INTERNATIONAL STANDARD

ISO 10817-1

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Rotating shaft vibration measuring systems —

Part 1:
Relative and absolute sensing of radial vibration

Systèmes de mesure des vibrations des arbres tournants —

Partie 1: Captage relatif et captage absolu des vibrations radiales

Reference number
ISO 10817-1:1998(E)

Contents

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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 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.

International Standard ISO 10817-1 was prepared by Technical Committee ISO/TC 108, *Mechanical vibration and shock*, Subcommittee SC 3, *Use and calibration of vibration and shock measuring instruments*.

ISO 10817 consists of the following parts, under the general title *Rotating shaft vibration measuring systems*:

— *Part 1: Relative and absolute sensing of radial vibration*

— *Part 2: Signal processing*

Annexes A and B of this part of ISO 10817 are for information only.

Rotating shaft vibration measuring systems —

Part 1:
Relative and absolute sensing of radial vibration

1 Scope

This part of ISO 10817 gives details of how to obtain reproducible measurement results in order to enable the monitoring and evaluation of shaft vibrations according to the ISO 7919 series. As such, it is concerned primarily with the measurement of shaft vibrations for large machines (e.g. steam turbine generator sets, gas turbines, industrial turbosets, hydraulic machines).

This part of ISO 10817 is applicable to radial vibration measuring systems on shafts, both for absolute and relative measurements. It covers the sensing device (i.e. transducer), signal conditioning, attachment methods and calibration procedures.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of ISO 10817. 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 10817 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 683-1, *Heat-treatable steels, alloy steels and free-cutting steels — Part 1: Direct-hardening unalloyed and low-alloyed wrought steel in form of different black products.*

ISO 2041, *Vibration and shock — Vocabulary.*

ISO 4287, *Geometrical Product Specification (GPS) — Surface texture: Profile method — Terms, definitions and surface texture parameters.*

ISO 5347, *Methods for the calibration of vibration and shock pick-ups* (all parts).

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

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

ISO 7919-2, *Mechanical vibration of non-reciprocating machines — Measurements on rotating shafts and evaluation criteria — Part 2: Large land-based steam turbine generator sets.*

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

ISO 7919-4, *Mechanical vibration of non-reciprocating machines — Measurements on rotating shafts and evaluation criteria — Part 4: Gas turbine sets.*

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

ISO 8042, *Characteristics to be specified for seismic pick-ups.*

ISO 16063-1*, Methods for the calibration of vibration and shock transducers — Part 1: Basic concepts.*1)

GUM:1995, *Guide to the Expression of Uncertainty in Measurement* (BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML).

IEC 60068-2-6, *Environmental testing — Part 2: Tests — Test Fc: Vibration (sinusoidal).*

IEC 60068-2-29, *Environmental testing — Part 2: Tests — Test Eb and guidance: Bump.*

IEC 60529:1989, *Degrees of protection provided by enclosures (IP Code).*

3 Terms and definitions

For the purposes of this part of ISO 10817, the terms and definitions given in ISO 2041 apply.

4 Shaft vibration measuring systems overview

A measuring system to evaluate the radial vibration of a rotating shaft can be thought of as consisting of several distinct subsystems: a transducer or transducers for either relative or absolute vibration measurement; a transducer signal-conditioning instrumentation and associated cabling; a phase reference to relate a position on the rotating shaft to the position of the measurement in the time domain (e.g. a shaft encoder); signal processing instrumentation to output the measurement in a specified format; and an output device to display the measurement. Figure 1 shows the interrelationship of these subsystems. ISO 10817-2 covers instrumentation requirements for signal processing and analysis.

The output signals from the measuring devices, S_{ext}, can be processed via specific systems and software packages which provide the quantities required for machine analysis and maintenance purposes. These systems and software packages are not part of this part of ISO 10817.

The relative motions are generally measured with non-contacting transducers. The absolute rotor motions can be sensed with non-contacting relative motion transducers in combination with an absolute motion detection made at the positions of the relative motion transducers. These absolute motion measurements could also be sensed by seismic transducers, e.g. shaft-riding transducers.

This part of ISO 10817 deals with the signal sensing block only, see Figure 1.

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1) Revision of ISO 5347-0.

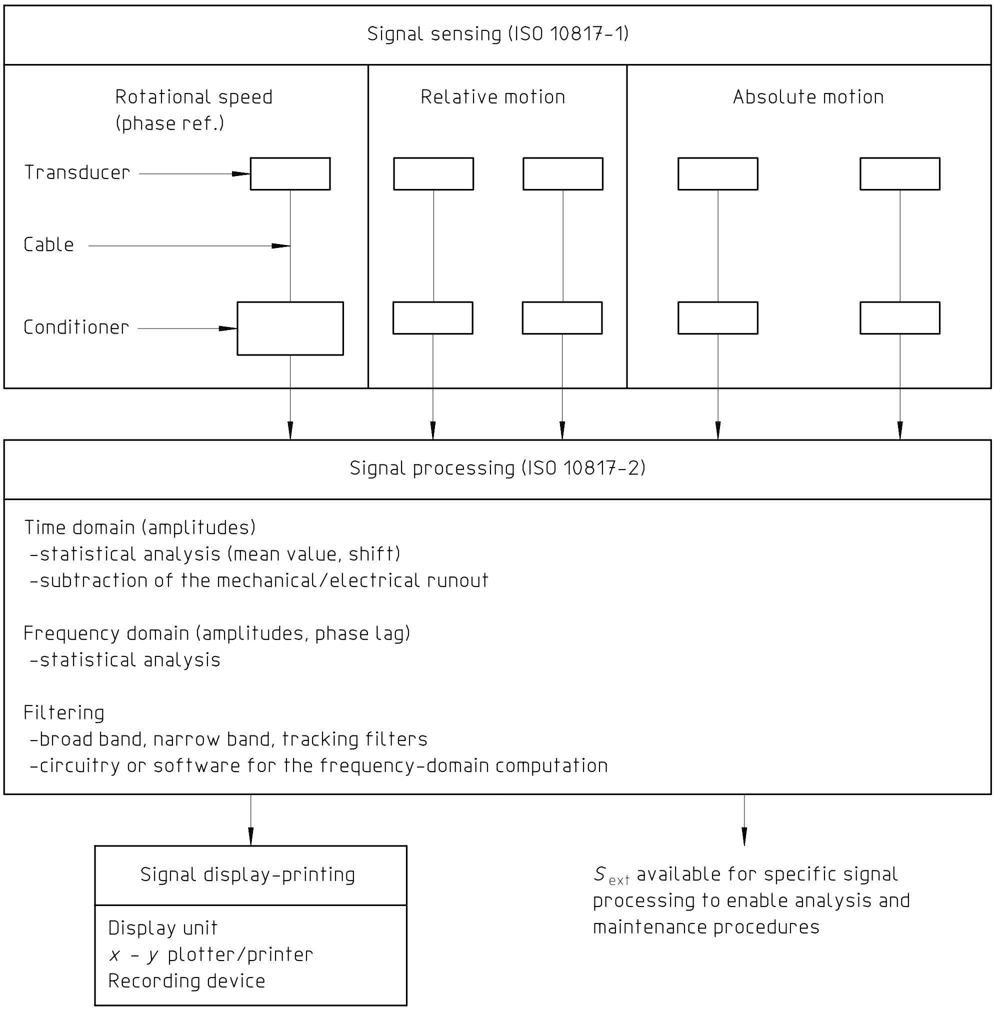


Figure 1 — Structure of rotating shaft measuring systems

5 Sensing systems

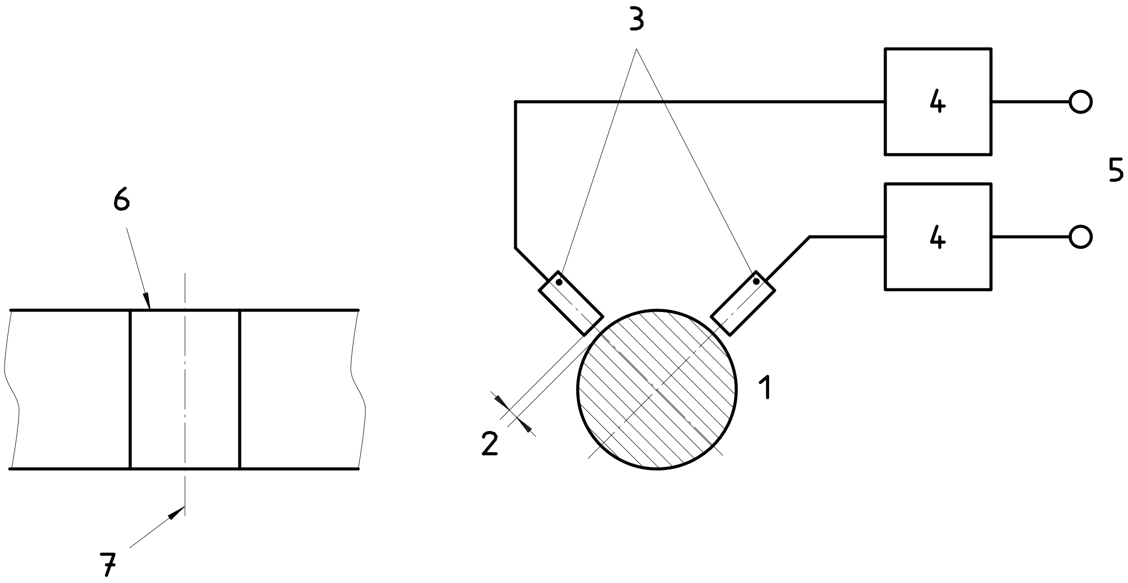
5.1 Relative shaft-vibration measuring systems

5.1.1 Introduction

Relative shaft-vibration transducers take advantage of changes in either the optical path length, inductance or capacitance between a position on a rotating shaft and a point removed from the shaft, usually in very close proximity to the shaft, to determine the relative displacements in time. This reference point (i.e. the location point of the relative shaft vibration transducer) often undergoes significant vibration from other sources. Seismic transducers placed at the location of the sensing element of the non-contacting sensor can be used to determine absolute vibration values (see 5.2).

5.1.2 General structure of the sensing systems

A shaft vibration sensing system according to the requirements of this part of ISO 10817 consists of relative displacement transducers, cabling and the appropriate conditioners (see Figure 2).

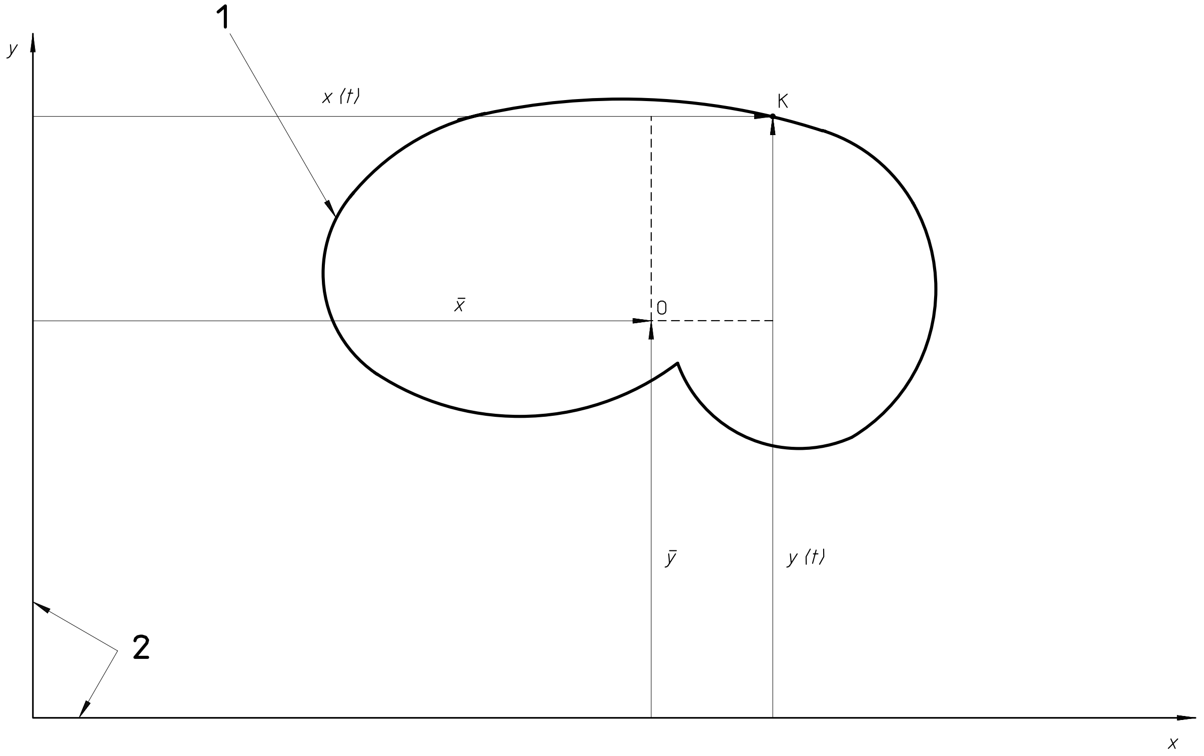


Key

1 Shaft
2 Transducer to shaft distance
3 Transducers
4 Conditioners
5 Signal outputs
6 Measurement track
7 Measurement plane

Figure 2 — Shaft vibration measuring system for measurements in one plane

Two orthogonal transducers are preferably required to determine the total dynamic motion and mean position of the shaft (see Figure 3). The two transducers are arranged in two perpendicular measurement directions in one measurement plane. Generally for one machine set there are several measurement planes which may have a pair of measuring devices for each plane. The system of all measuring devices belonging to one machine set is called a measuring system for shaft vibration.



Key

1	Kinetic orbit of shaft	K	Instantaneous position of shaft centre
2	Reference axes	$\bar{x}, \bar{y}$	Mean values of shaft displacement
O	Mean position of orbit	$x(t), y(t)$	Time-dependent alternating values of shaft displacement

Figure 3 — Kinetic orbit of the shaft

Depending on the measurement method, a conditioner may be necessary between the transducer and the signal processing instrumentation. The conditioner may be either a self-contained unit or may be integral with the transducer or the signal processing instrumentation.

No requirements are given in this part of ISO 10817 for the indication instruments and the recording equipment.

5.1.3 Operating ranges

The user should select a transducer system which is at least compatible with the relevant part of ISO 7919 and/or the specification of the machine under evaluation. The output signal tolerances are given in clause 6.

5.1.4 Characteristics to be specified

The manufacturer shall specify the following:

- the range where the signal output is linear proportional to the gap between the target and transducer;
- the amplitude and phase response as a function of frequency where linearity is maintained (see 6.2);
- the overall size and thread of the transducer for each measurement range (tip diameter 5 mm, 8 mm and 18 mm, and thread M8×1, M10×1 and M20×1 are recommended);
- the cable length (5 m is recommended);
- the power supply (–24 V d.c. is recommended);
- the sensitivities (8 mV/µm for the 2 mm range and 4 mV/µm for the 4 mm range is recommended where applicable);

- the output signal mode (voltage-current);
- the maximum output signal;
- the output impedance and permissible load impedance;
- the classes of temperature;
- degree of protection [IP-67 (dust-tight and protected against the effects of temporary immersion) in accordance with IEC 60529:1989 is recommended].

NOTE The above are recommended industry standards in common use.

5.2 Absolute shaft vibration measuring systems

5.2.1 Introduction

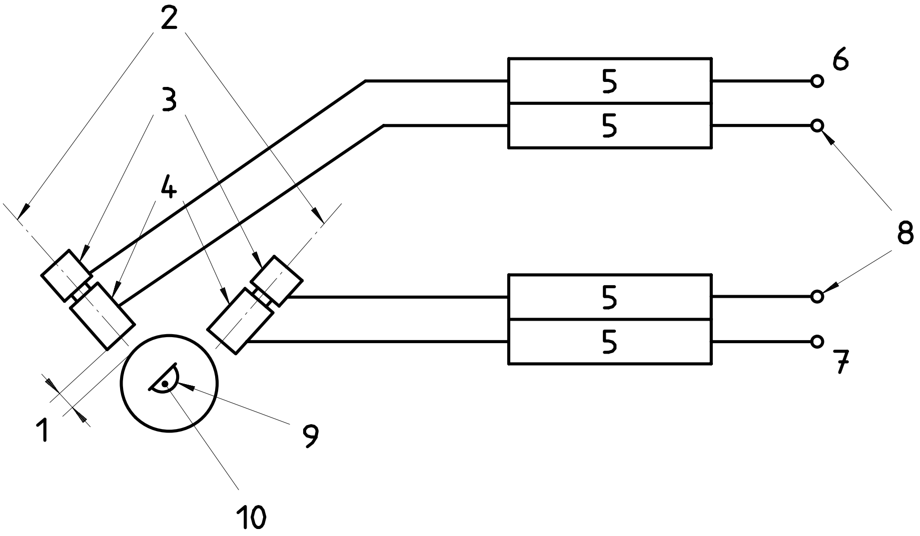
Two types of measuring systems are in use for the measurement of absolute shaft vibrations, as follows.

a) A combined absolute-vibration and relative-vibration measuring system using a seismic transducer and a relative shaft displacement transducer (non-contacting) mounted on the same structure. Their conditioned outputs are summed to provide a measurement of the absolute shaft motion.

b) A shaft-riding probe, where a seismic transducer is mounted on the shaft so that it measures directly the absolute shaft motion.

5.2.2 General structure of the sensing systems

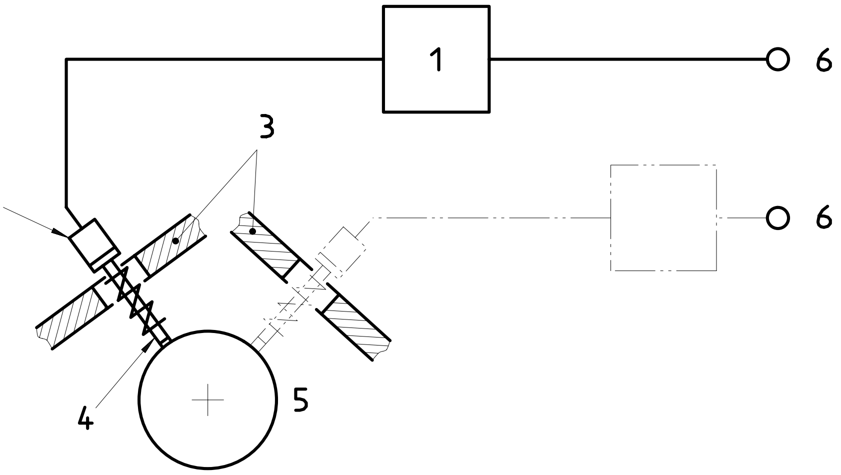
An absolute shaft vibration sensing system according to the requirements of this part of ISO 10817 consists either of two sets of seismic and non-contacting transducers (non-contacting measurement) or of two shaft-riders (direct measurement) and the appropriate conditioners (Figures 4 and 5).



Key

1	Transducer to shaft distance	6	Direction 1
2	Measurement axes	7	Direction 2
3	Seismic transducers	8	Signal outputs
4	Non-contacting transducers	9	Trajectory of absolute precession of the centre of the rotor section
5	Conditioners	10	Geometrical centre of the trajectory

Figure 4 — Absolute shaft vibration sensing system using a combination of non-contacting and seismic transducers for one measurement plane



Key

1	Signal conditioner
2	Seismic transducer
3	Machine structure
4	Shaft rider
5	Shaft
6	Signal outputs

Figure 5 — Absolute shaft vibration sensing system using a shaft-rider transducer assembly for one measurement plane

The two transducer assemblies are radially mounted in orthogonal measurement directions in one measurement plane. Generally at one machine set there are several measurement planes with one or two shaft sensing devices for each plane.

Depending on the measurement method, a conditioner may be necessary between the transducer(s) and the signal processing instrumentation. The conditioner may be either a self-contained unit or may be integral with the transducer.

5.2.2.1 Combined seismic and non-contacting sensing system

A combined seismic and non-contacting sensing device consists of two sets of transducers, each set fitted with one non-contacting type relative displacement transducer as described in 5.1 and one absolute seismic transducer mounted on a common rigid structure in close proximity with their sensitive axes in-line or parallel to ensure that both transducers undergo the same absolute structural motion. Their conditioned outputs are summed to provide a measurement of the absolute shaft motion.

The combined absolute shaft vibration sensing system has to have at least two outputs for each measuring direction:

a) the relative shaft vibration transducer displacement output, which is identical to that described in 5.1.1;

b) the output of the seismic transducer, which is proportional to the acceleration or velocity motion of the structure to which it and the non-contacting transducer are mounted.

The seismic transducer output shall be processed to provide a displacement signal (single integration in the case of velocity or double integration in the case of acceleration signal).

The seismic transducer placed at the location of the non-contacting transducer can also be used to determine the absolute vibration values according to the ISO 10816 series.

5.2.2.2 Direct absolute shaft vibration sensing system (shaft-rider)

A direct absolute shaft vibration sensing system consists of two transducer assemblies, each having one seismic transducer mounted on a shaft-riding mechanism which transmits the shaft vibration to the seismic transducer.

The absolute shaft vibration sensing system shall have an output for each measurement direction which is proportional to the motion. This output can be conditioned to provide an accurate measurement of the absolute displacement of the shaft. Measurement of the shaft mean position relative to the structure is not possible using this method. It should also be noted that various limitations such as surface speed and/or formation of hydrodynamic oil films beneath the shaft-rider mechanism limit the frequency range of such a system. Special attention should be paid to ensuring that the shaft-riding mechanism is properly mounted on the machine structure.

5.2.2.3 Precautions

The user should select the measurement method (non-contacting or shaft-rider) which best suits the investigation and interpretation of the absolute shaft vibration of the machine. The transducer system should at least be compatible with ISO 7919-1 and/or fulfil the measurement requirements of the machine under test. For seismic pick-ups, the influence of the added mass of the pick-up on the structure should be taken into consideration (in relation of the mass of the pick-up to the mass of the shaft), as well as the maximum unbalance of the system used.

The user should be aware of:

a) the possibility of loss of contact with the shaft due to wear;

b) intermittent or permanent loss of contact with the shaft surface due to inadequate contact pressure (weakening of the loading spring or counter forces created by internal pressure in the bearing housing are typical causes);

c) stick slip vibration;

d) the fact that essential shaft centreline position information may not be available.

NOTE The combined seismic and non-contacting sensing system is subject to errors due to eventual phase differences between the two measuring channels. In actual fact this limits the frequency of use of the combined system. The user should take into consideration the possible errors due to the different transfer functions existing between velocity (or acceleration) channel and displacement channel before the sum of the two signals.

5.2.3 Operating ranges

The criteria for the vibration magnitude at rated speeds as well as the recommended frequency ranges for both absolute and relative shaft vibration are given in ISO 7919, parts 2 to 5, for respectively large steam turbine generator sets, coupled industrial machines, gas turbine and hydraulic machine sets.

When possible, the frequency range of the measuring system should include all of the excitation spectrum of the related machine set, and the amplitude range should be approximately five times the value expected under normal operation so that transient operating conditions can be monitored satisfactorily.

In practice, the following general characteristics are in accordance with the basic requirements of ISO 7919, parts 2 to 5:

— relative displacement transducer frequency range: 0 Hz to 1,5 kHz; amplitude range: 2 mm or 4 mm (see 5.1.4);

— seismic transducer frequency range: 5 Hz to 5 kHz;

— sensitivity range ±10 % of nominal.

NOTE For frequencies below 5 Hz, refer to the manufacturer's specification. When used with shaft-rider mechanism, the upper frequency of the measuring system is limited to a few hundred hertz.

5.2.4 Characteristics to be specified

5.2.4.1 Combined seismic and non-contacting sensing system

The characteristics to be specified are defined in 5.1.4 for the relative shaft motion transducers and in ISO 8042 for the seismic transducers. The characteristics and recommendations for mounting seismic transducers are specified in ISO 5348. The support and/or mounting adapters used to fit the transducers on the machine shall be free of the influence of system natural frequencies which would affect the accuracy of the measurements.

5.2.4.2 Direct absolute shaft vibration sensing system (shaft-rider)

The characteristics to be specified contained in ISO 8042 are applicable for the measuring element.

The frequency limitations of such systems are essentially dependent on the design characteristics of the shaft-rider mechanism.

In order to carry out these measurements with known accuracy, the methods specified in the ISO 5347 series shall be applied.

NOTE For both the relative and the absolute shaft vibration measuring systems the measurement path should take into account the total axial shaft position change due to normal axial shaft movement and differential thermal expansion. Under all normal machine conditions, transducer sensing elements should not be exposed to geometric discontinuities (such as keyways, lubrication oil passages, threads, changes in shaft diameter, stencil marks, chain marks and corrosion) as in the case of non-contacting transducers, to metallurgical non-homogeneities, or local residual magnetism, which may cause false signals.

6 Measurement uncertainties

6.1 Measurement principles

The accuracy of the reading depends on the realization of the measurement principle and the accuracy of the measuring system.

Generally, the measurement principle of shaft vibrations is based on an interrelation between the surface of the machine shaft and the transducers. Regardless of the measurement principle, deviations of the shaft cross-section from a circle and of the eccentricity of the measurement track influence the reading.

Furthermore, for non-contacting electric measurements, influences on the measurement signal (often called “runout”) have to be taken into account, which may be caused by the material, the character of surface, the local residual magnetism and from the texture differences at the area of the measurement track on the shaft surface. The measurement track on the shaft surface should have no coating (e.g. chromium when using the inductive or the eddy current method) which may adversely influence the measured values. If the shaft is coated, special care shall be exercised when calibrating the transducer.

The shaft vibrations simulated by the influences of the shaft surface should not exceed the limiting values stated in ISO 7919-1:1996, subclause 3.3.2 (see also 6.2.1).

6.2 Accuracy requirements on the measuring system

6.2.1 Measurement uncertainty

Measurement uncertainty limits are agreed maximum values of (positive or negative) deviations of the reading or output of the measuring system. These limits form a tolerance band which shall not be exceeded under reference conditions and an extended tolerance band for influence quantities under deviating conditions.

This part of ISO 10817 defines measurement uncertainty limits for the analog outputs of the measuring system. However, these limits do not take into account the influence of measurement track irregularities described in 6.1 or the limits of any measuring equipment.

The term “measurement uncertainty” refers to the estimated expanded uncertainty associated with the *in situ* use of the measuring system to determine the amplitude of shaft vibrations, excluding any uncertainty components resulting from those sources of uncertainty noted in the previous paragraph. This expanded uncertainty shall be calculated in accordance with methodologies described in the *Guide to the Expression of Uncertainty in Measurement* (GUM) using Type A and Type B uncertainty components and a coverage factor of $k = 2$.

The reference conditions for non-seismic measuring systems are as follows:

- measurement object plane with a mean surface roughness of $R_y = 4$ µm (see ISO 4287);
- steel, material 42CrMo4 according to ISO 683-1;
- sinusoidal vibration in both measurement directions with a frequency of 80 Hz and amplitudes in the range of 10 % to 100 % of full scale at any phase between 0° and 90°;
- length of the cable between the transducer and conditioner, 5 m;
- ambient temperature, 20 °C.

The measurement uncertainty limits of the measuring system shall not exceed the values given in Table 1.

For seismic systems, see the ISO 5347 series.

Table 1 — Measurement uncertainty limits under reference conditions

Measured quantities and parameters	Measurement uncertainty limits	Other reference conditions
Parameter	3 % of MV + 1 % of FSV	$\bar{x}_1 = \bar{x}_2 = 0$
Displacement values	3 % of MV + 1 % of FSV	$\bar{x}_1 = \bar{x}_2 = 0$
Direct components	3 % of a_A within working displacement range	$s_1(t) = s_2(t) = 0$ for all values of t

MV = measured value; FSV = full-scale value; note that symbols refer to Figure 7.

NOTE The following parameters are defined as the parameters of shaft vibration (see also Figure B.1):

S_{max} denotes the maximum shaft excursion (parameter A);

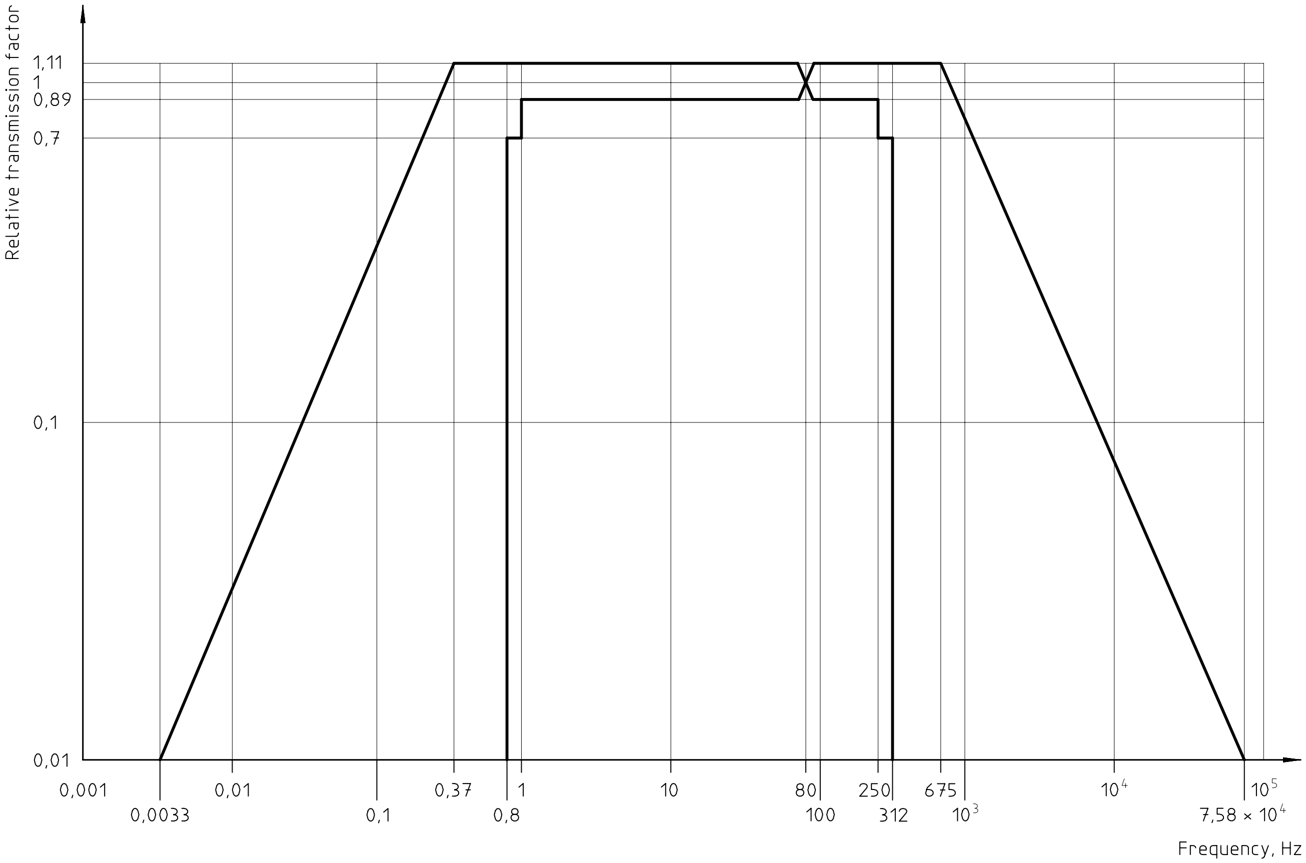
$S_{\mathrm{(p\text{-}p)max}}$ denotes the larger excursion (parameter B).

One of these two parameters is sufficient for assessing the running condition.

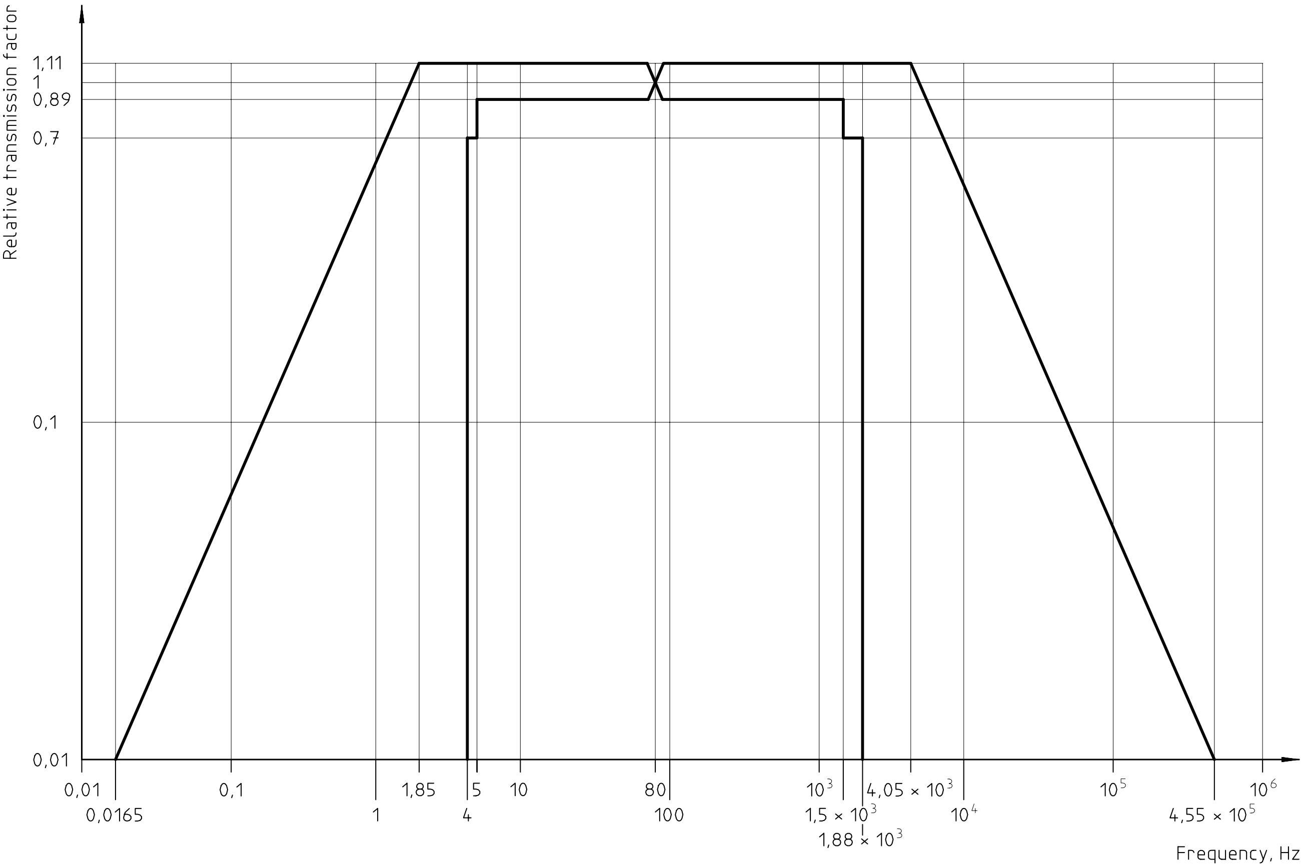
6.2.2 Measurement deviations caused by influencing factors

If reference conditions are not given, additional deviations which are caused by influencing factors shall not exceed the extended measurement uncertainty limits according to Table 2 and Figures 6 and 7.

Influence quantities not specified, such as sinusoidal measurement signals, pressure, humidity, acceleration, shock, noise and auxiliary power supply, shall not affect the measured value by more than 2 % of full scale.



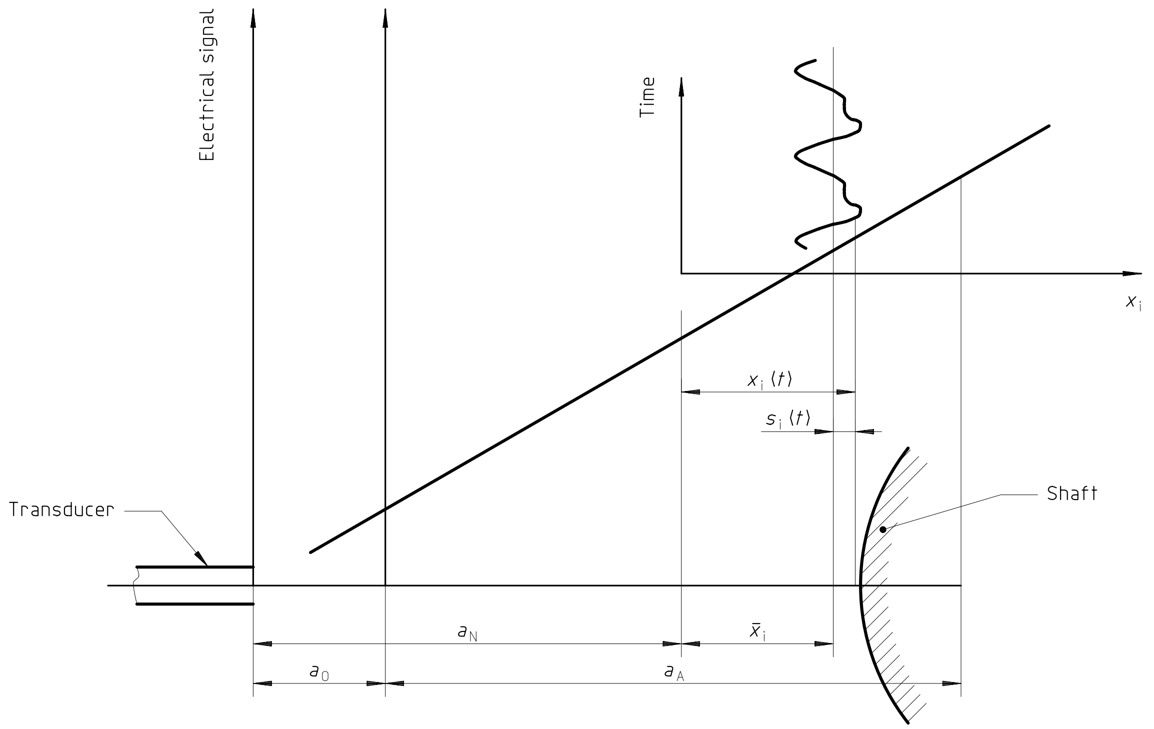
a) Operating frequency range 1 Hz to 250 Hz



b) Operating frequency range 5 Hz to 1 500 Hz

Figure 6 — Tolerance ranges for the amplitude frequency characteristic of the vibration parameters

The amplitude frequency response represents the function of the relative transfer factor depending on the frequency. In this case the relative transfer factor is defined as the ratio of the transfer factor to that at the reference condition. The transfer factor as it is understood in this part of ISO 10817 is formed by the output quantity according to clause 4 relative to the input quantity S_{max}. The measurement conditions are stated in Table 2. The tolerance bands are valid for input quantities at full scale reading.



Key

a_A	Working displacement range
a_N	Nominal distance ($a_N = a_0 + 0{,}5a_A$)
a_0	Residual distance
$x_i(t)$	Instantaneous distance
$\bar{x}_i$	Time-integrated mean value of shaft displacement
$s_i(t)$	Instantaneous displacement value

Figure 7 — Displacement characteristic of a shaft vibration measuring system for one of the two measurement directions

Table 2 — Wider uncertainty limits for conditions differing from the reference conditions

Influencing factors	Uncertainty limits			Conditions differing from the reference conditions
	Parameters	Displacement levels	Constant values	
Instantaneous distance $x_1(t)$ within the operating displacement range a_A	6 % of MV + 3 % of FSV	6 % of MV + 3 % of FSV	5 % of a_A	Constant vibration displacement amplitude corresponding to the full scale of the lowest measurement range applied successively in the two measurement directions
Ambient temperature of the transducer and signal conditioner at any value	8 % of MV + 4 % of FSV	8 % of MV + 4 % of FSV	5 % of a_A	$\bar{x}_1 = \bar{x}_2 = 0$ Constant vibration displacement amplitude corresponding to the full scale of the lowest measurement range applied successively in the two measurement directions
Frequency of the shaft vibration in the operating frequency range	13 % of MV + 3 % of FSV (See note 1)	13 % of MV + 3 % of FSV	(See note 2)	$\bar{x}_1 = \bar{x}_2 = 0$
Cable length	6 % of MV	6 % of MV	6 % of a_A	For vibration parameter and time function a constant vibration displacement amplitude corresponding to the full scale for the lowest measurement range effective in the two measurement directions

MV = measured value; FSV = full-scale value.

NOTE 1 The actual value of the output signal is its time-dependent peak value at superposed modulation.

NOTE 2 Damping of the superposed shaft vibration signal according to clause 8.

6.3 Monitoring of critical machinery

Due to the importance of system integrity and reliability for monitoring critical machinery, transducer system operation should be continuously monitored. Transducer status (proper operation and fault conditions) should be clearly annunciated. To increase system integrity, monitoring instruments may include such functions as voting logic between channels, alarm bypass in the event of transducer fault conditions, compensation for transducer system error (e.g. due to temperature changes), and transfer function analysis.

7 Environmental conditions

7.1 Transducers

7.1.1 Operating temperature ranges

The operating temperature ranges are permanent acceptable values of the ambient temperature at operation. There are four temperature classes to be considered, see Table 3.

Table 3 — Temperature classes

Temperature class	1	2	3	4
Operating temperature range in °C	0 to 70	0 to 125	0 to 180	below 0 to above 180

Systems operating below 0 °C or above 180 °C may require special attention to calibration and installation (manufacturer's literature should be consulted).

7.1.2 Protection

The degree of protection shall be at least IP 67 (dust-tight and protected against the effects of temporary immersion) in accordance with IEC 60529:1989. The transducers shall, also, be resistant against water, lubricating oils, hydraulic fluids and grease-dissolving cleaning agents. The transducers should be intrinsically safe, where required.

7.1.3 Vibration and shock resistance

The vibration and shock resistance should meet the requirements according to the relevant parts of the IEC 60068-2 series.

7.2 Non-integral conditioners

7.2.1 General

Non-integral conditioners located within the environment of the machine shall meet the following requirements.

7.2.2 Environmental conditions

Operating temperature range:	0 °C to 65 °C
Storage temperature range:	–40 °C to 80 °C
Relative humidity:	maximum acceptable rating is 95 %, non-condensing

7.2.3 Protection

The conditioners shall be intrinsically safe, and the degree of protection shall be at least IP 54 (dust-protected and protected against splashing water) in accordance with IEC 60529:1989.

7.2.4 Vibration and shock resistance

The vibration and shock resistance should meet at least the following requirements according to the relevant parts of the IEC 60068-2 series. Testing the resistance to vibration and shock shall be based at least on the following parameters specified in IEC 60068-2-6 and IEC 60068-2-29:

a) resistance to vibration as defined in IEC 60068-2-6:

- constant displacement amplitude: 0,35 mm at 10 Hz to 55 Hz,
- constant acceleration amplitude: 49 m/s^2 at 55 Hz to 150 Hz,
- test duration: 6 h;

b) resistance to shock as defined in IEC 60068-2-29:

- peak acceleration: 392 m/s^2,
- nominal duration of shock: 6 ms,
- number of shocks: 4 000 ± 10.

For the test, the transducers shall be affixed in the manner recommended by the manufacturer.

8 Calibration

8.1 Relative shaft vibration measuring systems

8.1.1 Verification of performance

It is recommended that the transducer sensitivity for the constant value x_i be established from a nominal shaft-transducer displacement, a_N, except in case b) listed below.

Verification within the specified ranges shall include the influence of:

a) temperature (see 6.2.2, 7.1, Table 3, and note 3 below);

b) frequency (see 5.2.3, Table 1, 6.2.1, and note 4 below);

c) amplitude linearity;

d) humidity (see 6.2.2 and note 5 below);

e) pressure (see 6.2.2 and note 6 below);

f) vibration and shock (see 7.1.3);

g) the length of cable (see 6.2.1);

h) the power supply (see 6.2.2);

i) distance between probe and target.

NOTE 1 The calibration should be carried out using a measurement object plane and material as defined in 6.2.1.

NOTE 2 It is recommended that the manufacturer make measurements to ensure that the measurement object plane has magnetic and permeability variations which do not influence the output of the measuring system.

NOTE 3 The transducer should be mounted in a metal housing within a temperature regulated oven. The transducer face should be held against the measurement object plane with a flat ceramic disc interposed between the two. At least 75 % of the cable should be contained within the oven and the cable entry to the oven should be thermally insulated. The oven should be heated to the maximum temperature of class 1, 2 or 3 and the output voltage of the system measured. The measurements should then continue for a period of 3 h with the maximum temperature being maintained.

NOTE 4 It is recommended that a flat measurement plane be mounted on a shaker table, which should also have a separate measurement facility (e.g. an accelerometer) attached to monitor the distortion of the vibration sine wave, which should be as low as possible. The transducer to be tested should be mounted in a fixture separately from the shaker table. The fixture should also have a separate measurement facility to enable any influencing vibration to be established.

NOTE 5 The effect of humidity should be assessed using the same arrangement as for ambient temperature assessments (see note 3), except that the ceramic disc are omitted. The humid environment should be allowed to impinge on the transducer cable entry if the entry is normally exposed to a humid environment.

NOTE 6 The effect of pressure should be tested with the whole transducer subjected to pressure, and with a positive differential pressure between the transducer face and cable entry point.

8.1.2 Individual verification

The manufacturer shall provide an individual verification for each transducer with a nominal power supply containing at least the following information:

a) sensitivity in the sensitive axis;

b) deviation from linearity.

8.2 Absolute shaft vibration measuring systems

8.2.1 Combined non-contacting and seismic transducers

8.2.1.1 Relative shaft vibration non-contacting measurements

The specifications for the instrumentation and procedure to be used for calibration and for individual verification are described in 8.1.

8.2.1.2 Seismic vibration measurements

The calibration shall be carried out according to the methods and recommendations of the various parts of the ISO 5347 series which deals with the instrumentation and procedures to be used for calibration. ISO 16063-1 (previously ISO 5347-0) contains definitions and describes basic absolute calibrations. The ISO 5347 series details the specifications for various methods for the calibration of vibration and shock pick-up axial sensitivity, as well as methods for measuring transverse vibration and shock sensitivity, base strain, resonance frequency, mounting torque, temperature, magnetic field sensitivity, etc.

8.2.2 Verification of performance

8.2.2.1 Seismic transducers

The indication and the verification of seismic transducer characteristics shall be established for each prototype according to ISO 8042.

8.2.2.2 Shaft-rider and seismic transducers

The characteristics of these devices are linked to the intrinsic characteristics of the shaft-rider mechanism and of the mounting arrangement. The verification procedure and the characteristics established for each prototype shall be described by the manufacturer.

8.2.2.3 Individual verification

The manufacturer shall carry out as a minimum an individual verification of the following characteristics:

a) sensitivity;

b) deviation of sensitivity over the applicable frequency range of the seismic transducer;

c) frequency response when mounted to a structure.

The frequency response should be established by vibrating the tip of the shaft-rider probe at a known vibration and over the specified frequency range at the recommended contact pressure. The results of this test shall be documented.

Annex A
(informative)

Mechanics of shaft vibration

The vibration of a rotating shaft is characterized at any axial location by its kinetic orbit, which describes the variation of the position of the shaft centre with time. Figure 3 shows a typical orbit. The shape of the orbit depends upon the dynamic characteristics of the shaft, the bearings and the bearing supports/foundations, the axial location on the rotor and the form of vibration excitation. For example, if the excitation takes the form of a single-frequency sinusoidal force, the orbit is an ellipse, which can, under certain circumstances, be a circle or straight line, and the time taken for the shaft centre to complete one circuit of the ellipse is equal to the reciprocal of the rotational frequency of the shaft. However, there are other forms of excitation, such as rotor cross-section asymmetry, for which the frequency is equal to multiples of the rotational frequency of the shaft. Where the vibration arises as a result of, for example, destabilizing self-excited forces, the orbit will not normally be of a simple shape, but will change form over a period of time and it will not necessarily be harmonically related. In general, the vibration of the shaft may arise from a number of different sources and, therefore, a complex orbit will be produced, which is the vector sum of the effects of the individual excitation forces.

At any axial location, the orbit of the shaft can be obtained by taking measurements with two vibration transducers mounted in different radial directions, separated by 90° (this is the preferred separation, but small deviations from this do not cause significant errors). If the angle between the transducer locations is substantially different from 90°, a vector resolution into the orthogonal directions will be required. If the transducers measure absolute vibration, then the orbit of the shaft is independent of the vibratory motion of the non-rotating parts. If the transducers measure relative vibration, then the measured orbit will be relative to that part of the structure upon which the transducers are mounted.

Annex B
(informative)

Measurement quantities

B.1 Time-integrated mean position

The mean values of the shaft displacement in any two specified orthogonal directions, relative to a reference position, as shown in Figure 3, are defined by integrals with respect to time, as shown in the following equations:

$$\bar{x} = \left(\frac{1}{t_2 - t_1}\right)\int_{t_1}^{t_2} x(t)\,\mathrm{d}t \tag{B.1}$$

$$\bar{y} = \left(\frac{1}{t_2 - t_1}\right)\int_{t_1}^{t_2} y(t)\,\mathrm{d}t \tag{B.2}$$

where $(t_2 - t_1)$ is large relative to the period of the lowest frequency vibration component, and $x(t)$, $y(t)$ are the time-dependent alternating values of displacement relative to the reference position.

In the case of absolute vibration measurements, the reference position is fixed in space. For relative vibration measurements, these values give an indication of the mean position of the shaft relative to the non-rotating parts at the axial location where the measurements are made. Changes in the values may be due to a number of factors, such as bearing/foundation movements, changes in oil film characteristics, etc., which normally occur slowly relative to the period of vibration components which make up the alternating values. It should be noted that the time-integrated mean position in any direction differs from the position defined by taking half the sum of the maximum and minimum displacement values (see Figures 7 and B.1). However, when the shaft vibration is a single frequency and sinusoidal, then the locus of the shaft centre will be an ellipse. Under such circumstances, the time-integrated mean position in any direction of measurement will be the same as the position identified by taking half the sum of the maximum and minimum displacement values.

B.2 Vibration peak-to-peak displacement

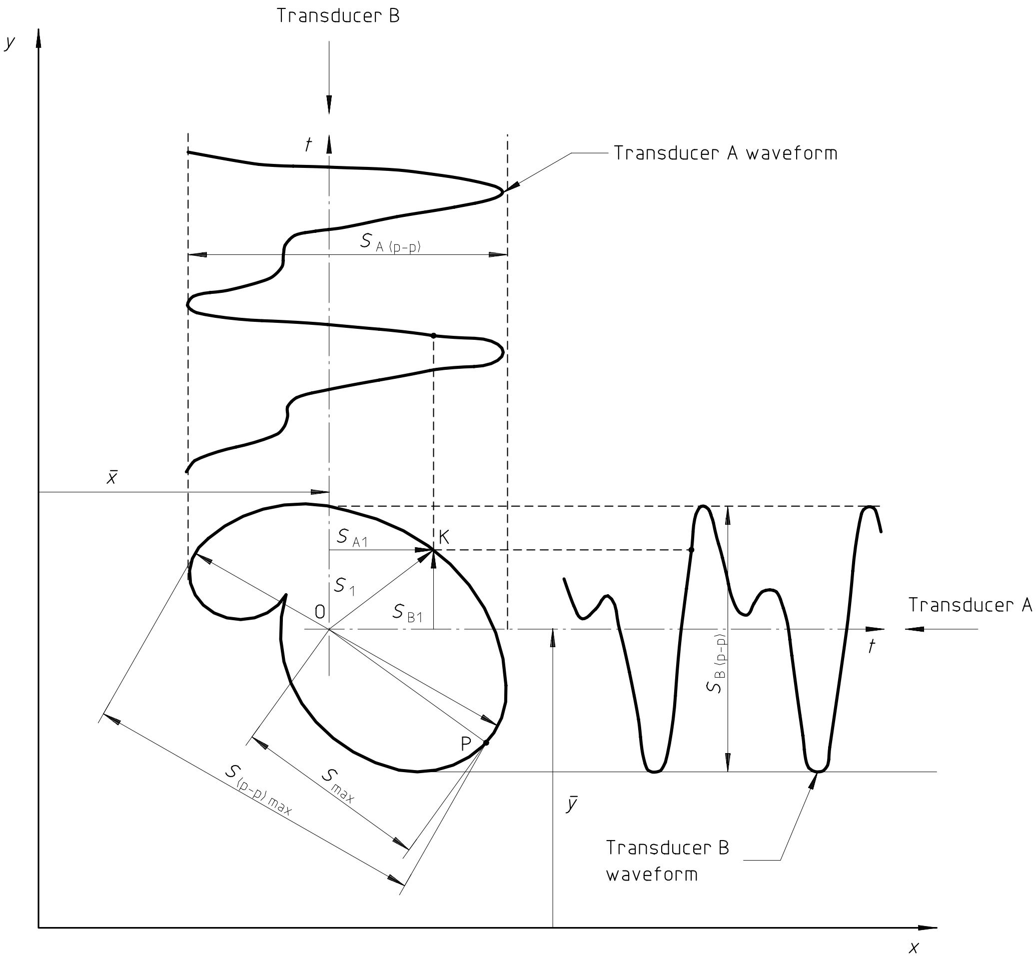
The primary quantities of interest in shaft measurements are the alternating values which describe the shape of the orbit. Consider the kinetic shaft orbit shown in Figure 3 and assume that there are two transducers A and B mounted 90° apart, which are used to measure the shaft vibration. At some instant the shaft centre will be coincident with the point K on the orbit and the corresponding instantaneous value of the shaft displacement from the mean position will be S_1. However, in the plane of the transducers A and B, the instantaneous value of shaft displacement from the mean position will be S_{A1} and S_{B1}, respectively

where

$$S_1 = \sqrt{{S_{\mathrm{A1}}}^2 + {S_{\mathrm{B1}}}^2} \tag{B.3}$$

The values of S_1, S_{A1} and S_{B1} will vary with time as the shaft centre moves around the orbit; the corresponding waveforms measured by each transducer are shown in Figure B.1.

NOTE If the orbit is elliptical then these waveforms would be pure sine waves of the same frequency.



Key

x, y	Fixed reference axes
O	Time-integrated mean position of orbit
$\bar{x}, \bar{y}$	Time-integrated mean values of shaft displacement
K	Instantaneous position of shaft centre
P	Position of shaft for maximum displacement from time-integrated mean position
S_1	Instantaneous value of shaft displacement
S_{max}	Maximum value of shaft displacement from time-integrated mean position 0
S_{A1}, S_{B1}	Instantaneous values of shaft displacement in directions of transducers A and B, respectively
$S_{(p-p)max}$	Maximum value of peak-to-peak displacement
$S_{A(p-p)}$ $S_{B(p-p)}$	Peak-to-peak values of shaft displacement in directions of transducers A and B, respectively

Figure B.1 — Time variation of the shaft centre as it moves around the orbit and the corresponding waveforms measured by each transducer

The peak-to-peak value of the displacement in the direction of transducer A [$S_{A(p-p)}$] is defined as the difference between the maximum and minimum displacements read by transducer A and similarly for S_B for transducer B. Clearly $S_{A(p-p)}$ and $S_{B(p-p)}$ values will not be equal and, in general, they will be different from similar measurements made in other radial directions. Hence, the value of the peak-to-peak displacement is dependent on the direction of the measurement.

Peak-to-peak displacement is the unit which has been used most frequently for monitoring shaft vibration of rotating machines.

Whereas measurement of the peak-to-peak displacement in any two given orthogonal directions is a simple matter, the value and angular position of the maximum peak-to-peak displacement shown in Figure B.1 is difficult to derive. However, in practice, it has been found acceptable to use alternative measurement quantities which enable a suitable approximation for the maximum peak-to-peak displacement value to be obtained. For more precise determinations, it is necessary to examine the shaft orbit in more detail, as for example with an oscilloscope.

B.3 Method A: Resulting value of the peak-to-peak displacement values measured in two orthogonal directions

The value of $S_{\text{(p-p)max}}$ can be approximated by the following equation:

$$S_{\text{(p-p)max}} = \sqrt{\left[S_{\text{A(p-p)}}\right]^2 + \left[S_{\text{B(p-p)}}\right]^2} \qquad \text{(B.4)}$$

The use of equation (B.4) as an approximation when the vibration is predominantly at synchronous frequency will generally overestimate the value of $S_{\text{(p-p)max}}$ with a maximum error of approximately 40 %.

The maximum error occurs for a circular orbit and progressively reduces as the orbit becomes flatter, with a zero error for the degenerate case of a straight line orbit.

B.4 Method B: Taking the maximum value of the peak-to-peak displacement values measured in two orthogonal directions

The value of $S_{\text{(p-p)max}}$ can be approximated from the following equation:

$$S_{\text{(p-p)max}} = S_{\text{A(p-p)}} \text{ or } S_{\text{B(p-p)}} \qquad \text{(B.5)}$$

whichever is greater.

The use of equation (B.5) as an approximation when the vibration is predominantly at synchronous frequency will generally underestimate the value of $S_{\text{(p-p)max}}$ with a maximum error of approximately 30 %.

The maximum error occurs for a flat orbit and progressively reduces as the orbit becomes circular, with a zero error when the orbit is circular.

B.5 Method C: Measurement of S_{max}

The instantaneous value of the shaft displacement can be defined by S_1, as shown in Figure B.1, which is derived from the transducer measurements S_{A1} and S_{B1} using equation (B.3). There is a point on the orbit, where the displacement from the mean position is a maximum. The value of S_1 corresponding to this position is denoted by S_{max}, which is defined as the maximum value of displacement:

$$S_{\text{max}} = \left[S_1(t)\right]_{\text{max}} = \left[\sqrt{\left[S_{\text{A1}}(t)\right]^2 + \left[S_{\text{B1}}(t)\right]^2}\right]_{\text{max}} \qquad \text{(B.6)}$$

The point on the orbit where S_{max} occurs does not necessarily coincide with the points where S_{A1} and S_{B1} are at their maximum values. Clearly, for a particular orbit, there is one value of S_{max} and this value is independent of the position of the measuring transducers.

The value of $S_{\text{(p-p)max}}$ can be approximated from the following equation:

$$S_{\text{(p-p)max}} = 2\,S_{\text{max}} \qquad \text{(B.7)}$$

Equation (B.7) will be correct when the two orthogonal measurements from which S_{max} is derived are of single-frequency sinusoidal form. In most other cases, this equation will over-estimate $S_{\mathrm{(p\text{-}p)max}}$. The degree of this over-estimation will depend on the nature of the harmonic vibration components present.

It should be noted that implicit in the definition of S_{max} is the requirement to know the time-integrated mean value of the shaft displacement. The measurement of S_{max} is, therefore, limited to those measuring systems which can measure both the mean and alternating values. Furthermore, the evaluation of S_{max} from the signals produced by two vibration transducers is a relatively complex computational procedure requiring specialized instrumentation.

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