INTERNATIONAL STANDARD

ISO 21940-31

First edition
2013-08-15

Mechanical vibration — Rotor balancing —

Part 31: Susceptibility and sensitivity of machines to unbalance

Vibrations mécaniques — Équilibrage des rotors —

Partie 31: Susceptibilité et sensibilité des machines aux balourds

Reference number
ISO 21940-31:2013(E)

Contents

Page

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.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2, www.iso.org/directives.

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received, www.iso.org/patents.

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

The committee responsible for this document is 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 first edition of ISO 21940-31 cancels and replaces ISO 10814:1996, of which it constitutes a technical revision. The main change is modification to the modal amplification factors to make this part of ISO 21940 more consistent with relevant parts of ISO 7919, e.g. machines predicted to operate in ISO 7919-2[2] zone A would be classified as very low (range A) and machines predicted to operate in ISO 7919-2[2] zone B would be classified as low (range B).

ISO 21940 consists of the following parts, under the general title *Mechanical vibration — Rotor balancing*:

— *Part 1: Introduction*1)

— *Part 2: Vocabulary*2)

— *Part 11: Procedures and tolerances for rotors with rigid behaviour*3)

— *Part 12: Procedures and tolerances for rotors with flexible behaviour*4)

— *Part 13: Criteria and safeguards for the in-situ balancing of medium and large rotors*5)

— *Part 14: Procedures for assessing balance errors*6)

---

1) Revision of ISO 19499:2007, *Mechanical vibration — Balancing — Guidance on the use and application of balancing standards*

2) Revision of ISO 1925:2001, *Mechanical vibration — Balancing — Vocabulary*

3) Revision of ISO 1940-1:2003 + Cor.1:2005, *Mechanical vibration — Balance quality requirements for rotors in a constant (rigid) state — Part 1: Specification and verification of balance tolerances*

4) Revision of ISO 11342:1998 + Cor.1:2000, *Mechanical vibration — Methods and criteria for the mechanical balancing of flexible rotors*

5) Revision of ISO 20806:2009, *Mechanical vibration — Criteria and safeguards for the in-situ balancing of medium and large rotors*

6) Revision of ISO 1940-2:1997, *Mechanical vibration — Balance quality requirements of rigid rotors — Part 2: Balance errors*

— *Part 21: Description and evaluation of balancing machines*[7)]

— *Part 23: Enclosures and other protective measures for the measuring station of balancing machines*[8)]

— *Part 31: Susceptibility and sensitivity of machines to unbalance*[9)]

— *Part 32: Shaft and fitment key convention*[10)]

7) Revision of ISO 2953:1999, *Mechanical vibration — Balancing machines — Description and evaluation*

8) Revision of ISO 7475:2002, *Mechanical vibration — Balancing machines — Enclosures and other protective measures for the measuring station*

9) Revision of ISO 10814:1996, *Mechanical vibration — Susceptibility and sensitivity of machines to unbalance*

10) Revision of ISO 8821:1989, *Mechanical vibration — Balancing — Shaft and fitment key convention*

Introduction

Rotor balancing during manufacture (e.g. as described in ISO 1940-1[1] and ISO 11342[4]) is normally sufficient to attain acceptable in-service vibration magnitudes if other sources of vibration are absent. However, additional balancing during commissioning may become necessary and after commissioning, some machines may require occasional or even frequent rebalancing *in situ*.

If vibration magnitudes 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 balancing *in situ*. If high vibration magnitudes can be reduced by installing relatively small correction masses, high sensitivity to unbalance is indicated. This can arise, for example, if a resonance rotational speed is close to the normal operating 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 resonance speed, damping or other parameters to obtain acceptable vibration magnitudes. Therefore, there is a need to consider permissible sensitivity values of the machine.

The repeatability of the unbalance 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 particular operational parameters (e.g. 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 its support conditions including the foundation. It should be noted that the rotor support conditions may vary with time (e.g. wear and tear).

This part of ISO 21940 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.

Mechanical vibration — Rotor balancing —

Part 31:
Susceptibility and sensitivity of machines to unbalance

1 Scope

This part of ISO 21940 specifies methods for determining machine vibration sensitivity to unbalance and provides evaluation guidelines as a function of the proximity of relevant resonance rotational speeds to the operating speed. This part of ISO 21940 is only concerned with once-per-revolution vibration caused by unbalance. It also makes recommendations on how to apply the numerical sensitivity values in some particular cases.

It includes a classification system that can be applied to machines which is related to their susceptibility to a change in unbalance. Machines are classified into three types of susceptibility and five ranges of sensitivity. The sensitivity values are intended for use on simple machine systems, preferably with rotors having only one resonance speed over their entire operating speed range. The sensitivity values can also be used for machines that have more resonance speeds in their operating speed range if the resonance speeds are widely separated (e.g. by more than 20 %).

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

The consideration of the sensitivity values alone does not guarantee that a given magnitude of vibration in operating is not exceeded. Many other sources of vibration can occur which lie outside the scope of this part of ISO 21940.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 1925, *Mechanical vibration — Balancing — Vocabulary*[11)]

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 1925 apply.

NOTE Some of the terms used are explained in Annex A.

4 Machine susceptibility classification

4.1 General

Machine susceptibility classification is based on the likelihood of a machine experiencing significant unbalance during operation. Machines with low susceptibility are allowed higher sensitivity values

11) To become ISO 21940-2 when revised.

(require less damping), and machines with high susceptibility are restricted to lower sensitivity values (require more damping).

4.2 Type I: Low susceptibility

Machines of this type have a low likelihood of experiencing significant unbalance changes during operation. Typically they have a large rotor mass in comparison to their support housing and operate in a clean environment, have negligible wear and exhibit minimal rotor distortion caused by temperature change.

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

4.3 Type II: Moderate susceptibility

Machines of this type have a moderate likelihood of experiencing significant unbalance changes during operation. Typically they are machines which operate in environments with large temperature changes or experience moderate wear.

EXAMPLES Pumps in clean media, electric armatures, gas and steam turbines, generators, and turbo compressors.

4.4 Type III: High susceptibility

Machines of this type have a high likelihood of experiencing significant unbalance changes during operation. Typically they are machines which run in deposit producing (e.g. pumps operating in sludge) or corrosive environments.

EXAMPLES Centrifuges, fans, screw conveyors, and hammer mills.

4.5 Machine susceptibility correction factors

The remainder of this part of ISO 21940 focuses on moderate susceptibility classification machines (type II). For evaluation of low susceptibility or high susceptibility machines, a correction factor can be applied to adjust the sensitivity range. Table 1 shows correction factors that are applied to the sensitivity values (see Clause 5) based on machine susceptibility type (see 4.2 to 4.4).

Table 1 — Correction factors

Machine type	Machine susceptibility classification	Correction factor
I	Low susceptibility	$\frac{4}{3}$
II	Moderately susceptibility	1 (Base)
III	High susceptibility	$\frac{2}{3}$

5 Modal sensitivity

5.1 General

Modal sensitivity is given in terms of the modal amplification factor, M_n, which is a constant value defining the quality range for each resonance rotational speed of a machine. For machines to achieve low unbalance sensitivity, there needs to be adequate separation between their operating and resonance speeds or sufficient damping.

Modal sensitivity at any or each resonance speed is also important to avoid excessive vibration when passing through them to reach the operating speed or speed range.

5.2 Modal sensitivity ranges

Allowable modal amplification factors, which vary with machine rotational speed, make up the modal sensitivity ranges used to classify machines with respect to their expected operating conditions. Table 2 defines the ranges of modal sensitivity.

Table 2 — Modal sensitivity range

Range designation	Description	Expected operating conditions
A	Very low sensitivity	Very smooth
B	Low sensitivity	Smooth
C	Moderate sensitivity	Acceptable
D	High sensitivity	Sensitive to unbalance
E	Very high sensitivity	Too sensitive to unbalance

5.3 Characteristics of modal sensitivity ranges

While range A (see Table 2) theoretically appears to be the most desirable, considerations of cost and feasibility may often make it necessary to operate with higher modal sensitivities.

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

For machines for which balancing *in situ* is not practical or not economical, smaller values of modal sensitivity may have to be selected.

Consideration of the sensitivity does not always give sufficient assurance that, at all parts of the machine, vibration limits are not exceeded (see Clauses 7 and 8).

5.4 Values of modal sensitivity

5.4.1 General

Values of modal sensitivity in terms of modal amplification factors, M_n, are constants that are used with a series of formulae to define the modal sensitivity ranges. These values have been derived from permissible eccentricity as defined in ISO 1940-1[1] and allowable vibration amplitude established in ISO 7919-2[2] and ISO 7919-4.[3] Together these documents can be used to develop values of modal sensitivity for operation at operational speed.

5.4.2 Permissible eccentricity

The permissible residual unbalance of a rotor, U_{per}, is

$$U_{per} = e_{per} m \tag{1}$$

where

e_{per} is the permissible residual eccentricity;

m is the rotor mass.

ISO 1940-1[1] establishes balance quality grades, G, that permit a classification of balance quality based on the rotor type. The established grades are based on the machine operating speed Ω:

$$G = e_{per}\Omega \qquad (2)$$

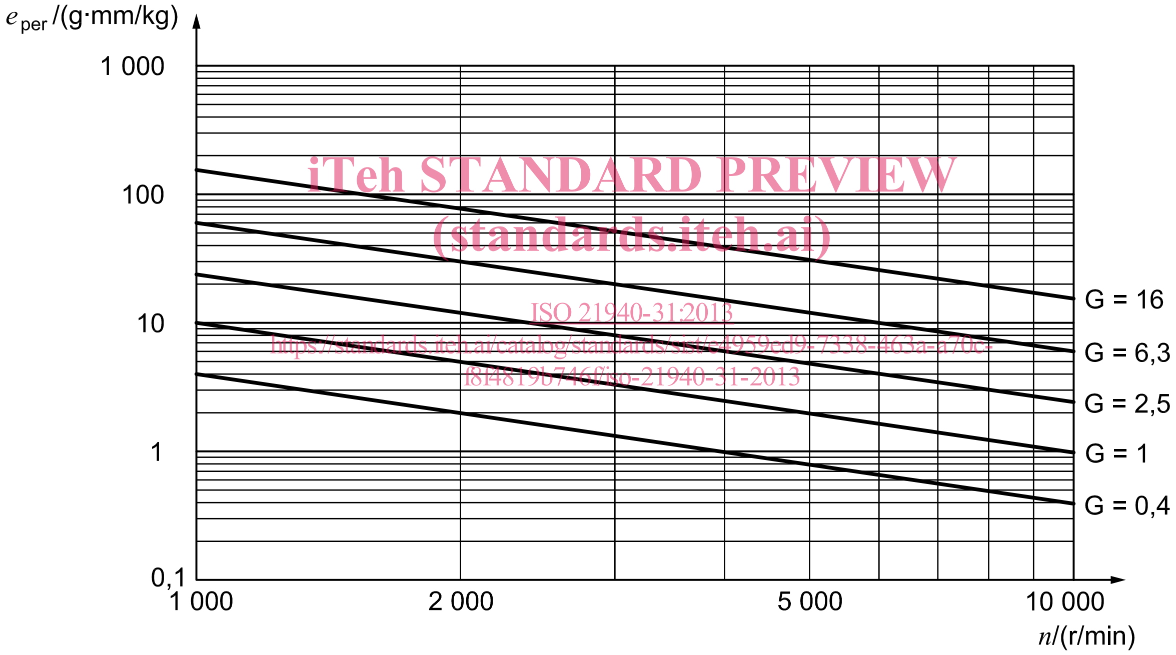
The balance quality grade, G, is constant for a given machine type (e.g. $e_{per}\Omega$ = 2,5 mm/s = G 2,5).

NOTE The operating speed Ω is the numerical value of the angular velocity of the rotational speed n in r/min (revolutions per minute), expressed in rad/s (radians per second), with $\Omega = 2\pi n/60 \approx n/10$.

Reorganizing Formula (2) yields an expression for permissible eccentricity based on the machine operating speed and balance quality grade:

$$e_{per} = \frac{G}{\Omega} \qquad (3)$$

Permissible eccentricity as a function of rotational speed is shown in Figure 1 for various balance quality grades. For machines with balance quality grade G 2,5 and a rotational speed of n = 3 000 r/min, the permissible eccentricity is 8,0 µm and for 3 600 r/min machines, the permissible eccentricity is 6,6 µm.



Key

e_{per} permissible eccentricity

n rotational speed

NOTE Units g·mm/kg are equivalent to µm.

Figure 1 — Permissible eccentricity according to ISO 1940-1[1]

5.4.3 Allowable vibration magnitude

ISO 7919-2[2] and ISO 7919-4[3] define evaluation zones for steady-state shaft vibration. These zones are:

— zone A: the vibration of newly commissioned machines;

— zone B: acceptable for unrestricted long-term operation;

— zone C: unsatisfactory for long-term continuous operation, machine to be operated for limited period until suitable opportunity arises for remedial action;

— zone D: vibration sufficient to cause damage to machine.

These peak-to-peak vibration zone boundaries are inversely proportional to the square root of the maximum normal operating speed *n*, in revolutions per minute, as shown in Formulae (4) to (6):

Zone boundary A/B

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

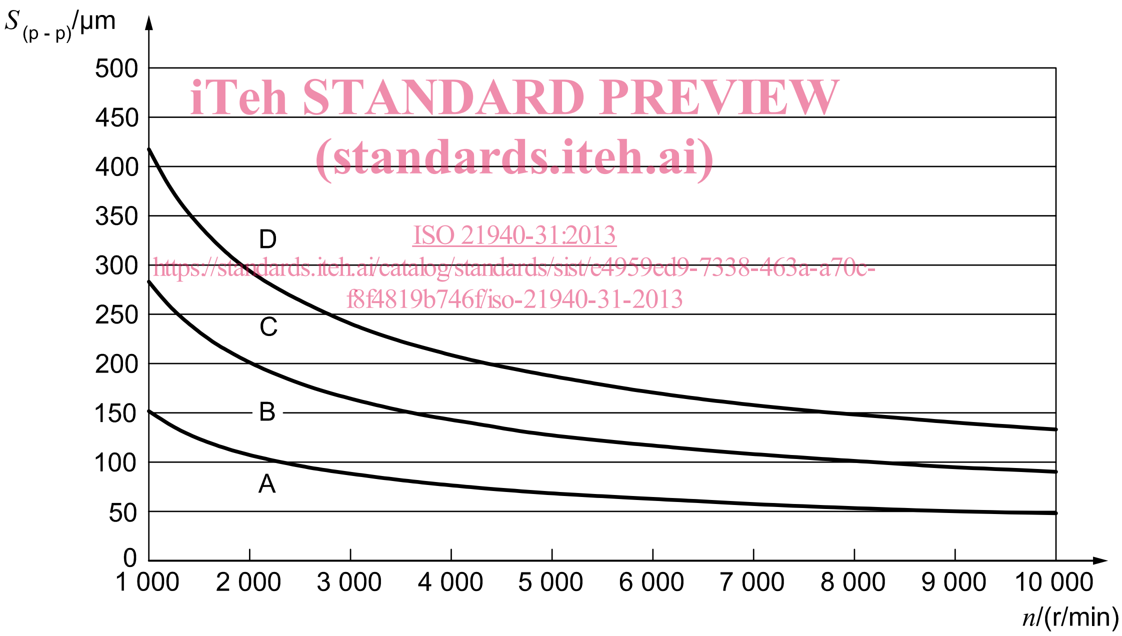
Zone boundary B/C

$$S_{(p-p)} = \frac{9\,000}{\sqrt{n}}\ \mu m \tag{5}$$

Zone boundary C/D

$$S_{(p-p)} = \frac{13\,200}{\sqrt{n}}\ \mu m \tag{6}$$

Figure 2 shows how Formulae (4) to (6) vary with rotational speed and Table 3 shows vibration limits for common type II machine operating speeds.



Key

$S_{(p-p)}$ peak-to-peak vibration magnitude

n machine operating speed

NOTE A to D are the zones given in 5.4.3.

Figure 2 — Zone boundary curves according to ISO 7919-2[2] and ISO 7919-4[3]