INTERNATIONAL STANDARD

ISO 21940-14

First edition
2012-07-01

Mechanical vibration — Rotor balancing —

Part 14:
Procedures for assessing balance errors

Vibrations mécaniques — Équilibrage des rotors —

Partie 14: Modes opératoires d'évaluation des erreurs d'équilibrage

Reference number
ISO 21940-14:2012(E)

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Published in Switzerland

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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 2.

The main task of technical committees is to prepare International Standards. 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.

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.

ISO 21940-14 was prepared by Technical Committee 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 21940-14 cancels and replaces ISO 1940-2:1997, of which it constitutes a technical revision. The main change is extension of the applicability to rotors with flexible behaviour.

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)

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

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

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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*

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*

- *Part 31: Susceptibility and sensitivity of machines to unbalance*[9)]
- *Part 32: Shaft and fitment key convention*[10)]

[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

The balance quality of a rotor is assessed in accordance with the requirements of ISO 1940-1 or ISO 11342 by measurements taken on the rotor. These measurements might contain errors which can originate from a number of sources. Where those errors are significant, they should be taken into account when defining the required balance quality of the rotor.

ISO 1940-1 and ISO 11342 do not consider in detail balance errors or, more importantly, the assessment of balance errors. Therefore this part of ISO 21940 gives examples of typical errors that can occur and provides recommended procedures for their evaluation.

Mechanical vibration — Rotor balancing —

Part 14:
Procedures for assessing balance errors

1 Scope

This part of ISO 21940 specifies the requirements for the following:

a) identifying errors in the unbalance measuring process of a rotor;

b) assessing the identified errors;

c) taking the errors into account.

This part of ISO 21940 specifies balance acceptance criteria, in terms of residual unbalance, for both directly after balancing and for a subsequent check of the balance quality by the user.

For the main typical errors, this part of ISO 21940 lists methods for their reduction in an informative annex.

2 Normative references

The following referenced documents are indispensable for the application of this document. 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)

ISO 1940-1, *Mechanical vibration — Balance quality requirements for rotors in a constant (rigid) state — Part 1: Specification and verification of balance tolerances*12)

ISO 11342, *Mechanical vibration — Methods and criteria for the mechanical balancing of flexible rotors*13)

ISO 21940-21, *Mechanical vibration — Rotor balancing — Part 21: Description and evaluation of balancing machines*

3 Terms and definitions

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

4 Balance error sources

4.1 General

Balancing machine balance errors can be classified into:

a) systematic errors, in which the magnitude and angle can be evaluated either by calculation or measurement;

b) randomly variable errors, in which the magnitude and angle vary in an unpredictable manner over a number of measurements carried out under the same conditions;

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11) To become ISO 21940-2 when revised.

12) To become ISO 21940-11 when revised.

13) To become ISO 21940-12 when revised.

c) scalar errors, in which the maximum magnitude can be evaluated or estimated, but its angle is indeterminate.

Depending on the manufacturing processes used, the same error can be placed in one or more categories.

Examples of error sources which may occur are listed in 4.2, 4.3, and 4.4.

Some of these errors are discussed in greater detail in Annex A.

4.2 Systematic errors

Examples of balancing machine systematic error sources are:

a) inherent unbalance in the drive shaft;

b) inherent unbalance in the mandrel;

c) radial and axial runout of the drive element on the rotor shaft axis;

d) radial and axial runout in the fit between the component to be balanced or in the balancing machine mandrel (see 5.3);

e) lack of concentricity between the journals and support surfaces used for balancing;

f) radial and axial runout of rolling element bearings which are not the service bearings and which are used to support the rotor;

g) radial and axial runout of rotating races (and their tracks) of rolling element service bearings fitted after balancing;

h) unbalance due to keys and keyways;

i) residual magnetism in the rotor or mandrel;

j) reassembly errors;

k) balancing equipment and instrumentation errors;

l) differences between service shaft and balancing mandrel diameters;

m) universal joint defects;

n) temporary bend in the rotor during balancing;

o) permanent bend in the rotor after balancing.

4.3 Randomly variable errors

Examples of balancing machine randomly variable error sources are:

a) loose parts;

b) entrapped liquids or solids;

c) distortion caused by thermal effects;

d) windage effects;

e) use of a loose coupling as a drive element;

f) transient bend in the horizontal rotor caused by gravitational effects when the rotor is stationary.

4.4 Scalar errors

Examples of balancing machine scalar error sources are:

a) changes in clearance at interfaces that are to be disassembled after the balancing process;

b) excessive clearance in universal joints;

c) excessive clearance on the mandrel or shaft;

d) design and manufacturing tolerances;

e) runout of the balancing machine support rollers if their diameters and the rotor journal diameter are the same, nearly the same or have an integer ratio.

5 Error assessment

5.1 General

In some cases, rotors are in balance by design, are uniform in material and are machined to such narrow tolerances that they do not need to be balanced after manufacture. Where rotor initial unbalance exceeds the permitted values given in ISO 1940-1 or ISO 11342, the rotor should be balanced.

5.2 Errors caused by balancing equipment and instrumentation

Balance errors caused by balancing equipment and instrumentation can increase with the magnitude of the unbalance present. By considering unbalance causes during the design stage, some error sources can be completely eliminated (e.g. by combining several parts into one) or reduced (e.g. by specifying decreased tolerances). It is necessary to weigh the cost due to tighter specified tolerances against the benefit of decreased unbalance. Where the causes of unbalance cannot be eliminated or reduced to negligible levels, they should be mathematically evaluated.

5.3 Balance errors caused by component radial and axial runout

When a perfectly balanced rotor component is mounted eccentrically to the rotor shaft axis, the resulting static unbalance, $\boldsymbol{U}_\mathrm{S}$, of the component, in g·mm, is given by Formula (1):

$$\boldsymbol{U}_\mathrm{S} = m \cdot \boldsymbol{e} \tag{1}$$

where

m is the mass of the component, in g;

$\boldsymbol{e}$ is the eccentricity of the rotor component relative to the rotor shaft axis, in mm.

NOTE The mass can be stated in kg, the eccentricity in µm, but the static unbalance remains in units of g·mm.

The static unbalance of the component creates an identical static unbalance of the assembled rotor. An additional moment unbalance results if the component is mounted eccentrically in a plane other than that of the centre of mass. The further the plane distance is from the centre of mass, the larger the moment unbalance.

If a perfectly balanced component is mounted concentrically, but with its principal axis of inertia inclined to the rotor shaft axis, a moment unbalance results; see Figure 1.

For a small inclination angle, $\Delta\gamma$, between the two axes, the resulting moment unbalance. $\boldsymbol{P}_\mathrm{r}$, in g·mm^2, is approximately equal to the difference between the moments of inertia about the component x- and z-axes, multiplied by the angle, $\Delta\gamma$, in radians; see Formula (2):

$$\boldsymbol{P}_\mathrm{r} \approx (I_x - I_z)\,\Delta\gamma \qquad (2)$$

where

I_x is the moment of inertia about the transverse x-axis through the component centre of mass, in g·mm^2;

I_z is the moment of inertia about the principal z-axis of the component, in g·mm^2;

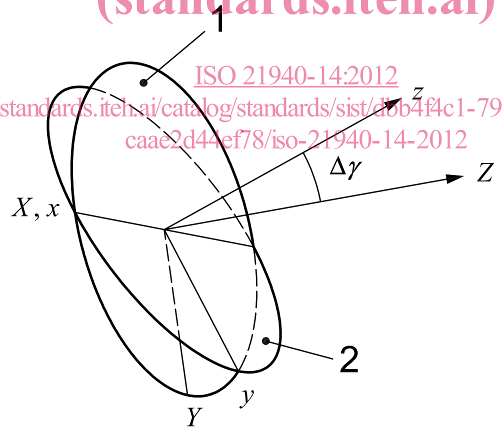
$\Delta\gamma$ is the small angle between the component principal axis of inertia and the rotor shaft axis, in radians.

Formula (2) is valid only if the component is symmetric about its rotational axis and is therefore particularly applicable to the balancing of disks on arbors.

The effects of radial runout and axial runout of a component mounted on the rotor can be calculated separately.

For rotors with rigid behaviour, the separate unbalance components can be allocated to the bearing or correction planes and then combined vectorially.

For rotors with flexible behaviour, a rigid balance quality might be maintained, but accumulated axial disk runout errors (often described as skew) can lead to significant vibration due to the moment unbalance generated by the skewed disk(s).



Key

1	rotor plane, perpendicular to the rotor shaft axis	x	component transverse axis
2	component plane	y	component transverse axis
X	rotor shaft transverse axis	z	component principal axis
Y	rotor shaft transverse axis	$\Delta\gamma$	angle between the component principal axis of inertia and the rotor shaft axis
Z	rotor shaft axis		

Figure 1 — Coordinates of the rotor shaft and component axes, showing a component inclined to the rotor shaft axis

5.4 Assessment of balancing operation errors

The purpose of balancing is to produce rotors that are within specified limits of residual unbalance or vibration. To ensure that the set limits have been met, errors need to be controlled and taken into account.

When a balancing machine is used, various error sources exist, for example:

a) the type of rotor to be balanced;

b) the tooling used to support or drive the rotor;

c) the balancing machine support structure (e.g. machine bearings and cradles);

d) the balancing machine sensing system;

e) the electronic and read-out system.

However, it is important that in those cases where the error is taken into account by calculation, both the measured unbalance before correction and the corrected value are reported.

The balancing machine used should be such that all its systematic errors are eliminated or corrected. When balancing rotors that have a rigid behaviour at their balancing speed, the requirements of ISO 21940-21 apply.

5.5 Experimental assessment of randomly variable errors

5.5.1 General

If significant randomly variable errors are suspected to exist it is necessary, where practical, to carry out several measuring runs to assess their magnitude.

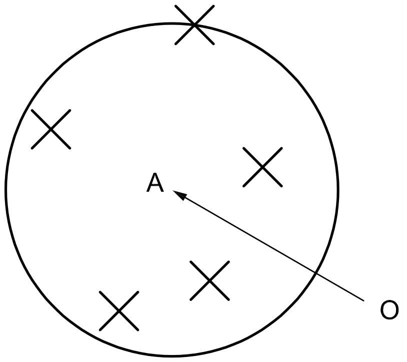
When carrying out measuring runs, it is important to ensure that the random errors are themselves produced randomly in each run (e.g. by ensuring that the angular position of the rotor is different at the start of each run).

The random error magnitude can be evaluated by applying standard statistical techniques to the measurement results obtained. However, in most cases, carrying out the procedure described in 5.5.2 is adequate.

5.5.2 Procedure

Plot the measured vectors of residual unbalance or vibration and find the mean vector $\overrightarrow{OA}$ from all the runs (see Figure 2). Draw the smallest circle about centre A to enclose all the points. The vector $\overrightarrow{OA}$ represents an estimation of the measured residual unbalance or vibration, and the radius of the circle an estimation of the maximum possible error of each single reading. The uncertainty of these results is usually diminished by increasing the number of runs carried out.

NOTE In some cases, particularly if one point is significantly different from the others, the error estimated can be unacceptably large. In this case, a more detailed analysis is necessary to determine the errors.



Plots of several measurements are indicated by ×.

Figure 2 — Plot of measured vectors of residual unbalance or vibration (randomly variable errors)