INTERNATIONAL STANDARD

ISO 7919−2

Second edition
2001−11−15

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

## Part 2: Land−based steam turbines and generators in excess of 50 MW with normal operating speeds of 1 500 r/min, 1 800 r/min, 3 000 r/min and 3 600 r/min

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

Partie 2:
Turbines à vapeur et alternateurs installés sur fondation radier, excédant 50 MW avec des vitesses normales de fonctionnement de 1 500 r/min, 1 800 r/min, 3 000 r/min et 3 600 r/min

References number
ISO 7919−2:2001(E)

## Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

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 part of ISO 7919 may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

International Standard ISO 7919 2 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*.

This second edition cancels and replaces the first edition (ISO 7919−2:1996), which has been technically revised. Criteria for transient operating conditions, such as run up and run down, have been included.

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*

Annex A forms a normative part of this part of ISO 7919. Annex B is for information only.

## Introduction

ISO 7919   1 is the basic document which describes the general requirements for measurement and evaluation of the vibration of various machine types when the vibration measurements are made on rotating shafts. This part of ISO 7919 is applicable to steam turbines and generators.

Evaluation criteria, based on previous experience, are presented which may be used as guidelines for assessing the vibratory condition of such machines. It must be recognized that these criteria do not form the only basis for judging the severity of vibration. For steam turbines and generators, it is common practice also to judge the vibration based on measurements taken on non−rotating parts. Requirements and evaluation criteria for measurements on non−rotating parts are addressed in separate standards, ISO 108161 and ISO 108162.

The evaluation procedures presented in this part of ISO 7919 are based on broad−band measurements. However, it is important to note that because of advances in technology, the use of narrow−band measurements or spectral analysis has become increasingly widespread, particularly for the purposes of vibration evaluation, condition monitoring and diagnostics. The specification of criteria for such measurements is beyond the present scope of this part of ISO 7919. They will be dealt with in ISO 13373   1 for vibration condition monitoring of machines. Further parts of this series are currently under development.

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

## Part 2:
## Land−based steam turbines and generators in excess of 50 MW with normal operating speeds of 1 500 r/min, 1 800 r/min, 3 000 r/min and 3 600 r/min

## 1 Scope

This part of ISO 7919 gives guidelines for applying evaluation criteria for shaft vibration measured in the radial direction at or close to the bea-rings of steam turbines and generators. These guidelines are presented in terms of:

vibration under normal steady−state operating conditions;

vibration during transient operation, including passage through resonant speeds during run up or run down;

changes in vibration which can occur during normal steady−state operation.

The numerical values specified are not intended to serve as the only basis for vibration evaluation since, in general as described in the introduction to ISO 7919 1, the vibratory condition of a machine is assessed by consideration of both the shaft vibration and the associated structural vibration (see ISO 108162).

This part of ISO 7919 is applicable to land−based steam turbines and generators with a normal operating speed of 1 500 r/min, 1 800 r/min, 3 000 r/min or 3 600 r/min, and power outputs greater than 50 MW. It also includes steam turbines and/or generators which are directly coupled to a gas turbine (such as for combined cycle applications). In such cases the criteria of this part of ISO 7919 apply only to the steam turbine and the generator. Evaluation of the gas turbine vibration should be carried out in accordance with ISO 79194 and ISO 108164 .

## 2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of ISO 7919. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this part of ISO 7919 are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 7919 1, *Mechanical vibration Evaluation of machine vibration by measurements on rotating shafts Part 1: General guidelines*

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

## 3 Measurement procedures

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

Early experience on steam turbines and generators was restricted to the measurement of absolute shaft vibration using shaft−riding transducers. More recently, as non−contacting transducers were developed, relative shaft vibration measurements have become more common but, if required, the absolute shaft vibration can be obtained by vectorially combining the outputs of a non−contacting transducer and a seismic transducer on a common mounting which measures the structural vibration. Both approaches are at present in common use and measurements of relative shaft vibration or absolute shaft vibration are therefore equally acceptable for the purposes of this part of ISO 7919.

For monitoring purposes, the measuring system shall be capable of covering overall vibration up to a frequency corresponding to not less than three times the normal operating speed. However, it should be noted that for diagnostic purposes it may be desirable to cover a wider frequency range.

Prior to running steam turbines and generators up to speed, slow−roll measurements of shaft displacement may be carried out to assess the amount of runout obtained at low speed when stable bearing oil films have been established but centrifugal effects are negligible (for example, on a machine of rated speed 3 000 r/min , the runout could be assessed at a speed of the order of 200 r/min ). The results obtained are compared with expected vibration vectors and may be used as a basis for judging whether the state of the shaft line is satisfactory; for example, whether a temporary bend is present in the shaft or whether there is any lateral or angular misalignment between couplings ( crank effect ). Such measurements cannot normally be regarded as giving a valid indication of shaft runout under normal operating conditions since they can be affected by, for example, temporary bows, erratic movements of the journal within the bearing clearance, axial movements, etc. In particular, it is recommended that vector subtraction of slow−roll measurements from rated speed vibration measurements should not be carried out without consideration of the above factors, since the results may provide a misleading interpretation of the machine vibration (see ISO 79191).

If slow−roll measurements are taken, it is important to ensure that the low−frequency characteristics of the measuring system are adequate.

# 4 Evaluation criteria

## 4.1 General

Criteria for vibration magnitude, changes in vibration magnitude and operational limits are presented below.

The vibration magnitude is the higher value of the peak−to−peak displacement measured in two selected orthogonal measurement directions. The values presented are the result of experience with machinery of this type and, if due regard is paid to them, acceptable operation may be expected. If only one measurement direction is used, care should be taken to ensure that it provides adequate information (see ISO 79191).

Two evaluation criteria are used to assess the shaft vibration of steam turbines and generators, measured at or close to the bearings. One criterion considers the magnitude of the observed broad−band shaft vibration; the second considers changes in magnitude, irrespective of whether they are increases or decreases.

Criteria are presented for steady−state operating conditions at the specified rated speed and load ranges, including the normal slow changes in electrical load of the generator. Alternative values of vibration magnitude are also provided for transient operation.

It should be noted that an overall judgement of the vibratory state of a machine is often made on the basis of both shaft vibration as defined above and of measurements made on non−rotating parts (see ISO 10816 1 and ISO 10816 2).

## 4.2 Criterion I: Vibration magnitude

### 4.2.1 General

This criterion is concerned with defining limits for shaft vibration magnitude consistent with acceptable dynamic loads on the bearings, adequate margins on the radial clearance envelope of the machine, and acceptable vibration transmission into the support structure and foundation.

### 4.2.2 Vibration magnitude at rated speed under normal steady−state operating conditions

#### 4.2.2.1 General

The maximum shaft vibration magnitude observed at each bearing is assessed against four evaluation zones established from international experience.

#### 4.2.2.2 Evaluation zones

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

**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.

NOTE The evaluation zones defined above are relevant to normal steady−state operation at rated speed. Subclause 4.2.4 provides guidelines for transient operation.

#### 4.2.2.3 Evaluation zone boundaries

Recommended values for the zone boundaries are given in annex A for both relative shaft vibration and absolute shaft vibration. These values, which are based on present accumulated experience of shaft vibration measurements in this field, are not intended to serve as acceptance specifications, which shall be subject to agreement between the machine manufacturer and customer. However, they provide guidelines for ensuring that gross deficiencies or unrealistic requirements are avoided.

In most cases the values given in Tables A.1 and A.2 are consistent with ensuring satisfactory operation. However, in certain cases, specific features or available experience associated with a particular machine type may require different zone boundaries to be used (lower or higher). Examples are as follows.

a) Where bearings with small clearance are used, or for bearings with built−in preloads (e.g. generator to exciter) which reduce the minimum bearing clearance, the values given in Table A.1 might be greater than the available bearing clearance. In such cases the zone boundary values will need to be reduced.

NOTE This applies only if the shaft relative vibration is measured on the pedestal close to the bearing. The degree to which the zone boundary values are to be reduced will vary, depending on the type of bearing used and the relationship between the measurement direction and the minimum clearance. It is therefore not possible to give precise recommendations but annex B provides a representative example for a plain cylindrical bearing.

b) For comparatively lightly loaded bearings (e.g. exciter rotor steady bearings) or other more flexible bearings, other criteria based on the detailed machine design may be necessary.

c) Where vibration measurements are made away from the bearing.

d) For some machine designs, where the rotor and bearings are supported on a compliant base/support structure, the magnitudes of absolute shaft vibration might be higher than those for steam turbines and generators that have more rigid bearing support structures. It may then be acceptable, based on demonstrated satisfactory operating history, for the zone boundary values given in annex A to be increased.

In general when higher zone boundary values are used, it might be necessary for technical justification to be provided to confirm that the machine reliability will not be compromized by operating with higher vibration magnitudes. This could be based, for example, on successful operating experience with machines of similar structural design and support. Higher values may also be tolerated during transient conditions, such as run up and run down (see 4.2.4).

### 4.2.3 Operational limits for steady−state operation

#### 4.2.3.1 General

For long−term steady−state operation, it is common practice to establish 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 loading and support stiffness, may be specified for different measurement positions and directions.

#### 4.2.3.2 Setting of ALARMS

The ALARM values may vary for individual machines. The values chosen will normally be set relative to a baseline value determined from experience for the measurement position or direction for that particular machine.

It is recommended that the ALARM value be set higher than the baseline by an amount equal to 25 % of the zone boundary B/C. 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 not normally exceed 1,25 times the zone boundary B/C.

If the steady−state baseline changes (for example after a machine overhaul), the ALARM setting should be revised accordingly. Different operational ALARM settings may then exist for different bearings on the machine, reflecting differences in dynamic loading and bearing support stiffnesses.

#### 4.2.3.3 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 more precise 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 zone boundary C/D.

 

### 4.2.4 Vibration magnitude during transient operation

#### 4.2.4.1 General

The vibration values given in annex A are specified with regard to the long−term operation of the steam turbine and/or generator at the specified steady−state operating conditions. Higher values of vibration can be tolerated during transient operation. This includes both transient operation at rated speed and during run up or run down, particularly when passing through resonant speed ranges. The higher values allowed for transient operation may exceed the ALARM values specified in 4.2.3.

As with the steady−state vibration, any acceptance values for specific cases shall be subject to agreement between the machine manufacturer and customer. However, guidelines are given below which should ensure that gross deficiencies or unrealistic requirements are avoided.

#### 4.2.4.2 Vibration magnitude during transient operation at rated speed

This includes operation at no load following synchronization, rapid load or power factor changes and any other operational conditions of relatively short duration. For such transient conditions, the vibration magnitude shall normally be considered to be acceptable provided that it does not exceed the zone boundary C/D.

#### 4.2.4.3 Vibration magnitude during run up, run down and overspeed

The specification of vibration limits during run up, run down and overspeed may vary depending on particular machine constructional features, or the specific operational requirements. For example, higher vibration values may be acceptable for a base load unit for which there may be only a small number of starts, whereas more stringent limits may apply for a unit which undergoes regular two−shift operation and may be subject to specific time constraints for achieving guaranteed output levels. Furthermore, the vibration magnitude when passing through resonant speeds during run up and run down will be strongly influenced by the damping and the rate of change of speed. For example, as the rate of change of speed is generally lower during run down than run up, higher vibration values may be experienced when passing through resonant speeds during run down (see also ISO 10814 for further information about the sensitivity of machines to unbalance).

In this part of ISO 7919 it is only possible to provide general guidelines which can be used if there are no established baseline values available for similar machines. The guideline is that the allowable shaft vibration to prevent damaging levels of vibration from being experienced during run up, run down or overspeed should not exceed the following.

a) For speeds greater than 0,9 times the normal operating speed: the vibration magnitude corresponding to the zone boundary C/D.

b) For speeds less than 0,9 times the normal operating speed: 1,5 times the vibration magnitude corresponding to the zone boundary C/D.

This relationship is shown in graphical form in Figure 1.

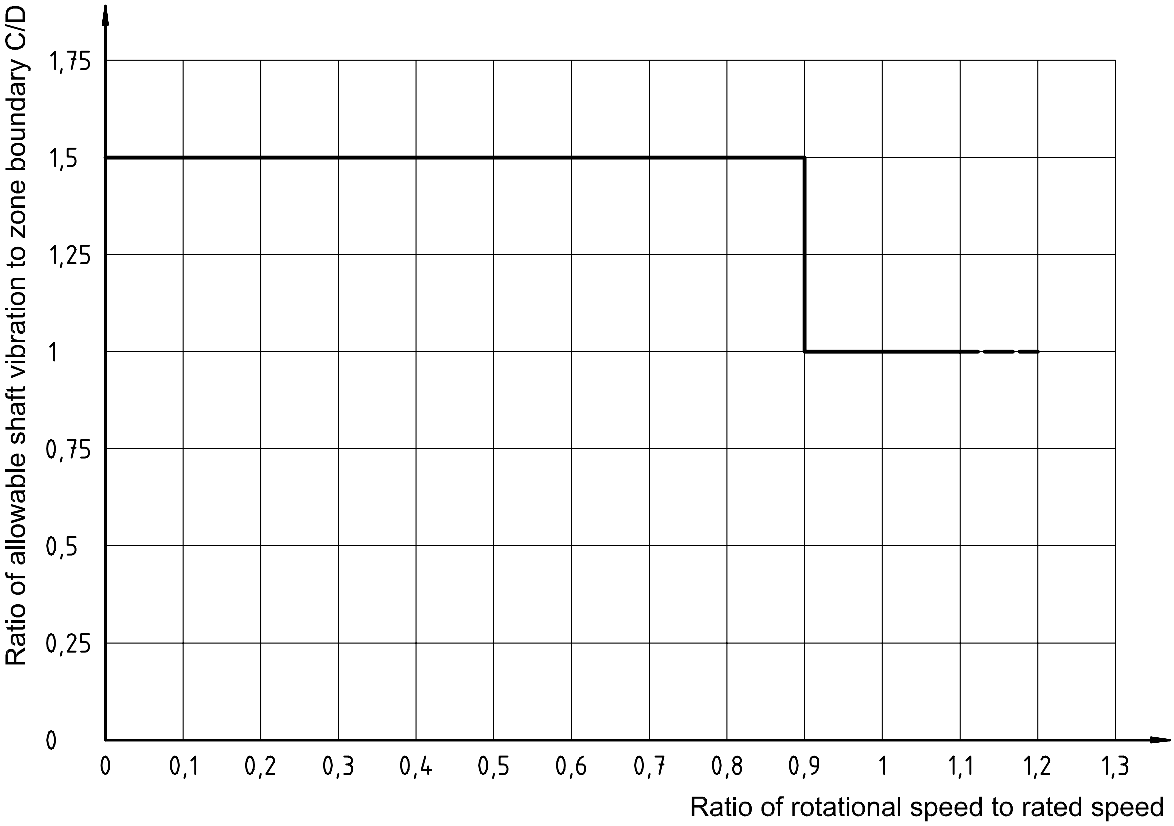


**Figure 1 − Allowable shaft vibration during run up, run down and overspeed**

The maximum values will normally occur during passage through resonant speed ranges. In order to avoid excessive vibration it is recommended that, where possible, the vibration should be assessed before a resonant speed is reached and compared with typical vibration vectors obtained under the same conditions during previous satisfactory runs. If any significant differences are observed, it may be advisable to take further action before proceeding (for example, hold speed until the vibration stabilizes or returns to previous values, carry out a more detailed investigation or check operational parameters).

As is the case for vibration measured under normal steady−state operating conditions, any ALARM values during run up, run down and overspeed should normally be set relative to the corresponding baseline values determined from experience during run up, run down or overspeed for the particular machine. As explained in 4.2.2.3, suitable adjustments may be required for bearings with small clearance (see also annex B).

It is recommended that the ALARM value during run up, run down and overspeed should be set above the baseline value by an amount equal to 25 % of the zone boundary B/C. In those cases where no reliable baseline data are available, it is recommended that the maximum ALARM value should be not greater than the values given in a) and b) above.

In most cases it is not normal practice to define TRIP settings during run up, run down and overspeed. For example, if excessive vibrations build up during run up it may be more appropriate to reduce speed rather than to initiate a TRIP. On the other hand there is little point in initiating a high−vibration TRIP during run down since this will not change the action (i.e. to run down) which has already been taken.

## 4.3 Criterion II: Change in vibration magnitude

This criterion provides an assessment of a change in vibration magnitude from a previously established baseline value. A significant increase or decrease in shaft vibration magnitude can occur which requires some action even though zone C of Criterion I has not been reached. Such changes can be instantaneous or progressive with time, and may indicate that damage has occurred or be a warning of an impending failure or some other irregularity. Criterion II is specified on the basis of the change in shaft vibration magnitude occurring under steady−state 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. The baseline value for this criterion is the typical, reproducible normal vibration, known from previous measurements for the specific operating conditions. If this baseline value changes by a significant amount (typically 25 % of the zone boundary B/C), regardless of whether this increases or decreases the magnitude of vibration, steps should be taken to ascertain the reason for the change. A decision on what action to take, if any, should then be made after consideration of the maximum value of vibration and whether the machine has stabilized at a new condition.

It is necessary to appreciate that a criterion based on change of vibration has limited application, since significant changes of varying magnitude and rates can and do occur in individual frequency components, but the importance of these is not necessarily reflected in the broad−band shaft vibration signal (see ISO 7919 1). For example, the propagation of a crack in a rotor may introduce a progressive change in vibration components at multiples of rotational frequency, but their magnitude may be small relative to the amplitude of the once−per−revolution rotational frequency component. Consequently, it may be difficult to identify the effects of the crack propagation by looking at the change in the broad−band vibration only. Therefore, although monitoring the change in broad−band vibration will give some indication of potential problems, it may be necessary in certain applications to use measuring and analysis equipment which is capable of determining the trends of the vector changes that occur in individual frequency components of the vibration signal. This equipment might be more sophisticated than that used for normal supervisory monitoring and its use and application requires specialist knowledge. Hence, the specification of detailed criteria for measurements of this type is beyond the scope of this part of ISO 7919.

## 4.4 Supplementary procedures/criteria

The measurement and evaluation of vibration given in this part of ISO 7919 may be supplemented or replaced by measurements made on non−rotating parts and the applicable criteria given in ISO 10816 2. It is important to recognize that there is no simple way to relate shaft vibration to bearing vibration, or vice versa. The difference between the shaft absolute and shaft relative measurements is related to the bearing vibration but might not be numerically equal to it because of phase angle differences. Thus, when the criteria of this part of ISO 7919 and those of ISO 10816 2 are both applied in the assessment of machine vibration, independent shaft and bearing measurements shall be made. If the application of the different criteria leads to different assessments of vibration severity, the more restrictive classification generally applies.

## 4.5 Evaluation based on vibration vector information

The evaluation considered in this part of ISO 7919 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 the machine. In some cases these changes would go undetected when using only broad−band vibration measurements (see, for example, ISO 79191).

Phase− and frequency−related vibration information is being used increasingly for condition monitoring and diagnostic purposes. The specification of criteria for this, however, is beyond the present scope of this part of ISO 7919.

# Annex A
(NORMATIVE)

## Evaluation zones boundaries

In most cases the values given in Tables A.1 and A.2 are consistent with ensuring satisfactory operation. However, in certain cases, specific features associated with a particular machine type might require different zone boundary values to be used (see 4.2.2.3).

**Table A.1 − Recommended values for maximum relative displacement of the shaft for steam turbines and generators at the zone boundaries**

| **Zone boundary** | **Shaft rotational speed** r/min | | | |
|---|---|---|---|---|
| | **1 500** | **1 800** | **3 000** | **3 600** |
| | **Peak−to−peak relative displacement of shaft** µm | | | |
| A/B | 100 | 90 | 80 | 75 |
| B/C | 200 | 185 | 165 | 150 |
| C/D | 320 | 290 | 260 | 240 |

**Table A.2 − Recommended values for maximum absolute displacement of the shaft for steam turbines and generators at the zone boundaries**

| **Zone boundary** | **Shaft rotational speed** r/min | | | |
|---|---|---|---|---|
| | **1 500** | **1 800** | **3 000** | **3 600** |
| | **Peak−to−peak absolute displacement of shaft** µm | | | |
| A/B | 120 | 110 | 100 | 90 |
| B/C | 240 | 220 | 200 | 180 |
| C/D | 385 | 350 | 320 | 290 |

# Annex B
(INFORMATIVE)

## Evaluation zone boundary values and bearing clearance

This annex gives an example of reducing evaluation zone boundary values to allow for small bearing clearance.

Assume that the HP rotor of a steam turbine generator set with rated speed of 3 000 r/min is supported by plain cylindrical bearings of 180 mm diameter and 0,1 % clearance ratio. In this case the diametral clearance of the bearing will be 180 µm.

From Table A.1 the peak−to−peak zone boundary values are:

A/B 80 µm

B/C 165 µm

C/D 260 µm

In this case the B/C value is just less than the bearing diametral clearance and the C/D value is in excess of the bearing clearance. It is therefore recommended that the peak−to−peak zone boundary values should be reduced accordingly, for example:

A/B 0,4 times bearing clearance = 72 µm

B/C 0,6 times bearing clearance = 108 µm

C/D 0,7 times bearing clearance = 126 µm

NOTE The above example applies only to the case where shaft relative vibration is measured on the pedestal close to the bearing. The degree to which the zone boundary values are to be reduced will vary, depending on the type of bearing used and the relationship between the measurement direction and the minimum clearance.

# Bibliography

[1] ISO 79193, *Mechanical vibration Evaluation of machine vibration by measurements on rotating shafts Part 3: Coupled industrial machines*

[2] ISO 79194, *Mechanical vibration Evaluation of machine vibration by measurements on rotating shafts Part 4: Gas turbine sets*

[3] ISO 10814, *Mechanical vibration Susceptibility and sensitivity of machines to unbalance*

[4] ISO 108161, *Mechanical vibration Evaluation of machine vibration by measurements on non−rotating parts Part 1: General guidelines*

[5] ISO 108163, *Mechanical vibration Evaluation of machine vibration by measurements on non−rotating parts Part 3: Industrial machines with nominal power above 15 kW and nominal speeds between 120 r/min and 15 000 r/min when measured in situ*

[6] ISO 108164, *Mechanical vibration Evaluation of machine vibration by measurements on non−rotating parts Part 4: Gas turbine driven sets excluding aircraft derivatives*

[7] ISO 108171, *Rotating shaft vibration measuring systems Part 1: Relative and absolute sensing of radial vibration*

[8] ISO 133731, *Condition monitoring and diagnostics of machines Vibration condition monitoring Part 1: General procedures*