INTERNATIONAL STANDARD

ISO 7919-4

Second edition
2009-10-01

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

Part 4:
Gas turbine sets with fluid-film bearings

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

Partie 4: Turbines à gaz à paliers à film fluide

Reference number
ISO 7919-4:2009(E)

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Published in Switzerland

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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 7919-4 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*.

This second edition cancels and replaces the first edition (ISO 7919-4:1996), of which it constitutes a technical revision. The main changes are:

— clarification that the document applies only to gas turbine sets with fluid-film bearings;

— emphasis on acceptance specifications always being agreed on between the supplier and the purchaser of the gas turbine set prior to installation;

— the addition of provisions for evaluating the vibration of coupled gas turbine sets during transient operation;

— closer alignment of this part of ISO 7919 with ISO 7919-2, ISO 10816-2 and ISO 10816-4.

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*[1)]

— *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 with fluid-film bearings*

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

1) It is anticipated that when ISO 7919-1 is revised, it will have the same general title as the other parts of ISO 7919.

Introduction

ISO 7919-1 is the basic part of ISO 7919 giving the general requirements for evaluating the vibration of various machine types when the vibration measurements are made on rotating shafts. This part of ISO 7919 gives specific provisions for assessing the severity of radial shaft vibration measured at, or close to, the bearings of gas turbine sets. Measurements at these locations characterize the state of vibration reasonably well. Evaluation criteria, based on previous experience, are presented. These can be used for assessing the vibratory condition of such machines.

Two criteria are provided for assessing the machine vibration when operating under steady-state conditions. One criterion considers the magnitude of the observed vibration; the second considers changes in the magnitude. In addition, different criteria are provided for transient operating conditions. However, shaft vibration does not form the only basis for judging the severity of vibration. For gas turbine sets, it is also common to judge the vibration based on measurements taken on non-rotating parts. For such vibration measurement requirements, see ISO 10816-1 and ISO 10816-4.

The evaluation procedures presented in this part of ISO 7919 are based on broad-band measurements. However, 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 scope of this part of ISO 7919. They are dealt with in greater detail in ISO 13373 (all parts), which establish provisions for the vibration condition monitoring of machines.

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

Part 4: **Gas turbine sets with fluid-film bearings**

1 Scope

This part of ISO 7919 establishes provisions for evaluating the severity of *in-situ*, broad-band shaft vibration measured radial (i.e. transverse) to the shaft axis at, or close to, the main bearings. These are in terms of:

— vibration under normal steady-state operating conditions;

— vibration during other (non-steady-state) conditions when transient changes are taking place, including run up or run down, initial loading and load changes;

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

This part of ISO 7919 is applicable to heavy-duty gas turbine sets used in electrical and mechanical drive applications, with fluid-film bearings, outputs greater than 3 MW and an operating speed range under load between 3 000 r/min and 30 000 r/min. This includes gas turbines coupled to other rotating machinery either directly or through a gearbox. In some cases, this part of ISO 7919 is not applicable to the evaluation of the vibration of the coupled equipment (see the list of exclusions in this clause).

EXAMPLE For single-shaft combined-cycle power units in which a gas turbine is coupled to a steam turbine and/or generator, the evaluation of the gas turbine vibration is according to this part of ISO 7919, but that of the steam turbine and generator is according to ISO 7919-2 or ISO 7919-3.

This part of ISO 7919 is not applicable to the following:

a) aero-derivative gas turbines (including gas turbines with dynamic properties similar to those of aero-derivatives);

NOTE ISO 3977-3 defines aero-derivatives as aircraft propulsion gas generators adapted to drive mechanical, electrical or marine propulsion equipment. Large differences exist between heavy-duty and aero-derivative gas turbines, for example in casing flexibility, bearing design, rotor to stator mass ratio and mounting structure. Different criteria therefore apply for these two turbine types.

b) gas turbines with outputs less than or equal to 3 MW (see ISO 7919-3);

c) gas turbine driven pumps (see ISO 7919-3);

d) coupled steam turbines and/or generators with outputs less than or equal to 50 MW (see ISO 7919-3);

e) coupled steam turbines and/or generators with outputs greater than 50 MW (see ISO 7919-2);

f) synchronizing clutches which couple the gas turbine to a steam turbine or generator (see ISO 7919-2);

g) coupled compressors (see ISO 7919-3);

h) gearbox vibration (see this clause);

i) rolling element bearing vibration.

This part of ISO 7919 is applicable to other driven equipment not included in this list of exclusions.

This part of ISO 7919 is applicable to machines which can be coupled to a gearbox, but does not address the evaluation of the vibration condition of those gears. Specialist techniques are required for evaluating the vibration condition of gears which are outside the scope of this part of ISO 7919.

The numerical values specified are not intended to serve as the only basis for judging the severity of vibration. For gas turbine sets, it is also common to judge the vibration based on measurements taken on non-rotating parts. For such vibration measurement requirements, see ISO 10816-1 and ISO 10816-4.

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 7919-1:1996, *Mechanical vibration of non-reciprocating machines — Measurements on rotating shafts and evaluation criteria — Part 1: General guidelines*

ISO 10816-4:2009, *Mechanical vibration — Evaluation of machine vibration by measurements on non-rotating parts — Part 4: Gas turbine sets with fluid-film bearings*

3 Measurement procedures

The measurement procedures and instrumentation shall comply with the general requirements of ISO 7919-1 and are as follows.

In gas turbine sets, shaft vibration relative to the bearing is normally measured. Therefore, unless stated otherwise, the vibration displacements referred to in this part of ISO 7919 conform to this convention. In view of the relatively high operating speeds involved with gas turbine sets, measuring methods using non-contacting transducers are most common and are generally preferred on rotors with operating speeds of 3 000 r/min and above.

For monitoring purposes, the measurement system shall be capable of measuring broad-band vibration over a frequency range from 1 Hz to at least three times the maximum normal operating frequency. If, however, the instrumentation is also used for diagnostic purposes, a wider frequency range and/or spectral analysis can be necessary. In special cases, where significant low-frequency vibration can be transmitted to the machine, such as in earthquake regions, it can be necessary to filter the low-frequency response of the instrumentation and/or implement an appropriate time delay. If measurements from different machines are compared, care should be taken to ensure that the same frequency range is used.

The locations of vibration measurements should be such that the transverse movement of the shaft at points of importance can be assessed. Care should be taken to avoid locating measurement positions at any vibration nodes and to ensure that the measurement equipment is not unduly influenced by external sources, such as combustion vibration, gear mesh vibration, and airborne and structure-borne noise. Typically, this requires measuring in two radial directions with a pair of orthogonal transducers at, or adjacent to, each main bearing. The transducers may be placed at any angular location, but it is common practice to select locations on the same bearing half which are either at ±45° to the vertical direction or close to the vertical and horizontal directions.

A single radial transducer may be used in place of the more typical pair of orthogonal transducers, if it is known to provide adequate information on the magnitude of the shaft vibration. In general, however, caution should be observed when evaluating vibration from a single transducer at a measurement plane since it might not be oriented to provide a reasonable approximation of the maximum value at that plane.

It is not common practice to measure axial shaft vibration on gas turbine sets.

The characteristics of the measurement system should be known with regard to the effects of the environment, including:

a) temperature variations;

b) magnetic fields;

c) airborne and structure-borne noise;

d) power source variations;

e) cable impedance;

f) transducer cable length;

g) transducer orientation;

h) stiffness of the transducer attachment.

Particular attention should be given to ensuring that the vibration transducers are correctly mounted and that the mounting arrangement does not degrade the accuracy of the measurement (see e.g. ISO 10817-1).

The surface of the shaft at the location of the transducer shall be smooth and free from any geometric discontinuities, metallurgical non-homogeneities and local residual magnetism, which can cause false signals (so-called electrical runout). The combined electrical and mechanical "slow roll" runout, as measured by the transducer, should not exceed 25 % of the zone A/B boundary at normal operating speed (see Figure A.1 and Table A.1).

Prior to running gas turbine sets up to speed, slow-roll measurements of shaft displacement may be carried out. If so, the low-frequency characteristics of the measurement system shall be adequate. 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 and axial movements. Vector subtraction of slow-roll measurements from operating speed vibration measurements should not be carried out without careful consideration of these factors since the results can provide a misleading interpretation of the machine vibration (see ISO 7919-1).

4 Evaluation criteria

4.1 General

ISO 7919-1 provides a general description of the two evaluation criteria used to assess the shaft vibration on various classes of machines. One criterion considers the magnitude of the observed broad-band shaft vibration; the second criterion considers changes in magnitude, irrespective of whether they are increases or decreases.

The values presented are the result of experience with machinery of this type and, if due regard is paid to them, acceptable operation can be expected.

NOTE These values are based on previous International Standards, on the results of a survey which was carried out when ISO 7919 (all parts) and ISO 10816 (all parts) were initially developed and on the feedback provided by the experts of ISO/TC 108.

Criteria are presented for steady-state operating conditions at the specified normal operating speed or speeds and load ranges, including normal slow changes in power output. Alternative criteria are also presented for other non-steady-state conditions when transient changes are taking place. The vibration criteria represent target values which give provisions for ensuring that gross deficiencies or unrealistic requirements are avoided. In particular, the basic assumption for safe operation is that metal-to-metal contact between the rotating shaft and stationary components is avoided. They serve as a basis for defining acceptance specifications (see 4.2.2.3).

The criteria relate to the vibration produced by the gas turbine set and not to vibration transmitted from outside the machinery set. If it is suspected that there is a significant influence due to transmitted vibration (either steady-state or intermittent), measurements should be taken with the gas turbine set shut down. If the magnitude of the transmitted vibration is unacceptable, steps should be taken to remedy the situation.

It should be noted that an overall judgement of the vibratory state of a machine is often made on the basis of measurements made on both rotating shafts and non-rotating parts.

4.2 Criterion I: Vibration magnitude

4.2.1 General

This criterion is concerned with defining values 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 normal operating speeds under 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 an assessment of the shaft vibration of a given machine under steady-state conditions at normal operating speed (or speeds) and to provide guidelines on possible actions.

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.

NOTE For transient operation, see 4.2.4.

4.2.2.3 Acceptance criteria

Acceptance criteria shall always be subject to agreement between the machine supplier and purchaser prior to installation. The evaluation zones provide a basis for defining acceptance criteria for new or refurbished machines.

NOTE Historically, for new machines, acceptance criteria have been specified in zone A or zone B, but would normally not exceed 1,25 times the zone A/B boundary.

4.2.2.4 Evaluation zone boundaries

For gas turbines operating with directly coupled steam turbines and/or generators and normal operating speed of 3 000 r/min or 3 600 r/min, the zone boundary values are given in Table A.1.

In accordance with accumulated experience of shaft vibration measurements in this field, the recommended values for the zone boundaries, in micrometres, for other gas turbine sets with outputs greater than 3 MW are inversely proportional to the square root of the maximum normal operating speed n (in r/min). The recommended values for such gas turbines are given in Equations (1), (2) and (3) and illustrated in Figure A.1. Generally the actual value used should be rounded to the nearest multiple of 5 µm:

Zone boundary A/B

$$S_{(p-p)} = \frac{4\,800}{\sqrt{n}} \tag{1}$$

Zone boundary B/C

$$S_{(p-p)} = \frac{9\,000}{\sqrt{n}} \tag{2}$$

Zone boundary C/D

$$S_{(p-p)} = \frac{13\,200}{\sqrt{n}} \tag{3}$$

NOTE 1 For a definition of $S_{(p-p)}$, see ISO 7919-1.

The values given in Table A.1 and Figure A.1 apply to radial shaft relative vibration measurements at or close to the bearings, when taken under steady-state conditions at normal operating speed (or speeds). The numerical values assigned to the zone boundaries were established from representative data provided by manufacturers and users. There was inevitably a significant spread in the data. The values given do nevertheless give provisions for ensuring that gross deficiencies or unrealistic requirements are avoided.

Higher vibration is permitted at other measurement positions and during transient conditions (see 4.2.4).

In most cases, the values given in Table A.1 and Figure A.1 are consistent with ensuring that adequate running clearances are maintained and that the dynamic loads transmitted to the bearing support structure and foundation are acceptable. However, in certain cases, there can be specific features or available experience associated with a particular machine type which can require other values (higher or lower) to be used for the zone boundaries. The following are examples.

a) The machine vibration can be influenced by its mounting system and coupling arrangement to driven machines. For example, higher shaft relative vibration can be expected if stiff bearing supports are used. It may then be acceptable, based on demonstrated satisfactory operating history, to use different zone boundary values.

b) Care should be taken to ensure that the shaft relative vibration does not indicate that the bearing clearance is exceeded. Furthermore, it should be recognized that the allowable vibration can be related to the journal diameter since, generally, running clearances are greater for larger diameter bearings. Where bearings with small clearance are used, the zone boundary values given in Table A.1 and Figure A.1 may be reduced. The degree to which the zone boundary values are to be reduced varies, dependent on the type of bearing used (circular, elliptical, tilting pad, etc.) 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.