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**Mechanical vibration—
Susceptibility and sensitivity
of machines to unbalance**

ICS 21.120.40

Descriptors : vibration, mechanical measurement, rotational motion, rotating electric machines, vibration measurement, vibration testing, balancing

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Foreword

This translation has been made based on the original Japanese Industrial Standard established by the Minister of International Trade and Industry through deliberations at the Japanese Industrial Standards Committee according to the proposal of establishing a Japanese Industrial Standard from the Japanese Standards Association (JSA), with a draft of Industrial Standard based on the provision of Clause 1, Article 12 of the Industrial Standardization Law.

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Mechanical vibration— Susceptibility and sensitivity of machines to unbalance

Introduction This Japanese Industrial Standard has been prepared based on the first edition of **ISO 10814** *Mechanical vibration—Susceptibility and sensitivity of machines to unbalance* published in 1996 without modifying the technical contents.

Portions underlined with dots are the matters not stated in the original International Standard.

Rotor balancing during manufacture (as described in **ISO 1940-1** and **ISO 11342**, for example) is normally sufficient to attain acceptable vibration levels in service if other sources of vibration are absent. There are exceptions, however, where additional balancing during commissioning becomes necessary. Furthermore, after commissioning, some machines may require occasional or even frequent field rebalancing.

If the vibration levels are unsatisfactory during commissioning, the reason may be inadequate balancing or assembly errors. Another important cause may be that an assembled machine is especially sensitive to relatively small residual unbalances which are well within normal balance tolerances.

If vibration magnitudes are unsatisfactory, the first step often is an attempt to reduce the vibration by field balancing. If high vibration can be reduced by relatively small correction masses, high sensitivity to unbalance is indicated. This can arise, for example, if a resonant speed is close to the normal service speed and the damping in the system is low.

A sensitive machine which is also highly susceptible to its unbalance changing, may require frequent rebalancing *in situ*. This may be caused, for example, by changes in wear, temperature, mass, stiffness and damping during operation.

If the unbalance and other conditions of the machine are essentially constant, occasional trim balancing may be sufficient. Otherwise it may be necessary to modify the machine to change the resonant speed, damping or other parameters. Therefore, there is a need to consider permissible sensitivity values of the machine.

The repeatability of the sensitivity of a machine is influenced by several factors and may change during operation. Some thermal machines, especially those with sleeve bearings, have modal vibration characteristics which vary with certain operational parameters such as steam pressure and temperature, partial steam admission or oil temperature. For electrical machines, other parameters such as the excitation current may influence the vibration behaviour. In general, the machine vibration characteristics are influenced by the design features of the machine, including coupling of the rotor and the support conditions including the foundation. It should be noted that the latter may vary with time, for example owing to wear and tear.

This Standard is only concerned with once-per-revolution vibration caused by unbalance; however it should be recognized that unbalance is not the only cause of once-per-revolution vibration.

1 Scope

1.1 This Standard defines methods for determining machine vibration sensitivity to unbalance and provides evaluation guidelines as a function of the proximity of relevant resonant speeds to the service speed.

It includes a classification of certain machines in groups associated with the susceptibility to a change in unbalance. This Standard also makes recommendations on how to apply the numerical sensitivity values in some particular cases.

1.2 Machines are classified into three types in clause 4, and sensitivity values assigned to different groups of machines are shown in clause 5. The sensitivity values should be used on simple machine systems, preferably with rotors having only one resonant speed over the entire service speed range. They may also be used for machines that have more resonant speeds in the service speed range if the resonant speeds are widely separated (e.g. more than 20 % spaced).

The proposed sensitivity values are not intended to serve as acceptance specifications for any machine group but rather to give indications of how to avoid gross deficiencies as well as exaggerated or unattainable requirements. They may also serve as a basis for more involved investigations, for example, when in special cases a more exact determination of the required sensitivity is necessary. If due regard is paid to the proposed values, satisfactory running conditions can be expected in most cases.

The consideration of these values alone does not guarantee that a given magnitude of vibration in service is not exceeded. Many other sources of vibration can occur which are not the subject of this Standard.

2 Normative references The following standards contain provisions which, through reference in this Standard, constitute provisions of this Standard. If the indication of the year of publication is given to these referred standards, only the edition of indicated year constitutes the provision of this Standard but the revision and amendment made thereafter are not applied.

ISO 1925 : 1990 *Mechanical vibration—Balancing—Vocabulary*

ISO 2041 : 1990 *Vibration and shock—Vocabulary*

3 Definitions For the purposes of this Standard, the definitions given in **ISO 1925** and **ISO 2041** and the following definitions apply.

3.1 susceptibility to unbalance An indication of the likelihood of a machine having a significant change of unbalance over a certain period of operation.

3.2 sensitivity to unbalance A measure of the vibration response of a machine to a change in unbalance.

Note : It is usually numerically expressed in the two ways shown in **3.2.1** and **3.2.2** below.

3.2.1 local sensitivity Ratio of the magnitude of the change of the displacement or velocity vector in a specified measuring plane to the magnitude of a change in the unbalance in a specified plane in the rotor at a specified speed.

In technical terms, the local sensitivity can be expressed as:

$$S_{k,r} = \frac{|\Delta \bar{S}_k|}{|\Delta \bar{U}_r|} \dots\dots\dots (1)$$

where

$\Delta |\bar{S}_k|$ is the change in once-per-revolution vibration in plane k;

$\Delta |\bar{U}_r|$ is the change in trial unbalance attached to plane r in the rotor (or change in trial unbalance set).

Note : The local sensitivity is frequently referred to as the “influence coefficient”. It is a dimensional quantity.

3.2.2 modal sensitivity, M_n Ratio of the change of the modal displacement vector to a change of the modal eccentricity (modal unbalance divided by modal mass). It is a non-dimensional quantity.

In practical determinations of modal sensitivity, care should be taken to extract the relevant modal components.

Modal sensitivity for excitation of the machine by unbalance for mode n can be shown to be:

$$M_n = \frac{\left(\frac{\Omega}{\omega_n}\right)^2}{\sqrt{\left(1 - \left(\frac{\Omega}{\omega_n}\right)^2\right)^2 + 4\zeta_n^2 \left(\frac{\Omega}{\omega_n}\right)^2}} \dots\dots\dots (2)$$

where

Ω is the rotational speed;

ω_n is the n th undamped resonant speed;

ζ_n is the damping ratio of the n th mode.

Under conditions where the rotational speed equals a resonant speed, M_n becomes approximately $1/(2\zeta_n)$. For light damping, this is the maximum amplification at resonance denoted by Q_n ; it is influenced only by the level of damping in the system.

Note : Modal sensitivity is sometimes referred to as the vibration magnification factor for mode n .

4 Machine susceptibility classification

4.1 Type I: Low susceptibility Machines of this type have a low likelihood of experiencing significant unbalance changes during operation. Typically, they have large rotor masses in comparison to the support housing and operate in a clean environment, have negligible wear and exhibit minimal rotor distortion caused by temperature changes.

Examples : Paper machine rolls, printing rolls and high-speed vacuum pumps.

4.2 Type II : Moderate susceptibility Machines of this type have a moderate likelihood of experiencing significant unbalance changes during operation, such as rotors in an environment with large temperature changes and/or moderate wear.

Examples : Pumps in clean media, electric armatures, gas and steam turbines, small turbo generators for industrial applications and turbo compressors.

4.3 Type III : High susceptibility Machines of this type have a high likelihood of experiencing significant unbalance changes during operation, such as blowers running in deposit producing environments, pumps operating in sludge, rotors with high wear or running in corrosive environments.

Examples : Centrifuges, fans, screw conveyors and hammer mills.

5 Modal sensitivity values

5.1 Modal sensitivity ranges A to E In figures 1 to 3, modal sensitivity is classified for service speeds below and above a resonant speed of the machine system. The range limits are chosen in such a way that, close to a resonant speed, the magnification factor is constant. The curves in figures 1 to 3 are derived from equation (2). The range limits depend on the type of machine in the susceptibility classification (the damping ratio being lower, in the same sensitivity range, for type III than for type I machines).

Generally, for the sensitivity ranges below, the corresponding running conditions given in table 1 can be expected.

Examples of how to use figures 1 to 3 are given in annex B.

Table 1

Modal sensitivity range	Expected running conditions
A: Very low sensitivity	Very smooth resonant speed; difficult to detect
B: Low sensitivity	Smooth, low and stable vibrations
C: Moderate sensitivity	Acceptable, moderate and slightly unsteady vibrations
D: High sensitivity	Sensitive to unbalance; regular field balancing may be required
E: Very high sensitivity	Too sensitive to unbalance; to be avoided

5.2 Characteristics of modal sensitivity

5.2.1 While range A will theoretically appear to be the most desirable, considerations of cost and feasibility may often make it necessary to operate with higher modal sensitivities.

5.2.2 For high-performance machines (e.g. those that have a short period between planned maintenance cycles), it may be permissible to allow higher values of modal sensitivity.