INTERNATIONAL STANDARD

**ISO 7919-5**

Second edition
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# Mechanical vibration — Evaluation of machine vibration by measurements on rotating shafts —

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



*Vibrations mécaniques — Évaluation des vibrations des machines par mesurages sur les arbres tournants —*

*Partie 5: Machines équipant les centrales hydroélectriques et les stations de pompage*



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ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

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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 7919-5 was prepared jointly 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*, and Technical Committee IEC/TC 4, *Hydraulic turbines*. The draft was circulated for voting to the national bodies of ISO and IEC separately.



This second edition cancels and replaces the first edition (ISO 7919-5:1997), of which it constitutes a technical revision. Evaluation criteria have been modified, substituting the former four evaluation zones by a more global division of the whole evaluation area into two major ranges, with changed definitions and divided by the former B/C borderline. Inside the two major ranges A-B and C-D, the old borderlines A/B and C/D are kept to indicate different statistically based severity grades. More information on the objectives of this revision is given in Annex D.



ISO 7919 consists of the following parts, under the general title *Mechanical vibration — Evaluation of machine vibration by measurements on rotating shafts:*

— *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: Coupled industrial machines*

— *Part 4: Gas turbine sets*

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

# Mechanical vibration — Evaluation of machine vibration by measurements on rotating shafts —

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

## 1 Scope

This part of ISO 7919 gives guidelines for applying evaluation criteria for shaft vibration measured at, or close to, the bearings of machines or machine sets in hydraulic power generating and pumping plants under normal operating conditions. These guidelines are presented in terms of both steady-state running vibration and any amplitude changes that can occur in these steady vibration values.

NOTE 1 The numerical values specified are not intended to serve as the only basis for vibration evaluation since, in general, the vibratory condition of a machine is assessed by consideration of both the shaft vibration and the associated structural vibration (see ISO 7919-1 and ISO 10816-1).



This part of ISO 7919 is applicable to machines or machine sets in hydraulic power generating and pumping plants where the hydraulic machines have speeds from 60 r/min to 1 800 r/min, shell- or shoe-type sleeve bearings, and main engine power of at least 1 MW. The position of the shaft line can be vertical, horizontal or at an arbitrary angle between these two directions.



Machine sets covered by this part of ISO 7919 include a combination of

— hydraulic turbines and generators,

— pumps and electrical machines operating as motors,

— pump-turbines and motor-generators, and

— hydraulic turbines, pumps and motor-generators (classic pump-storage machine sets),

including auxiliary equipment (e.g. starting turbines or exciters lying in the shaft line).

This part of ISO 7919 is also applicable to turbines or pumps connected to generators or electrical motors via gears and/or radially flexible couplings.

NOTE 2 Electrical machines with speeds between 1 000 r/min and 1 800 r/min are evaluated according to the criteria specified in ISO 7919-3.

This part of ISO 7919 is not applicable to

— pumps in thermal power plants or industrial installations (for these machines, see ISO 7919-3),

— hydraulic machines or machine sets having rolling element bearings, or

— hydraulic machines with water-lubricated bearings.

As specified in ISO 7919-1, shaft vibration of machines or machine sets in hydraulic power generating and pumping plants can be determined with regard to the following tasks:

— task A: changes in vibrational behaviour;

— task B: excessive kinetic load;

— task C: the monitoring of radial clearance.

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

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

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

## 3 Measurement procedures



### 3.1 General

The measurement procedures to be followed and the instrumentation to be used shall be as described in ISO 7919-1 and IEC 60994.



### 3.2 Measurement type

Relative and absolute shaft vibration measurements are carried out on hydraulic machine sets using non-contacting transducers. Shaft-riding probes with seismic transducers cannot generally be used due to the very low frequency range of the measuring equipment required for low-speed hydraulic machinery.

For relative measurements, transducers should be mounted directly on the bearing shell or the bearing pad. If the transducers are installed on the bearing support structure or bearing housing, as it is common for vertical machines, care shall be taken that the relative motion between the bearing shell or pad and the transducer itself is small compared with the shaft motion. If this is not so, the measured signal cannot be said to be representative of the relative movement between the shaft and bearing shell or bearing pad, respectively. This requirement can be assessed by static analysis of the structure or additional measurements; the latter is usually difficult and expensive.

With regard to the transducer support structures, it is advisable that the lowest natural frequency of those vibration modes that create significant movements in the working direction of shaft displacement transducers be greater than seven times the synchronous rotational frequency, and should not be a direct multiple of the synchronous rotational frequency.

The absolute vibration of the support frame should always be measured using seismic transducers installed on the support frame as close as possible to the shaft movement transducer and in the same direction of action. The readings from the seismic transducers may be used after conversion into displacements to evaluate the absolute shaft displacement.

NOTE Apart from the shaft vibration, the vibration of the bearing support is frequently monitored as well. The vibration measurement at the lower guide bearings of vertical machines can, however, be misinterpreted. The vibration value measured at the bearings and their supports, which are rigidly embedded in the building, is sometimes produced by hydraulic forces, directly transmitted from the hydraulic machine via the foundation, and is not produced by radial shaft vibration.

### 3.3 Measurement planes

Measurement tasks A and B (see Clause 1) require measurements to be taken at all main bearings of the machine set. If possible, the setting of the transducers at the different bearings should be in line. For vertical machines, in most cases the preferred measurement directions are upstream and 90° apart in the direction of rotation. For horizontal machines, the measurement directions are often chosen to be ± 45° from the vertical for practical reasons.

For monitoring purposes (task A) only, in some cases the measurement planes may be reduced to the most important ones, mainly at machine sets with four or more bearings. The selection should be based on vibration performance analyses, simulating all types of faults or disturbing events. The preferred measurement planes should be those where possible disturbing events produce significant shaft amplitudes.

Measurement task C requires the installation of transducers near to, or inside, the hydraulic machine seals or labyrinths, or at positions from where it is possible to reconstruct the shaft line deflection within the hydraulic machine for all relevant vibration modes. Appropriate measurements are, in special cases, part of the commissioning of a machine set. They yield transfer functions for the different permanent measurement planes.

NOTE When judging the vibration behaviour of the whole machine, it is important to measure also at a distance from the bearings (e.g. in the coupling area) to obtain information about the amplitude distribution along the shaft line. If a bearing plane is near to a vibration node, the vibration behaviour and the actual shaft line deflection can be underestimated.

### 3.4 Measuring equipment



The measuring equipment performance shall be in accordance with the requirements of ISO 10817-1 and IEC 60994.



The frequency range of the measuring equipment shall correspond to the wide excitation spectrum of shaft vibration in hydraulic machines. It should be from one-quarter of the nominal rotational frequency of the machine up to two times the bucket or blade passing frequency.



The amplitude range of the measurement system should be at least four times the values of the borderline between major ranges A-B and C-D (see A.2), so that transient operating conditions can be accurately monitored.

## 4 Evaluation criteria

### 4.1 Turbine operating conditions

Evaluation criteria for vibration magnitude and changes in vibration magnitude for machine sets in turbine operating conditions are presented in Annex A.

With respect to the special nature of the vibration orbits of vertical shaft hydromachines, the measurement quantity should preferably be the maximum vibration displacement $S_{max}$. Since most of the monitoring systems display displacement magnitudes as $S_{p\text{-}p}$ values (vibration peak-to-peak displacement in the direction of measurement; see ISO 7919-1), the evaluation criteria are specified for both measurement quantities. Application of these criteria is valid for machine sets with nominal speeds between 60 r/min and 1 800 r/min operating within the contractually permissible steady-state load.

The limiting values are applicable to all kinds of turbine-driven machine sets, independent of type, head and power, under steady-state conditions, except for the restrictions stated in Clause 1.

It shall be noted that, due to radial forces from swirling flow downstream of the runner, higher shaft vibration amplitudes may occur in off-design operation of axial turbines with non-regulated runner blades, Francis turbines and pump-turbines. The range affected is normally defined by a turbine discharge lower than 80 % of the respective discharge at maximum efficiency at each head.

In the case of pump-turbines, higher shaft vibration amplitudes than normally expected can occur due to the runner design, which is a compromise of the optimal design for turbine and pump runners. For hydromechanically smoother running turbine types (e.g. Pelton turbines, double-regulated Kaplan turbines), lower shaft vibration amplitudes can normally be expected.

### 4.2 Pump operating conditions

At present, insufficient data are available to prepare criteria for machine sets under pump operating conditions. They will be added to a future edition of this part of ISO 7919.

### 4.3 Special operating conditions

Attention should be paid to the following operating conditions:

a) steady-state operating conditions at low partial load, at overload, and the frequent transient operating conditions during start-up and shut-down;

b) rare transient operating conditions such as emergency shut-down, no discharge operation, and running through the brake quadrant with pumps and pump-turbines.

The evaluation of such processes is much more difficult than that of operation within the specified load range. At present there are insufficient values determined from experience to establish limiting curves for these operating conditions. The less the operating condition corresponds to the nominal conditions, the more the flow within the hydraulic machine is disturbed; disturbances such as separation and swirl generate violent stochastic vibration excitation. Due to the density of water, the forces caused by the stochastic excitation are much greater than in thermal turbomachines.



Therefore, during operations outside of the specified load range, the shaft vibration caused by mass unbalances can, in general, be totally masked by the stochastic components. Because of these large stochastic components under extraordinary operating conditions, it is not advisable to rely only on the momentary $S_{max}$ or $S_{p\text{-}p}$ vibration value, but more on their mean values averaged over at least ten rotations of the shaft.



It should be noted that, in general, an overall judgement of the vibratory state of a machine is made on the basis of both shaft relative vibration as defined above and of measurements made on non-rotating parts (see ISO 10816-5).

# Annex A
(normative)

# Evaluation criteria for relative shaft vibration of hydraulic turbine sets under specified operating conditions

## A.1 General

The relative shaft vibration of hydraulic machine sets measured at, or close to, the bearings should be evaluated on the basis of the following two criteria.

**Criterion I**: The reliable and safe running of a machine under normal operating conditions requires that the vibration magnitude remain below certain limits consistent with, for example, acceptable kinetic loads and adequate margins on the radial clearance envelope for the machine. Generally, this criterion will be taken as the basis for evaluation of machines in the absence of any other established knowledge of the satisfactory running characteristics for machines of that type (e.g. for new machine types).

**Criterion II**: Changes relative to a reference value should not be allowed to exceed certain limits. This is because changes in vibration magnitude, even though the specified limits are not exceeded, may point to incipient damage or some other irregularity.



## A.2 Criterion I: Vibration magnitude at rated speed under steady-state operating conditions



### A.2.1 General

Recommended values are given in Figure A.1 for the maximum vibration displacement in the plane of measurement, $S_{max}$, and in Figure A.2 for the vibration peak-to-peak displacement in the direction of measurement, $S_{p\text{-}p}$, as a function of the maximum service speed. Both quantities are measured in the radial direction at, or close to, the main load-carrying journal bearings at rated speed(s) under steady-state operating conditions as defined in 4.1. Higher values of vibration may be permitted at other measurement positions and under conditions described in Annex B.

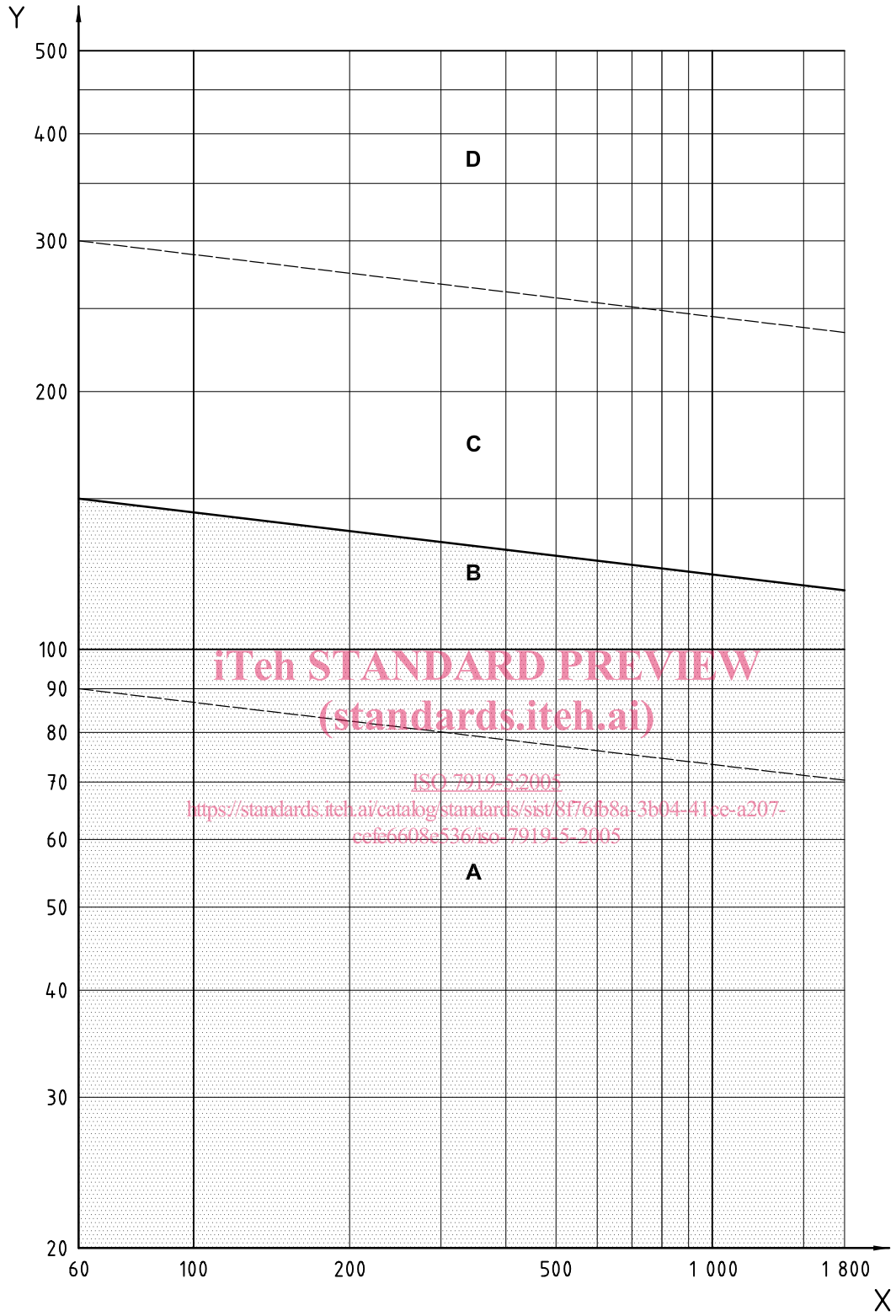
The total area of vibration magnitudes, shown in Figures A.1 and A.2, is divided into two major ranges that are defined as follows.

**Major range A-B**: Machines with vibration magnitudes within this major range are considered acceptable for unrestricted long-term operation.

**Major range C-D**: Machines in this major range have high vibration magnitudes. It is necessary in each case to check if the measured values are permissible for long-term continuous operation considering the specific design and operating conditions. In all cases, evaluation should be made comparing the shaft relative vibration in relation to the bearing running diametrical clearance and oil film thickness.

The values in Figures A.1 and A.2 are based on statistical analyses of more than 900 data sets collected worldwide from machines of all types, speeds and power. Measurements were made on machines that had been running in normal operation for a long time without problems. The analysis may therefore be used to establish the borderline between the two major ranges A-B and C-D. For the analysis procedure, see Annex C.

NOTE 1 The heavy solid borderline between major ranges A-B and C-D represents 92,5 % cumulative probability distribution in the underlying database. That is, 92,5 % of all analysed machines had vibration magnitudes below the heavy solid borderline.



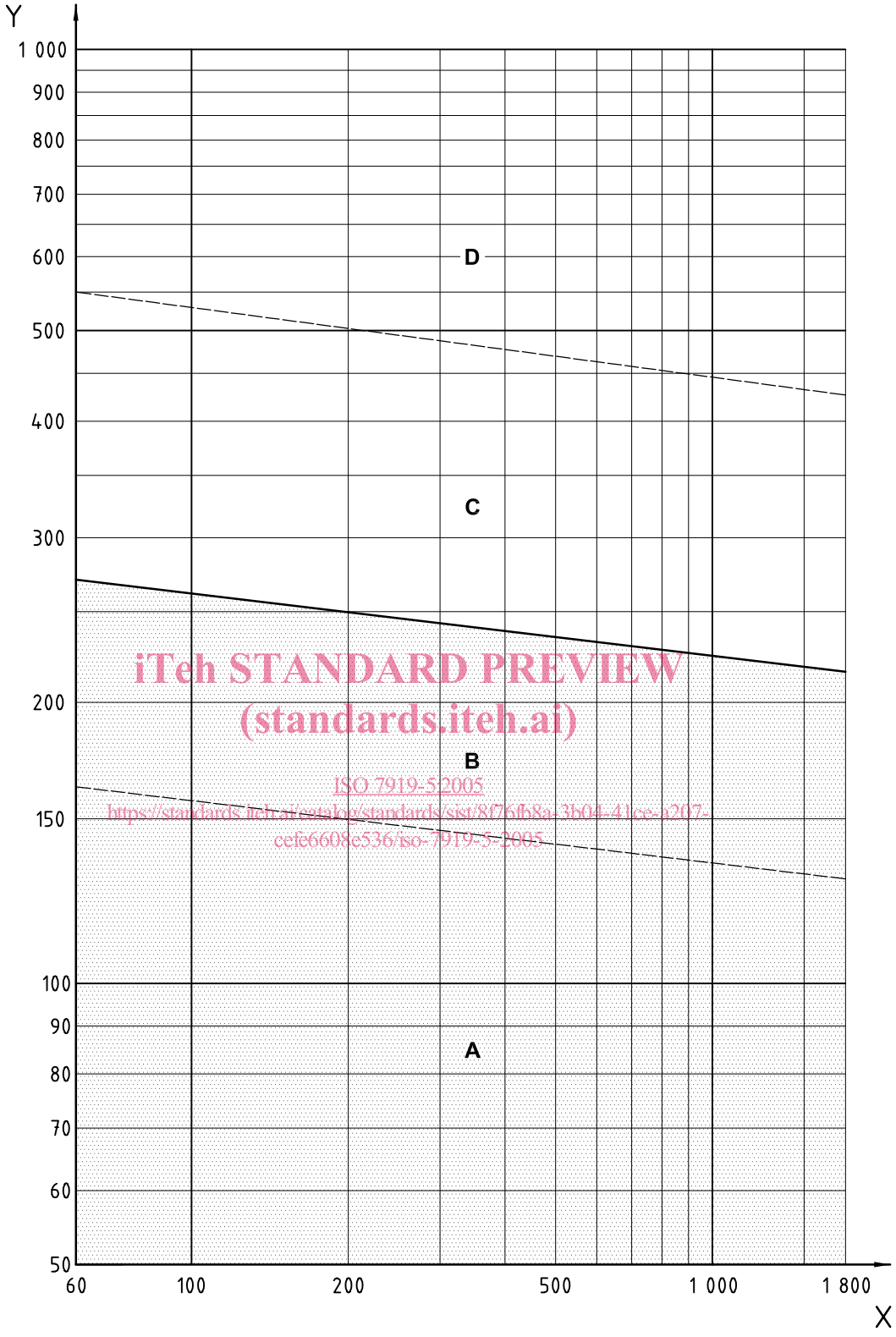



**Key**

X Maximum service speed, r/min

Y Shaft maximum relative vibration displacement, $S_{max}$, µm

**Figure A.1 — Recommended evaluation ranges for the maximum vibration displacement in the plane of measurement, $S_{max}$, of hydraulic machines or machine sets, valid for turbine operation within the contractually permissible steady-state flow range** (see 4.1)






**Key**

X Maximum service speed, r/min

Y Shaft relative vibration peak-to-peak displacement, $S_{p\text{-}p}$, µm

**Figure A.2 — Recommended evaluation ranges for the vibration peak-to-peak displacement in the direction of measurement, $S_{p\text{-}p}$, of hydraulic machines or machine sets, valid for turbine operation within the contractually permissible steady-state flow range** (see 4.1)