INTERNATIONAL STANDARD

ISO 1940-2

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Mechanical vibration — Balance quality requirements of rigid rotors —

Part 2:
Balance errors

Vibrations mécaniques — Exigences en matière de qualité dans l'équilibrage des rotors rigides —
Partie 2: Défauts d'équilibrage

Reference number
ISO 1940-2:1997(E)

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.

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.

International Standard ISO 1940-2 was prepared by Technical Committee ISO/TC 108, *Mechanical vibration and shock*, Subcommittee SC 1, *Balancing, including balancing machines.*

ISO 1940 consists of the following parts, under the general title *Mechanical vibration — Balance quality requirements of rigid rotors*:

— *Part 1: Determination of permissible residual unbalance*

— *Part 2: Balance errors*

Annexes A to C of this part of ISO 1940 are for information only.

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Introduction

The balance quality of a rigid rotor is assessed during the balancing operation in accordance with ISO 1940-1 by the measurement of residual unbalance. This measurement may contain errors which originate from a number of sources. It is therefore necessary to consider the errors involved. Where experience has shown that these are significant they should be taken into account when defining the balance quality of the rotor. ISO 1940-1 does not deal with balance errors in detail, and especially not with the assessment of balance errors, therefore this part of ISO 1940 gives examples of typical errors that can occur and provides recommended procedures for determining them. In addition generalized methods for evaluating the residual unbalance in the presence of balance errors are described.

Mechanical vibration — Balance quality requirements of rigid rotors —

Part 2:
Balance errors

1 Scope

This part of ISO 1940 covers the following:

- identification of errors in the balancing process of rigid rotors;
- assessment of errors;
- guidelines for taking errors into account;
- the evaluation of residual unbalance in any two correction planes.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this part of ISO 1940. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this part of ISO 1940 are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

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

ISO 1925:1990/Amd.1:1995, *Amendment 1 to ISO 1925:1990.*

ISO 1940-1:1986, *Mechanical vibration — Balance quality requirements of rigid rotors — Part 1: Determination of permissible residual unbalance.*

ISO 2953:1985, *Balancing machines — Description and evaluation.*

3 Definitions

For the purposes of this part of ISO 1940, the definitions given in ISO 1925 (and its Amendment 1) apply.

4 Sources of balance errors

Balance errors may be classified into one of the following groups:

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

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

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

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

Examples of the sources of errors which may occur are listed in 4.1, 4.2 and 4.3. Some of these errors are discussed in greater detail in annex A.

4.1 Systematic errors

The following are examples of the sources of systematic errors.

a) Inherent unbalance in the drive shaft of the balancing machine.

b) Inherent unbalance in the mandrel.

c) Radial and axial runout in the drive element on the rotor shaft axis.

d) Radial and axial runout in the rotor fit for components or in the mandrel (see subclause 5.3).

e) Lack of concentricity between 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 in the balancing machine.

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

h) Unbalance from keys and keyways.

i) Residual magnetism in rotor or mandrel.

j) Errors caused by re-assembly.

k) Errors caused by the balancing equipment and instrumentation.

l) Differences between service shaft and balancing mandrel diameters.

m) Defect in universal joints.

n) Permanent bend in a rotor after balancing.

4.2 Randomly variable errors

The following are examples of the sources of randomly variable errors.

a) Loose parts.

b) Entrapped liquids or solids.

c) Distorsion caused by thermal effects.

d) Windage effects.

e) Use of a loose coupling as drive element.

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

4.3 Scalar errors

The following are examples of the sources of scalar errors.

a) Clearance at interfaces which are to be disassembled after the balancing process.

b) Excessive clearance in universal joints.

c) Excessive clearance on 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 or nearly the same or have an integer ratio.

5 Assessment of errors

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. However, in the large majority of rotors initial unbalance exceeds the permitted levels given in ISO 1940-1, so that these rotors have to be balanced. Subclauses 5.2 to 5.6 deal with balance errors that may occur during this process.

5.2 Errors caused by balancing equipment and instrumentation

Balance errors caused by balancing equipment and instrumentation may increase with the amount of the unbalance present. Every attempt should therefore be made to design a symmetrical rotor. Furthermore, by considering unbalance causes during the design stage, some causes can be eliminated altogether, e.g. by combining several parts into one, or reduced by decreased fit tolerances. The cost of tighter tolerances must be weighed against the benefit of decreased unbalance causes. Where such causes cannot be eliminated or reduced to negligible levels, they should be mathematically evaluated.

5.3 Balance errors caused by radial and axial runout of fits for components

When a perfectly balanced rotor component is mounted eccentric to the rotor shaft axis, the resulting static unbalance U_S equals the mass m of the component multiplied by the eccentricity e:

$$U_S = m \cdot e \qquad \dots (1)$$

An additional unbalance couple results if the component is mounted eccentrically in a plane other than the plane of the rotor centre of mass. The larger the plane distance from the centre of mass, the larger will be the induced unbalance couple.

If a perfectly balanced component is mounted such that its principal axis of inertia is inclined to the rotor shaft axis but its centre of mass remains on the rotor shaft axis, an unbalance couple will result. For small angular displacement $\Delta\gamma$ between the two axes, the resulting unbalance couple D_{c} is nearly equal to the difference between the moment of inertia about a transverse axis through the component centre of mass, I_x, and the moment of inertia about its principal axis of inertia, I_z, multiplied by the angle $\Delta\gamma$ in radians:

$$D_{\mathrm{c}} \approx \left(I_x - I_z\right) \cdot \Delta\gamma \qquad \ldots (2)$$

This statement is only valid if the component presents rotational symmetry. Equation (2) is therefore particularly applicable to the balancing of disks on arbors.

If both radial and axial runout of the component occur, each error can be calculated separately in its allocated value in the bearing or correction planes and then be combined vectorially (see also ISO 1940-1:1986, figure 1).

5.4 Assessment of errors in the balancing operation

The purpose of balancing is to produce rotors that are within specified limits of residual unbalance. To ensure that the limits have been met, errors should be controlled and accounted for in the residual unbalance measurements.

When a balancing machine is used, various sources of errors exist, namely the type of rotor to be balanced, any tooling used to support or drive the rotor, the balancing machine support structure (machine bearings, cradles etc.), the balancing machine sensing system, and the electronics and read-out system. Any or all of these sources can contribute errors. By recognizing the characteristics of most errors, it may be possible to focus on their causes and either correct them, minimize them or take them into account in the assessment of residual unbalance by calculating their effects.

The balancing machine used should conform to ISO 2953, such that all its systematic errors are eliminated or corrected, and its randomly variable errors are limited to U_{mar} as defined in ISO 2953. Where the assessment is carried out in the balancing machine, and the rotor mass or measuring plane positions differ significantly from those for the proving rotor used in the balancing machine tests, further testing should be carried out with the actual workpiece to determine the minimum achievable residual unbalance at the specified measuring planes on the workpiece.

5.5 Experimental assessment of randomly variable errors

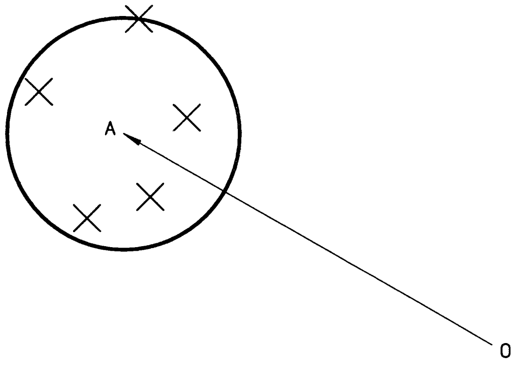
If significant randomly variable errors are suspected it is necessary to carry out several measuring runs to assess the magnitude of these errors.

In doing so it is important to ensure that the random errors are produced randomly in each run (e.g. by ensuring that the angular position of the rotor is different for the start of each run).

The magnitude of the error can be evaluated by applying standard statistical techniques to the results obtained. However, in most cases the following approximate procedure will be adequate.

Plot the measured residual unbalance vectors and find the mean vector $\overrightarrow{\mathrm{OA}}$ from all the runs (see figure 1). Draw the smallest circle about centre A to enclose all the points. The vector $\overrightarrow{\mathrm{OA}}$ represents an estimation of the residual unbalance and the radius of the circle an estimation of the maximum possible error of each single reading. The uncertainty of these results will usually be 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 may be unacceptably large. In this case a more detailed analysis will be necessary to determine the errors.



Plots of several measurements are indicated by ×.

Figure 1 — Plot of measured residual unbalance vectors (randomly variable errors)

5.6 Experimental assessment of systematic errors

In many cases most of the systematic errors can be found using index balancing. This involves carrying out the following procedure. Mount the rotor alternately at 0° and 180° relative to the item which is the source of a particular error. Measure the unbalances several times in both positions. If $\overrightarrow{OA}$ and $\overrightarrow{OB}$, as shown in figure 2, represent the mean unbalance vectors with the rotor mounted at 0° and 180° respectively, a diagram can be constructed for each measurement plane where C is the mid-point of the distance AB. The vector $\overrightarrow{OC}$ represents the particular systematic error and the vectors $\overrightarrow{CA}$ and $\overrightarrow{CB}$ represent the rotor residual unbalance with the rotor at 0° and 180°, respectively.

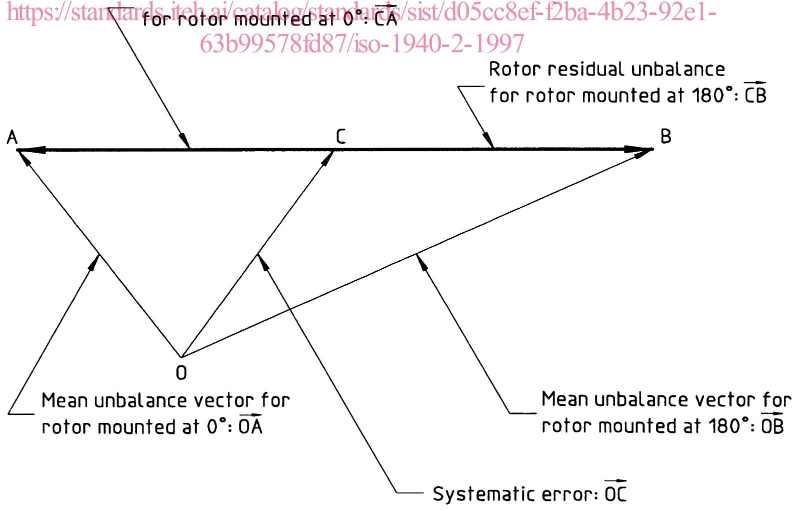


Figure 2 — Plot of measured residual unbalance vectors and systematic error

NOTE — In this case it has been assumed that the rotor has been turned relative to the phase reference. If, however, the phase reference remains fixed relative to the rotor:

— the vector $\overrightarrow{OC}$ represents the rotor residual unbalance; and

— the vectors $\overrightarrow{CA}$ and $\overrightarrow{CB}$ represent the particular systematic error with the phase reference at 0° and 180°, respectively.

6 Evaluation of combined error

Systematic errors whose magnitude and phase are known may be eliminated, for example, by applying temporary correction masses to the tooling or the rotor during the balancing process or by mathematically correcting the results. If the systematic errors are not corrected or not correctable in either of these ways, they should be combined as shown below with randomly variable errors and scalar errors.

Let

$\left|\Delta\vec{U}_i\right|$ be the amount of an uncorrected error from any source, preferably assessed with sufficient confidence limit,

ΔU be the amount of the combined uncorrected errors.

Then the following formula

$$\Delta U = \Sigma\left|\Delta\vec{U}_i\right| \qquad \text{... (3)}$$

is the one that gives the safest evaluation of errors. It guarantees that, even in case of the most unfavourable error combination, the rotor is acceptable, provided the criteria of clause 7 are met.

The formula $\Delta U = \Sigma\left|\Delta\vec{U}_i\right|$ is based upon the most pessimistic assumption that all the uncorrected errors fall into the same angular direction and their absolute numerical values should therefore be summed up.

If it is found that, after applying this formula and then inserting the value ΔU in the formula given in clause 7, the combined uncorrected error would cause the rotor to be out of tolerance, then an attempt to reduce the more significant errors is recommended.

In some cases a more realistic approach may be used. It takes into account that not all errors from various sources are likely to fall into the same angular direction. Then, the combined error ΔU may be evaluated by using the "root of the sum of the squares" formula

$$\Delta U = \sqrt{\Sigma\left|\Delta\vec{U}_i\right|^2} \qquad \text{... (4)}$$

The above procedures should be carried out for each measuring plane.

Under appropriate conditions the errors are evaluated by measurements on a significant sample of rotors. It is then assumed that errors of the same magnitude will be present on all similar rotors which have been manufactured and assembled in the same way.

For mass-produced rotors, a statistically based process for finding the combined error may need to be agreed upon between user and supplier.

7 Acceptance criteria

For each measuring plane, let

U_{per} be the magnitude of the permissible residual unbalance obtained from ISO 1940-1;

U_{rm} be the magnitude of the measured residual unbalance of a single reading after corrections have been carried out for systematic errors of known amount and angle;

ΔU be the magnitude of the combined error as defined in clause 6.

The rotor balance shall be considered acceptable by the manufacturer if the following condition is satisfied:

$$U_{\mathrm{rm}} \leqslant U_{\mathrm{per}} - \Delta U \qquad \ldots (5)$$

If ΔU is found to be less than 5 % of U_{per}, it may be disregarded.

If an additional balance check is performed by the user the rotor balance shall be accepted if

$$U_{\mathrm{rm}} \leqslant U_{\mathrm{per}} + \Delta U \qquad \ldots (6)$$

If this condition is not met, the balancing procedures may need to be reviewed or repeated.

NOTE — If a change of unbalance during transportation of the rotor is expected, this should also be taken into consideration.

8 Determination of residual unbalances

Clause 8 of ISO 1940-1:1986 describes methods for the determination of residual unbalance in a rigid rotor. The most important methods are:

a) the method set out in subclause 8.1; it requires a balancing machine according to ISO 2953;

b) the method set out in subclause 8.2; it requires an instrument reading amplitude and phase. Where two-plane balancing is required an additional procedure for plane separation is needed; for example a computer with an algorithm for the influence coefficient method. Annex B provides typical data which could be used to check such an algorithm.

NOTE — In most practical cases the two methods referred to above are adequate. However, if there is doubt about the procedures, improved accuracy could be obtained by using known trial masses at different angular positions in both planes. There are a number of possible ways of doing this; the method referred to in subclause 8.3, ISO 1940-1:1986, applied to two planes, is one such method. If there is concern about the linearity of the response to unbalance, the procedure should be repeated using trial unbalances of different amounts.