INTERNATIONAL STANDARD ISO 3945

Mechanical vibration of large rotating machines with speed range from 10 to 200 rev/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

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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.

International Standard ISO 3945 was developed by Technical Committee ISO/TC 108, *Mechanical vibration and shock,* and was circulated to the member bodies in October 1975.

It has been approved by the member bodies of the following countries :

Australia	Japan	Spain
Austria	Korea, Rep. of	Sweden
Brazil	Mexico	Turkey
Czechoslovakia	Netherlands	U.S.A.
France	New Zealand	U.S.S.R.
Germany	Romania	
Hungary	South Africa, Rep. of	

The member body of the following country expressed disapproval of the document on technical grounds :

Belgium

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0 INTRODUCTION

The problems of noise and vibration control have been brought to the forefront of mechanical and electro-mechanical 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 individual vibrating parts. Also, the only vibrations considered are those occuring, 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 un-suitable. 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 figure of merit 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 rev/s. Examples of these types of machines are electric motors and generators, steam and gas turbines, turbo-compressors, turbo-pumps and fans. 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 herein 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 herein, 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 must 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.

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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 here, 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 of 10 to 1 000 Hz. The greatest measured value, determined at prescribed measuring points and in prescribed directions, characterizes the vibratory state of a machine.

In general, vibration severity should lead to a relatively reliable evaluation which requires only simple prescribed 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 rms-value of the oscillating velocity may be calculated as follows :

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

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

When displacement amplitudes of the vibrations $\hat{s}_1, \hat{s}_2, \dots, \hat{s}_n$ or the oscillating velocity amplitudes $\hat{v}_1, \hat{v}_2, \dots, \hat{v}_n$ or the acceleration amplitudes $\hat{a}_1, \hat{a}_2, \dots, \hat{a}_n$

are known, the associated rms-velocities characterizing the motion are given by

$$
\begin{aligned}
v_{rms} &= \sqrt{\left(\frac{1}{2}\right)\left[\left(\frac{\hat{a}_1}{\omega_1}\right)^2 + \left(\frac{\hat{a}_2}{\omega_2}\right)^2 + \dots + \left(\frac{\hat{a}_n}{\omega_n}\right)^2\right]} \\
&= \sqrt{\left(\frac{1}{2}\right)\left(\hat{s}_1^{\,2}\omega_1^{\,2} + \hat{s}_2^{\,2}\omega_2^{\,2} + \dots + \hat{s}_n^{\,2}\omega_n^{\,2}\right)} \\
&= \sqrt{\left(\frac{1}{2}\right)\left(\hat{v}_1^{\,2} + \hat{v}_2^{\,2} + \dots + \hat{v}_n^{\,2}\right)}
\end{aligned}
$$

$$\dots (2)$$

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 by the (exact) relationship

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

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-rms indicating instrument (see note at the end of 4.1) is used, the rms value of the beating vibration may be determined approximately by the relationship

$$v_{rms} = \sqrt{\frac{1}{2}(R_{max}^2 + R_{min}^2)} \qquad \dots (4)$$

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 (4) it is clear that an average rms 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 of 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.

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1) See ISO 2954.

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.

NOTES — The signal-conditioning instrumentation should produce a processed or conditioned rms signal (true-rms) for indication by an electrical meter. Meters scaled to read rms 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 shall 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 pickup shall be excited by a rectilinear simple harmonic motion with a vibration direction which deviates by not more than $\pm 5°$ from that of the sensitive axis of the pickup. The distortion factor[1]) 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 $\pm 3 \%$ 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 is to 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 figures 2 and 3. In the case of vertical or inclined machines, the locations that give the maximum readings shall be used and the specific locations are to 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 must be taken 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 are 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 ~~flexible~~ 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 observation of a machine/support system's transient frequency response to an impact. The forced-vibration test consists of observing the machine/support system's steady-state response 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.

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

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1) distortion factor : The ratio of the rms harmonic content to the total rms value of the distorted sine wave.

7.3 Active environment determination

The aforementioned support systems 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 rev/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	satisfactory	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