	$0,5 \times$ bearing clearance in new state
C	Limited operation	$0,7 \times$ bearing clearance in new state
D	Risk of damage	$> 0,7 \times$ bearing clearance in new state
Maximum ALARM ^b		$0,6 \times$ bearing clearance in new state
Maximum TRIP ^b		$0,9 \times$ bearing clearance in new state
<i>In situ</i> acceptance test	Preferred operating range	$0,33 \times$ bearing clearance in new state
	Allowable operating range	$0,5 \times$ bearing clearance in new state
Factory acceptance test	Preferred operating range	$0,33 \times$ bearing clearance in new state
	Allowable operating range	$0,5 \times$ bearing clearance in new state
^a The pump manufacturer shall specify the nominal value of the hydrodynamic bearing clearance. ^b Recommended values. The vibration magnitudes should be above these limits for about 10 s before an ALARM or TRIP is released to avoid false alarms and trips.		

Annex C

(informative)

Example of setting ALARM and TRIP values

Consider the case of a 1 500 r/min centrifugal pump with a power of 100 kW classified as a Category II pump. The operational ALARM limit 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 the user. For this example, assume it has been set initially near the zone limit B/C for each bearing, for example to an r.m.s. value of 6 mm/s (the maximum recommended ALARM limit for this pump type is 6,4 mm/s according to Table A.1).

The recommended TRIP limit from the manufacturer to trip the pump in this example is an r.m.s. value of 9 mm/s (the maximum recommended TRIP limit for a Category II pump is 10,6 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 limit 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 3,8 mm/s (i.e. $2,5 \text{ mm/s} + 0,25 \times 5,1 \text{ mm/s}$) (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 5,6 mm/s ($4,3 \text{ mm/s} + 0,25 \times 5,1 \text{ mm/s}$). The difference between this (5,6 mm/s) and the initial ALARM limit (6,4 mm/s) is insignificant and therefore the ALARM limit would probably remain unchanged at 6,4 mm/s, within zone C.

For either bearing of the pump, however, the machine TRIP limit 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 limit 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 less than 75 % of the lowest excitation frequency of the machine (usually the running speed),
- rigid support where the natural frequency is more than 125 % of the lowest excitation frequency.

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

Experiences show that failures (e.g. ball bearing failures) depend on vibration magnitude only and not on the support situation.

The investigation of more than 1 500 pumps (done prior to the preparation of this part of ISO 10816) showed that the vibration values are not very much affected by the support flexibility. As a result of this fact, this part of ISO 10816 makes no distinction between rigid and flexible foundations.

This part of ISO 10816 does not distinguish between vertically and horizontally mounted pumps since the collected measurement values did not show significant differences.

Because vertical pumps are offered in various types with special support conditions affecting the vibration behaviour it is difficult to give precise values for each design. Nevertheless it should be stated as a result of the investigation and the analysis of the measurement values taken that vertical pumps can be well within the limits for horizontal pumps.

Bibliography

- [1] ISO 5199, *Technical specifications for centrifugal pumps — Class II*
- [2] ISO 5348, *Mechanical vibration and shock — Mechanical mounting of accelerometers*
- [3] ISO 7919-3, *Mechanical vibration — Evaluation of machine vibration by measurements on rotating shafts — Part 3: Coupled industrial machines*
- [4] 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*
- [5] ISO 9905, *Technical specifications for centrifugal pumps — Class I*
- [6] ISO 9908, *Technical specifications for centrifugal pumps — Class III*
- [7] ISO 10817-1, *Rotating shaft vibration measuring systems — Part 1: Relative and absolute sensing of radial vibration*
- [8] ISO 13373-1, *Condition monitoring and diagnostics of machines — Vibration condition monitoring — Part 1: General procedures*
- [9] ISO 13373-2, *Condition monitoring and diagnostics of machines — Vibration condition monitoring — Part 2: Processing, analysis and presentation of vibration data*
- [10] ISO 13709, *Centrifugal pumps for petroleum, petrochemical and natural gas industries*
- [11] ISO 15783, *Seal-less rotodynamic pumps — Class II — Specification*

