International Standard ISO 3945

Mechanical vibration of large rotating machines with speed range from 10 to 200 r/s — Measurement and evaluation of vibration severity *in situ*

Vibrations mécaniques des grandes machines tournantes dans la gamme des vitesses comprises entre 10 et 200 tr/s — Mesurage et évaluation de l'intensité vibratoire in situ

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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.

Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council. They are approved in accordance with ISO procedures requiring at least 75 % approval by the member bodies voting.

International Standard ISO 3945 was prepared by Technical Committee ISO/TC 108, *Mechanical vibration and shock.*

ISO 3945 was first published in 1977. This second edition cancels and replaces the first edition, which has been technically revised as follows:

— the factor 1/2 in equation (3) has been changed to 1/4;

.— a new final paragraph has been added to 7.2.

Users should note that all International Standards undergo revision from time to time and that any reference made herein to any other International Standard implies its latest edition, unless otherwise stated.

Mechanical vibration of large rotating machines with speed range from 10 to 200 r/s — Measurement and evaluation of vibration severity *in situ*

0 Introduction

The problems of noise and vibration control have been brought to the forefront of mechanical and electromechanical engineering technology with the continually increasing power and speed of present-day machinery. As a consequence, more restrictive demands have been placed on the operating quality of machines.

This International Standard is concerned only with severity of the mechanical vibration of individual machine systems and not with the sound energy radiated from the individual vibrating parts. Furthermore, the only vibrations considered are those occurring on the surfaces of the machines close to or on the bearings in the frequency range from 10 to 1 000 Hz. The evaluation is based on the effect of the following general considerations:

— the forces due to vibration in the machines (for example, on bearings, coupled machine parts, baseplates, floor);

— the necessity of maintaining trouble-free operation of a machine which might be jeopardized by malfunction or deterioration of its components (for example, excessive rotor deflections which can occur when it passes through a critical speed, or the loosening of frictional joints as a result of shaking forces, etc.);

— the characteristics of the machine and the measuring instruments;

— the physical and mental effects on man;

— the effects of the machine vibration on its environment, such as adjacently mounted instruments, machines etc.

It is clear that vibrations measurable at a surface may provide only a qualitative indication of the state of the vibratory stresses or motion within a machine. They do not necessarily give evidence of the magnitude of the actual vibratory stresses or motions of critical parts; neither do they give evidence of the vibratory forces transmitted to the surrounding structure nor do they ensure that excessive local vibratory stresses may not occur in the machine itself (for example, due to an internal resonance). In particular, torsional vibrations of rotating parts are not generally indicated by vibrations measurable on a surface.

Although in some cases the above-mentioned factors may be treated theoretically, evaluation specifications arising therefrom are usually unnecessarily complicated and unsuitable. It is advantageous and may be decisive that a single measured test value be used to define the vibratory state of a machine. For this reason, in industrial applications, it is preferable to choose a measurement quantity which can be used as a reference and which can be displayed on a simple scale. The measured values and the chosen scale should ensure a satisfactory evaluation appropriate to the majority of cases which occur in practice, i.e. the indicated evaluation should not contradict experience already obtained.

1 Scope and field of application

This International Standard is based on ISO 2372 and defines rules for evaluating the vibration performance of large prime movers and other large machines with rotating masses only, a power of more than 300 kW and speeds from 10 to 200 r/s. Electric motors and generators, steam and gas turbines, turbo-compressors, turbo-pumps and fans are examples of these types of machines. Some of these machines can be coupled rigidly or flexibly, or they can be connected through gears. The axis of the rotating shaft may be horizontal, vertical or inclined at any angle between these directions.

This International Standard does not apply to prime movers or driven equipment in which the major working components have a reciprocating motion.

The values of vibration severity recommended as limits in this International Standard are intended to serve as standard values for machines of similar types, when measured in accordance with the procedure specified in this International Standard and evaluated under similar conditions. These vibration severity values are useful for comparison purposes or general machine acceptance, but they are not intended to reflect specific design criteria and/or specifications which may exist for a given machine. Thus, in some instances, requirements either more or less stringent, or additional to the recommended limits stated in this International Standard, may be invoked.

Since the vibration severity of the machine is intended to reflect the vibratory forces generated by the machine, vibration entering the unit under test from other sources shall be excluded. Therefore, this International Standard is not applicable to marine or similar installations in which an active vibration environment, as defined in 7.3, may exist and unduly influence the vibration measurements.

1

2 References

ISO 2372, *Mechanical vibration of machines with operating speeds from 10 to 200 rev/s — Basis for specifying evaluation standards.*

ISO 2954, *Mechanical vibration of rotating and reciprocating machinery — Requirements for instruments for measuring vibration severity.*

3 Measurement quantity (vibration severity)

The term "vibration severity", as used in this International Standard, is defined as a comprehensive and simple characteristic quantity which can describe the vibratory state of a machine. This quantity is defined as the root-mean-square value of the vibration velocity in the range from 10 to 1 000 Hz. The greatest measured value, determined at stipulated measuring points and in stipulated directions, characterizes the vibratory state of a machine.

In general, vibration severity should lead to a relatively reliable evaluation which requires only simple stipulated measurements. In critical cases and under special conditions, an evaluation of the behaviour of a machine based on vibration severity should not be used in lieu of more precisely measured significant parameters, for example stresses at bearings and joints.

For harmonic vibration with an instantaneous velocity of $v_i = \hat{v}_i \cos \omega_i t$, and for complex vibrations which consist of a number of superimposed harmonic vibrations of different frequencies, vibration severity is defined and measured as the root-mean-square value of the oscillating velocity. It may be obtained and displayed directly by electrical instruments with a quadratic response characteristic.

From records of measured vibration velocity versus time, the r.m.s. value of the oscillating velocity may be calculated as follows:

$$v_{rms} = \sqrt{\frac{1}{T} \int_0^T v^2(t)\, dt} \qquad \ldots (1)$$

Acceleration, velocity and/or displacement amplitudes ($\hat{a}_j$, $\hat{v}_j$, $\hat{s}_j$, respectively; $j = 1, 2, \ldots, n$) are determined as functions of the angular frequencies ($\omega_1, \omega_2, \ldots, \omega_n$) from analyses of recorded spectra.

When displacement amplitudes of the vibrations $\hat{s}_1, \hat{s}_2, \ldots, \hat{s}_n$ or the oscillating velocity amplitudes $\hat{v}_1, \hat{v}_2, \ldots, \hat{v}_n$, or the acceleration amplitudes $\hat{a}_1, \hat{a}_2, \ldots, \hat{a}_n$, are known, the associated r.m.s. velocities characterizing the motion are given by

$$v_{rms} = \sqrt{\left(\frac{1}{2}\right)\left[\left(\frac{\hat{a}_1}{\omega_1}\right)^2 + \left(\frac{\hat{a}_2}{\omega_2}\right)^2 + \ldots + \left(\frac{\hat{a}_n}{\omega_n}\right)^2\right]}$$

$$= \sqrt{\left(\frac{1}{2}\right)\left(\hat{s}_1^2 \omega_1^2 + \hat{s}_2^2 \omega_2^2 + \ldots + \hat{s}_n^2 \omega_n^2\right)}$$

$$= \sqrt{\left(\frac{1}{2}\right)\left(\hat{v}_1^2 + \hat{v}_2^2 + \ldots + \hat{v}_n^2\right)}$$

$$\ldots (2)$$

In the case where vibration consists of only two proximate frequency components giving beats, v_{rms} may be determined from records of measured vibration velocity versus time be the (exact) equation

$$v_{rms} = \sqrt{\frac{1}{4}\left(\hat{v}^2_{max} + \hat{v}^2_{min}\right)} \qquad \ldots (3)$$

where

$\hat{v}_{max}$ is the peak value at the maximum of the envelope (the bulge);

$\hat{v}_{min}$ is the peak value at the minimum of the envelope (the waist).

When a true-r.m.s. indicating instrument (see note at the end of 4.1) is used, the r.m.s. value of the beating vibration may be determined approximately by the equation

$$v_{rms} = \sqrt{\frac{1}{2}\left(R^2_{max} + R^2_{min}\right)} \qquad \ldots (4)$$

where

R_{max} is the maximum reading from the instrument;

R_{min} is the minimum reading from the instrument.

NOTE — Indicator damping will cause an average reading of beats with a moderate frequency. From equation (4) it is clear that an average r.m.s. reading is an erroneous one. Maximum and minimum readings are unreliable by the indicator response, except at very low beat frequencies.

4 Measurement equipment

The vibration of a machine shall be measured and displayed or *recorded by means of electrical and/or mechanical instruments* and devices with a pass band from 10 to 1 000 Hz and which comply with existing International Standards.[1] Applicable standards which give rules or guidelines for making the vibration measurements and treatment of the recorded data shall be taken into account.

4.1 Performance

The characteristics of the measuring system shall be known with regard to the following:

— temperature variations;

— magnetic fields;

— sound fields;

— power source variations;

— transducer cable length;

— transducer orientation.

In addition to the above factors, other performance limitations, such as amplitude linearity, transverse sensitivity, etc. should be stated.

NOTE — The signal-conditioning instrumentation should produce a processed or conditioned r.m.s. signal (true-r.m.s.) for indication by an electrical meter. Meters scaled to read r.m.s. of rectified input sinusoidal signal are not acceptable, except where it can be shown that the vibration response is a pure sinusoid. The measurement system should have a frequency characteristic conforming to figure 1.

4.2 Calibration

Before using vibration-measuring instruments, the factors noted in 4.1 together with the machine location shall be considered for their effect on *the measurement instrumentation.* The instrumentation system shall be calibrated as often as necessary to ensure reliable results. The system shall include the sensing transducer, signal conditioner and indicator.

For calibration, the pick-up shall be excited by a rectilinear simple harmonic motion with a vibration direction which deviates by not more than ± 5° from that of the sensitive axis of the pick-up. The distortion factor[2] of the vibration velocity shall not exceed 5 %. The amplitude of the velocity of the exciting vibration shall be known with an uncertainty of less than ± 3 % within the whole measuring frequency range.

4.3 Mounting

Particular attention shall be given to ensuring that the vibration-sensing transducer is *correctly mounted and that its presence* does not affect the vibration response characteristics of the machine.

5 Measurement points

A measurement shall be made at or near each main bearing on the bearing housing, in both transverse and axial directions referred to the shaft axis, as shown in figure 2. In the case of vertical or inclined machines, the locations that give the maximum readings shall be used and the specific locations shall be recorded with the measurement. It is expected that measurements will usually be taken on exposed parts of the machine that are normally accessible. Care shall be taken to ensure that measurements represent fairly the vibration of the bearing housings and do not include any local resonances.

6 Operational conditions

Measurements shall be carried out when the rotor and the main bearings have reached their normal steady operating temperatures and with the machine running under rated conditions, for example at rated voltage, flow, pressure, load. On machines with fixed speeds or loads, the conditions for rated speed or load shall be as shown on the rating plate.

On machines with varying speeds or loads, measurements shall be made at all extreme rating conditions in addition to selected *conditions within these limits. The maximum measured value* shall be considered representative of vibration severity. (The equipment may be expected to operate at any operating combination within its rating limits during its life).

7 Machine/support system

Two passive support conditions are used to classify machine systems according to vibration severity. These support conditions are determined by the relationship between the machine and foundations flexibilities in the direction of measurement. For a flexible support, the fundamental natural frequency of the *machine/support system is lower than its main excitation frequency.* For a rigid support, the fundamental natural frequency of the machine/support system is higher than its main excitation frequency.

7.1 Class determination

If the class of a machine/support system cannot be readily determined from drawings and calculation, it may be determined by either a forced- or free-vibration test. The free-vibration test consists of observing the transient frequency response of a machine/support system to an impact. The forced-vibration test consists of observing the steady-state response of a machine/support system to forces of varied frequencies.

7.2 Support classification

The vibration severity ranges in this International Standard depend on the flexibility of the machine foundation and are classified as

— rigid supports;

— flexible supports.

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1) See ISO 2954.

2) **distortion factor**: The ratio of the r.m.s. harmonic content to the total r.m.s. value of the distorted sine wave.

In some cases, a machine/support system will be rigid at one measurement point in one measuring direction and flexible in the other. In such cases, the vibration severity shall be judged in accordance with the relevant classification and measurement.

As typical examples, large electric motors, pumps and small turbogenerators would normally be classified as having rigid supports, whereas gas turbines and turbogenerators with, for example, outputs greater than 10 MW would be classed as having flexible supports.

7.3 Active environment determination

The support systems mentioned in 7.2 are considered passive, admitting insignificant external disturbances to the machine. When the increase of vibration severity value, with the machine operating, is less than three times the non-operating value, then an active environment is said to exist. Vibration severity classifications for active support systems are not given in this International Standard.

7.4 Axial vibrations

The evaluation of axial bearing vibration depends on the bearing function and bearing construction.

In the case of thrust bearings, axial vibrations correlate with thrust pulsations which could cause damage to the metal liners of sliding bearings or to parts of antifriction bearings. Axial vibrations of these bearings should be judged in the same manner as transverse vibrations.

Where bearings have no axial restraints, a less exacting requirement may be permissible.

8 Recommended limits

Quality judgement of vibration severity for large machines, 10 to 200 r/s, is given in the table.

Table — Quality judgement of vibration severity

Vibration severity		Support classification	
v_{rms} mm/s	v_{rms} in/s	Rigid supports	Flexible supports
0,46	0.018	good	good
0,71	0.028	good	good
1,12	0.044	good	good
1,8	0.071	good	good
2,8	0.11	satisfactory	good
4,6	0.18	satisfactory	satisfactory
7,1	0.28	unsatisfactory	satisfactory
11,2	0.44	unsatisfactory	unsatisfactory
18,0	0.71	unacceptable	unsatisfactory
28,0	1.10	unacceptable	unacceptable
71,0	2.80	unacceptable	unacceptable
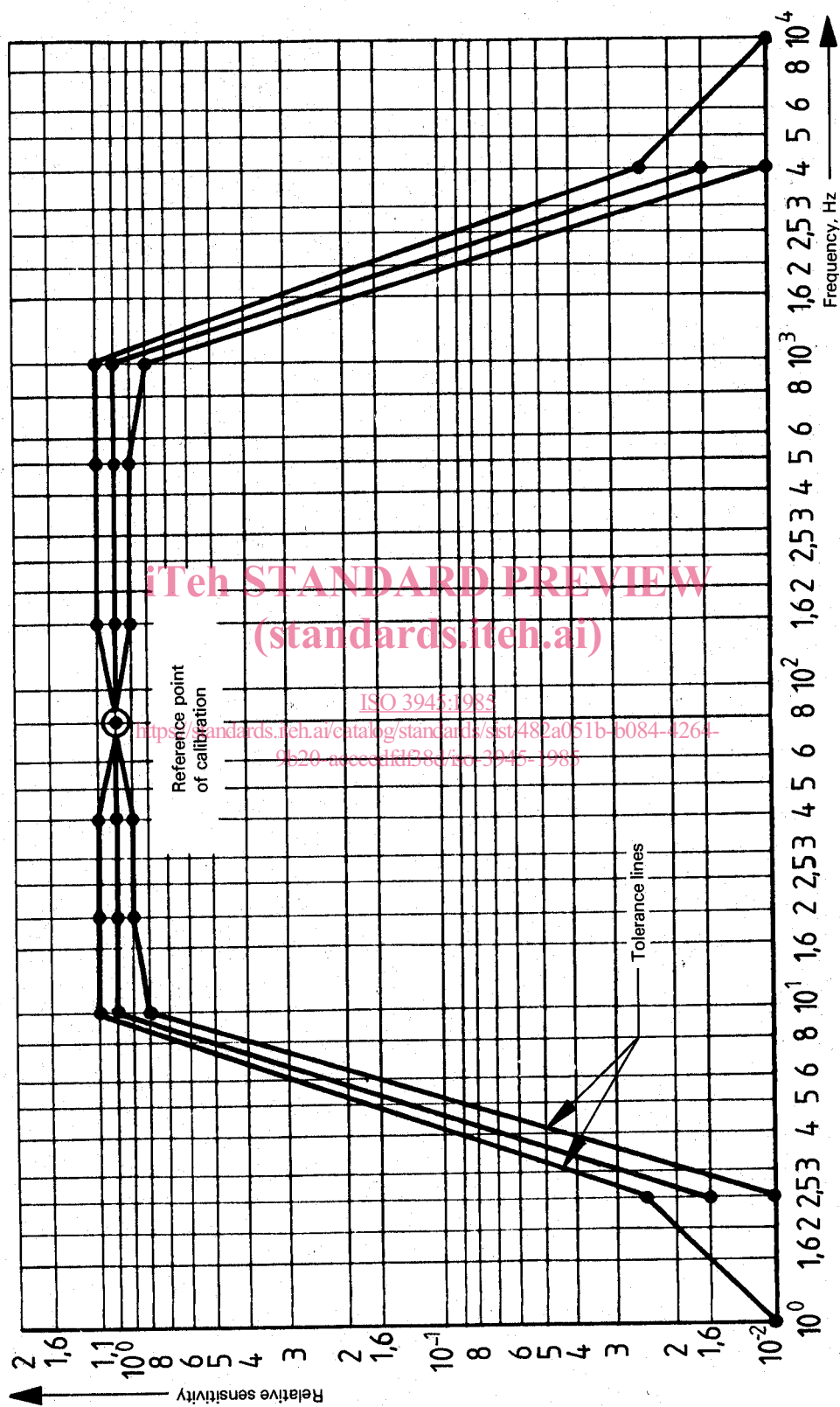
Figure 1 — Sensitivity-frequency characteristic for the vibration-measuring system
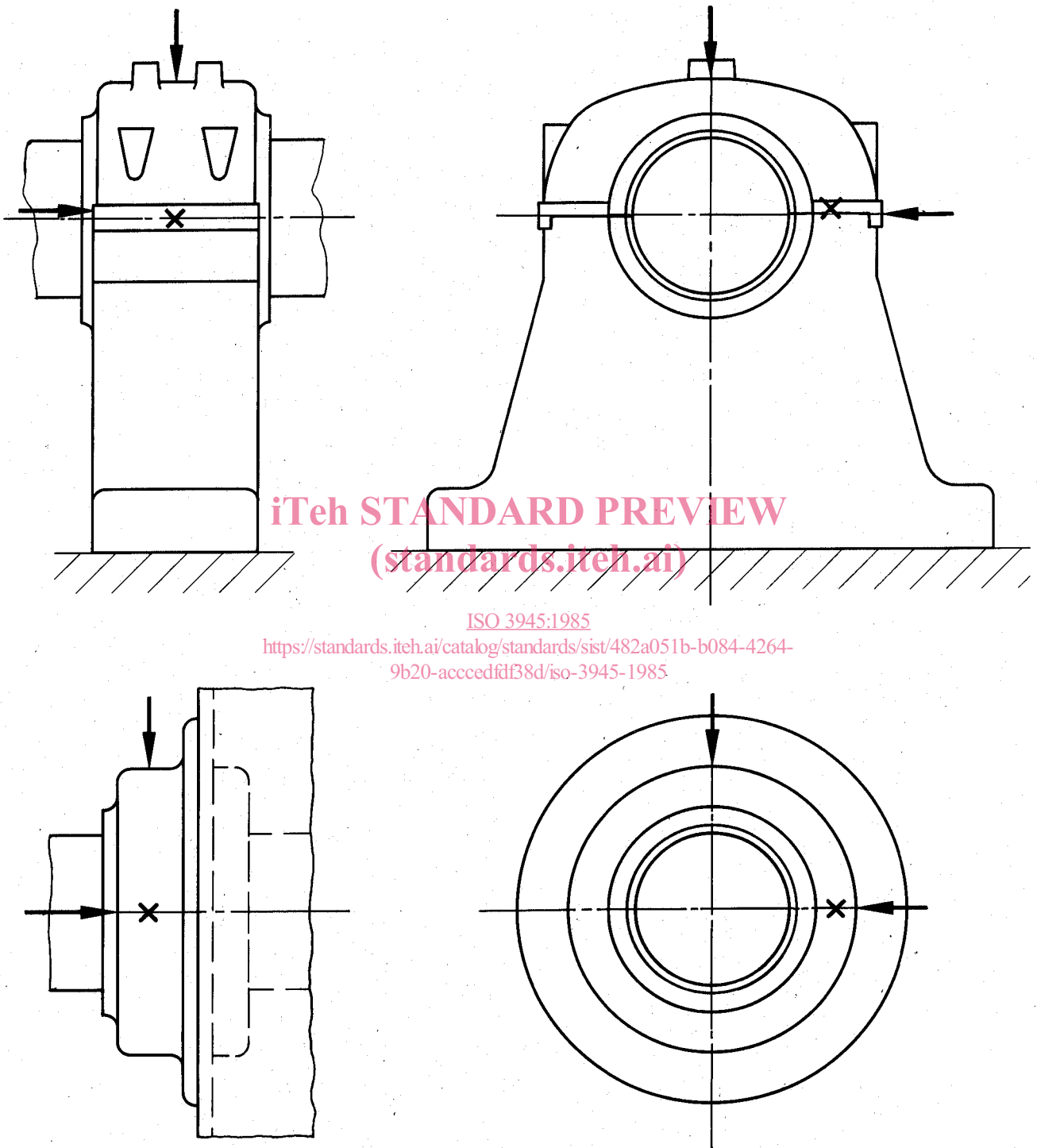
Figure 2 — Measuring points on main bearings