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Mechanical vibration — Balancing — Guidance on the use and application of balancing standards

Vibrations mécaniques — Équilibrage — Lignes directrices pour l'utilisation et l'application de normes d'équilibrage

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Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
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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.

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Introduction

Vibration caused by rotor unbalance is one of the most critical issues in the design and maintenance of machines. It gives rise to dynamic forces which adversely impact both machine and human health and well-being. The purpose of this International Standard is to provide a common framework for balancing rotors so that appropriate methods will be used. This standard serves essentially as guidance on the usage of other International Standards on balancing in that it categorizes types of machine unbalance. As such, it can be viewed as an introductory standard to the series of International Standards on balancing developed by ISO/TC 108.

Balancing is explained in a general manner, as well as the unbalance of a rotor. A certain representation of the unbalance is recommended for an easier understanding of the necessary unbalance corrections.

Mechanical vibration — Balancing — Guidance on the use and application of balancing standards

1 Scope

This International Standard provides an introduction to balancing and directs the user through the available International Standards associated with rotor balancing. It gives guidance on which of these standards should be used. Individual procedures are not included here as these will be found in the appropriate International Standards.

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 1925:2001, *Mechanical vibration — Balancing — Vocabulary*

ISO 2041, *Vibration and shock — Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 1925 and ISO 2041 apply.

4 Fundamentals of balancing

4.1 General

Balancing is a procedure by which the mass distribution of a rotor (or part or module) is checked and, if necessary, adjusted to ensure that balance tolerances are met.

Rotor unbalance may be caused by many factors, including material, manufacture and assembly, wear during operation, debris or an operational event. It is important to understand that every rotor, even in series production, has an individual unbalance distribution.

New rotors are commonly balanced by the manufacturer in specially designed balancing machines before installation into their operational environment. Following rework or repair, rotors may be rebalanced in a balancing machine or, if appropriate facilities are not available, the rotor may be balanced *in situ* (see ISO 20806 for details). In the latter case, the rotor is held in its normal service bearings and support structure and installed within its operational drive train.

The unbalance on the rotor generates centrifugal forces when it is rotated in a balancing machine or *in situ*. These forces may be directly measured by force gauges mounted on the structures supporting the bearings or indirectly by measuring either the motion of the pedestal or the shaft. From these measurements, the unbalance can be calculated and balancing achieved by adding, removing or shifting of correction masses on the rotor. Depending on the particular balancing task, the corrections are performed in one, two or more correction planes.

4.2 Unbalance distribution

In reality, unbalance is made up of an infinite number of unbalance vectors, distributed along the shaft axis of the rotor. If a lumped-mass model is used to represent the rotor, unbalance may be represented by a finite number of unbalance vectors of different magnitude and angular direction as illustrated in Figure 1.

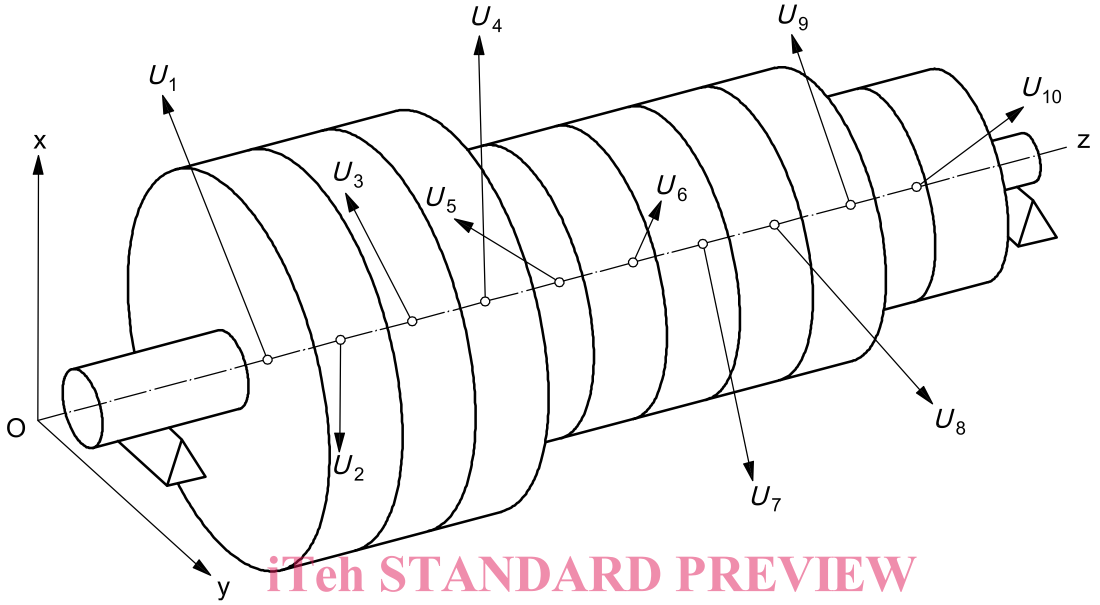


Figure 1 — Unbalance distribution in a rotor modelled as 10 elements perpendicular to the z-axis

If all unbalance vectors were corrected in their respective planes, then the rotor would be perfectly balanced. In practice, it is not possible to measure these individual unbalances and it is not necessary. A more condensed description is needed, leading to practical balancing procedures.

4.3 Unbalance representation

Rotor unbalance can be expressed by a combination of the following three kinds of unbalance representations:

a) resultant unbalance, $\vec{U}_{\mathrm{r}}$, the vector sum of all unbalance vectors distributed along the rotor;

b) resultant moment unbalance, $\vec{P}_{\mathrm{r}}$, the vector sum of the moments of all the unbalance vectors distributed along the rotor about the arbitrarily selected plane of the resultant unbalance;

c) modal unbalance, $\vec{U}_n$, that unbalance distribution which affects only the nth natural mode of a rotor/bearing system.

Mathematical and graphical representations of unbalances are shown in Annex A.

NOTE Resultant unbalance [see 4.3 a)] and resultant moment unbalance [see 4.3 b)] can be combined. The combination is called “dynamic unbalance” and is represented by two unbalances in two arbitrarily chosen planes perpendicular to the shaft axis.

5 Balancing considerations

5.1 General

In the past, International Standards classified all rotors to be either rigid or flexible, and balancing procedures for these two main classes of rotors are given in ISO 1940-1 and ISO 11342, respectively (see Table 1). However, the simple rigid/flexible classification is a gross simplification, which can lead to a misinterpretation and suggests that the balance classification of the rotor is only dependent on its physical construction. Unbalance is an intrinsic property of the rotor, but the behaviour of the rotor and its response to unbalance in its normal operating environment are affected by the dynamics of the bearings and support structure, and by its operating speed. Furthermore, the balance quality to which the rotor is expected to run and the magnitude and distribution of the initial unbalance along the rotor will dictate which balancing procedure is necessary; see Table 1.

Table 1 — Overview of rotor behaviour, related International Standards and balancing procedures

Rotor behaviour (Numbers refer to subclauses in this International Standard)	**Example**	**Related International Standard**	**Balancing task or procedure** (Letters as used in ISO 11342:1998)
Rigid behaviour (5.2)	Figure 4 a)	ISO 1940-1	One- and two-plane balancing [a]
Flexible behaviour (5.3)	Figure 4 b)	ISO 11342 [b]	Six low-speed balancing procedures (A to F) Balancing procedure at multiple speeds (G) Balancing procedure for one speed only (usually service speed) (H)
Component elastic behaviour (5.4.2)	Figure 4 c)		Fixed-speed balancing procedure (I)
Component seating behaviour (5.4.3)	Figure 4 d)		Settling of components at high speed [c]

[a] One- and two-plane balancing includes balancing the resultant unbalance and the resultant moment unbalance.

[b] ISO 11342:1998 uses “flexible” as a generic term that includes flexible, component elastic and component seating behaviours.

[c] This procedure is mentioned in Clause 7 of ISO 11342:1998, but no designated letter is given.

5.2 Rotors with rigid behaviour

An ideal rotor when rotating, with rigid behaviour on elastic supports, will undergo displacements that are combinations of the two dynamic rigid-body modes, as seen in Figure 2 for a simple symmetric rotor with unbalance. There is no flexure of the rotor and all displacements of the rotor arise from movements of the bearings and their support structure.

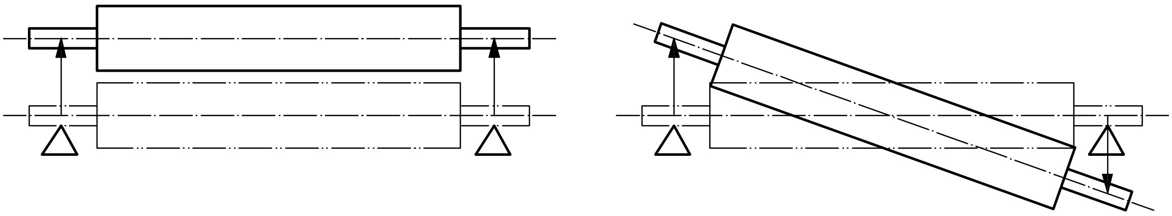


Figure 2 — Rigid-body modes of a symmetric rotor on a symmetric elastic support structure

In reality, no rotor will be totally rigid and will have small flexural deflections in relation to the gross rigid-body motion of the rotor. However, the rotor may be regarded as rigid provided these deflections caused by a given unbalance distribution are below the required tolerances at any speed up to the maximum service speed. The majority of such rotors, and indeed many manufactured rotors, can be balanced as rigid rotors, in accordance with the requirements of ISO 1940-1. This aims at balancing the resultant unbalance with at least a single-plane balance correction, or the dynamic unbalance with a two-plane balance correction.

NOTE Rotors designated to have rigid behaviour in the operating environment can be balanced at any speed on the balancing machine provided the speed is sufficiently low to ensure the rotor still operates with a rigid behaviour.

5.3 Rotors with flexible behaviour

5.3.1 General

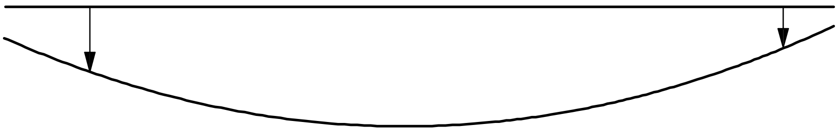
If the speed is increased or the tolerance reduced for the same rotor described in 5.2, it may become necessary to take flexible behaviour into account. Here the deflection of the rotor is significant, and rigid-body balancing procedures are not sufficient to achieve a desired balance condition. Figure 3 shows typical flexural mode shapes for a symmetric rotor. For these rotors that exhibit flexural behaviour, the balancing procedures in ISO 11342 should be adopted.

5.3.2 Low-speed balancing

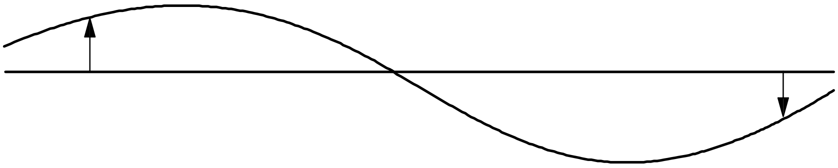
In special circumstances, even rotors with flexible behaviour may be balanced satisfactorily at low speed. ISO 11342:1998 describes procedures A to F, which, as far as possible, all aim to correct the unbalance in their planes of origin.

5.3.3 Multiple-speed balancing

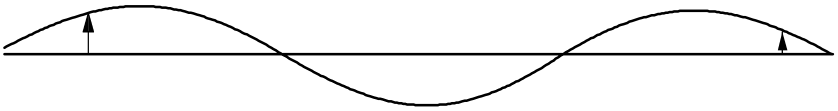
This procedure should be used to balance the resultant unbalance, the resultant moment unbalance and the relevant modal unbalances, according to ISO 11342:1998, procedure G.



a) First mode



b) Second mode



c) Third mode

Figure 3 — Schematic representation of the first three flexural modes of a rotor with flexible behaviour on an elastic support structure

5.3.4 Service speed balancing

These rotors are flexible and pass through one or more critical speeds on their way up to service speed. However, due to operating conditions or machine construction, high levels of vibration can be tolerated at the critical speeds and the rotor is only balanced at the service speed according to ISO 11342:1998, procedure H.

5.4 Rotors with special behaviour

5.4.1 General

The majority of rotors will exhibit either rigid or flexible behaviours, but the following special behaviours can exist and must be considered to achieve a successful balancing of the rotor.

5.4.2 Elastic behaviour of components

These rotors can have a shaft and body construction that either requires low-speed or high-speed balancing procedures. However, in addition, they have one or more components that themselves are either flexible or are flexibly mounted so that the unbalance of the whole system might consistently change with speed. Examples of such rotors are a rotor with tie bars that deflect at high speed, rubber-bladed fans and single-phase induction motors with a centrifugal switch. These should be balanced in accordance with ISO 11342:1998, procedure I.

5.4.3 Seating behaviour of components

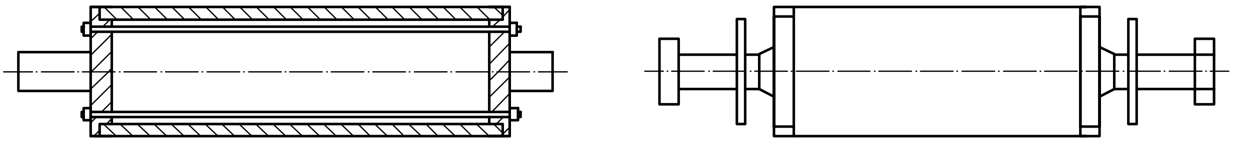
These rotors can have a construction where components settle after reaching a certain speed or other condition. This movement will then become stable after one or just a few events. The components will reach a final position and become re-seated, after which the rotor may require further balancing. Examples are shrunk-on turbine discs, built-up rotors, copper winding in generators and generator retaining rings. Subsequent behaviour of the rotor will then dictate the balancing procedure required. This rotor behaviour is mentioned in Clause 7 of ISO 11342:1998, but no procedure is specified.

5.5 Examples of rotor behaviours

The different behaviours may be represented by the following rotors (see Figure 4):

a) Rigid behaviour (a solid gear wheel)

b) Flexible behaviour (a disc on an elastic shaft, for example a Laval rotor)



c) Component elastic behaviour (a drum with tie bars, elastically deflecting under the centrifugal load)

d) Seating behaviour (a generator rotor with windings, once for all seating under a certain centrifugal load)

Figure 4 — Examples of rotor types that demonstrate particular rotor behaviours

Such illustrations are not sufficient for a full description: obviously, rotors such as those shown in Figures 4 c) and 4 d) may also show flexible behaviour; on the contrary, a rotor such as Figure 4 b) could be a low-speed fan without considerable flexible behaviour, i.e. a rotor with a rigid behaviour. Details of these types of behaviour are further explained in Annex B.

5.6 Influencing factors

5.6.1 General

A rotor's response characteristic is defined by its physical properties and those of its supporting structure. The vibration response measured at the supporting structure or on the rotor will depend on these physical properties plus the magnitude of unbalance and its distribution along the rotor, as well as the speed of rotation. Balancing to a required tolerance will therefore depend on all these parameters, and changing these or the tolerance specified may change the procedure needed to meet that tolerance.

5.6.2 Tolerances

By simply reducing the balance tolerance, it may be necessary to reconsider the behaviour of the rotor and adopt a different procedure to bring the rotor within tolerance, as given in the following examples.

a) A rotor with rigid behaviour, balanced using a single-plane procedure to reduce resultant unbalance, may simply require additional more accurate single-plane balancing.

b) A rotor with rigid behaviour, balanced using a single-plane procedure to reduce resultant unbalance, may also require a two-plane procedure to take into account the moment unbalance (or both resultant and moment unbalance together as a dynamic unbalance).

c) A rotor with rigid behaviour, balanced in two planes to reduce both resultant and moment unbalance (or both resultant and moment unbalance together as a dynamic unbalance), may additionally require flexible behaviour procedures to reduce contributions from the modal unbalances, even though the rotor is running below its first flexural critical speed.

d) A rotor with flexible behaviour, for which a flexible rotor behaviour procedure has been carried out to reduce the dynamic unbalance and a number of modal unbalances, may require additional flexible rotor behaviour procedures to reduce modal unbalances of even more (higher) flexural modes of the rotor, even though the rotor is running below the flexural critical speeds of the higher modes.

e) A rotor with either rigid or flexible behaviour, successfully balanced using the appropriate procedure, may need to consider special procedures to take into account component elastic or component seating behaviours.

f) Where a tighter tolerance can only be achieved at a single speed, the service speed balancing procedure may need to be considered.

5.6.3 Speed and support conditions

Other changes of rotor behaviour may occur if operational conditions are changed (e.g. by changing speed or support conditions).

5.6.4 Initial unbalance

The initial unbalance distribution has an influence on the response of the rotor system. It determines which unbalance (see Clause 4) is out of tolerance and therefore needs treatment. Different manufacturing and assembling procedures can lead to different levels of initial unbalance.

6 Balance tolerances

6.1 General

The balancing equipment and techniques available enable unbalances to be reduced to low limits. However, it would be uneconomic to over-specify the quality requirements. It is therefore necessary to define the optimum balance quality for the rotor to operate with acceptable vibration and dynamic forces in its normal service environment.

6.2 Permissible residual unbalances

There is a direct relation between rotor unbalance and the once-per-revolution vibration under service conditions. The relationship depends on the machine's dynamic characteristics (i.e. rotor, structure and bearing dynamic properties). However, the overall machine vibration may be due only in part to the presence of rotor unbalance. Other sources of vibration could be magnetic or fluid forces.

Guidance on the derivation of permissible residual unbalance tolerances is given in

- ISO 1940-1 for a rigid rotor behaviour, and
- ISO 11342, using tolerance data from ISO 1940-1, for other rotor behaviours.

6.3 Vibration limits

There is no easily recognizable relationship between the machine vibration under service conditions and vibration in the balancing machine. The relation depends on the differences between the bearings and the support structure used in the balancing machine and installed condition. Further, the rotor in the balancing machine is tested in isolation and does not include effects from other rotors in the shaft line, as experienced when installed in its operational environment. It should be noted that different balancing machines may have different pedestal stiffness and therefore vibration limits have to be set individually for each balancing machine.

Where detailed information is available concerning these parameters, a method to estimate these limits is presented in ISO 11342. *In-situ* vibration limits are presented in the appropriate parts of ISO 7919 for rotating shafts and ISO 10816 for non-rotating parts.

Where insufficient detail is available to obtain these parameters, guidance should be taken from the balancing machine facility from which rotors have operated satisfactorily *in situ*.

7 Selection of a balancing procedure

7.1 General

Since different balancing procedures require different types of balancing machines and resource input, it is important to select an appropriate procedure (see Table 1) to optimize the balancing process to meet the required balance tolerances.

Rotors with a **rigid behaviour** (see 5.2) can be balanced using the single- and two-plane balancing guidelines provided in ISO 1940-1.

In general, rotors with a **flexible behaviour** (see 5.3) should be dealt with in accordance with the guidelines given in ISO 11342, where a number of procedures are defined for different rotor configurations:

- the general procedure is that for multiple-speed balancing, see 5.3.3 (procedure G of ISO 11342:1998);
- rotors that spend most of their time at a single speed can use service speed balancing (see 5.3.4; (procedure H of ISO 11342:1998);