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:

$$D_c \approx (I_x - I_z) \cdot \Delta\gamma \qquad \text{... (2)}$$

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

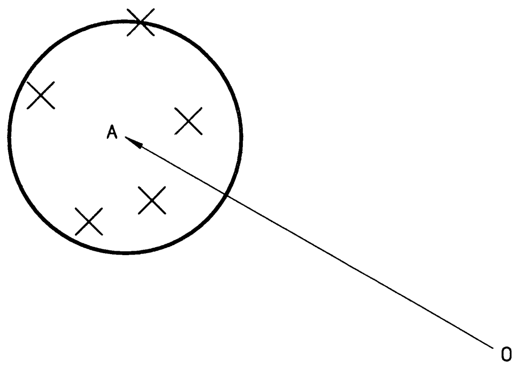
If significant randomly variable errors are suspected it is necessary to carry out several measuring runs to assess the magnitude of these errors.

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 $\overrightarrow{OA}$ from all the runs (see figure 1). Draw the smallest circle about centre A to enclose all the points. The vector $\overrightarrow{OA}$ 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.

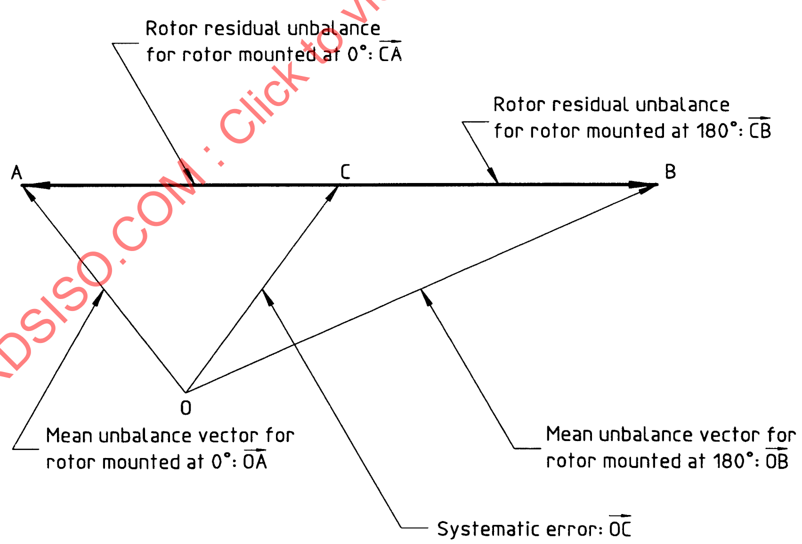


Figure 2 — Plot of measured residual unbalance vectors and systematic error

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:

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

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

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

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.

Annex A
(informative)

Examples of errors, their identification and evaluation

A.1 Errors originating from auxiliary equipment

Examples of errors associated with residual unbalances and originating from auxiliary equipment are discussed below and summarized in table A.1. See figures A.1, A.2 and A.3.

A.1.1 Errors originating from inherent unbalance and eccentricity in drive element, mandrel, etc.

These errors can be evaluated by index balancing. This procedure can be complicated by non-repeatability of mechanical fits (see A.1.3) and workpiece errors (see clause A.2).

A.1.2 Errors originating from bearings

If rolling element bearings are fitted for a balancing operation they will introduce an error proportional to the eccentricity or angular misalignment of the rotating races (and their tracks) and the rotor mass. This error may be determined by indexing the bearing races 180° on their mounting surfaces.

NOTE — In the context of this item, eccentricity is assumed to result from radial and/or axial runout.

A.1.3 Errors originating from mechanical fits

Mechanical fits can be a potential source of error, e.g. a change of unbalance may result from re-assembly.

There are many possible sources of errors from fits, for example if there is radial clearance or if the interference is too great or if the connecting bolts interfere with the spigot/pilot location.

The scatter caused by non-repeatability of fits should be determined by a repeated re-assembly, with clearances taken up at different angles. Each time unbalance readings are taken and a mean value is obtained.

A.1.4 Errors associated with the mass of balancing equipment

The mass of the rotating tooling for balancing (however, not necessarily the mandrel) should be reduced to a minimum to reduce the error resulting from spigot /pilot clearances or runouts.

Reducing the mandrel mass increases the sensitivity of a soft bearing machine but normally produces little benefit on a hard bearing machine.

A.2 Errors originating from the workpiece

Examples of errors associated with residual unbalances and originating from the workpiece are discussed below and summarized in table A.1. See figure A.2.

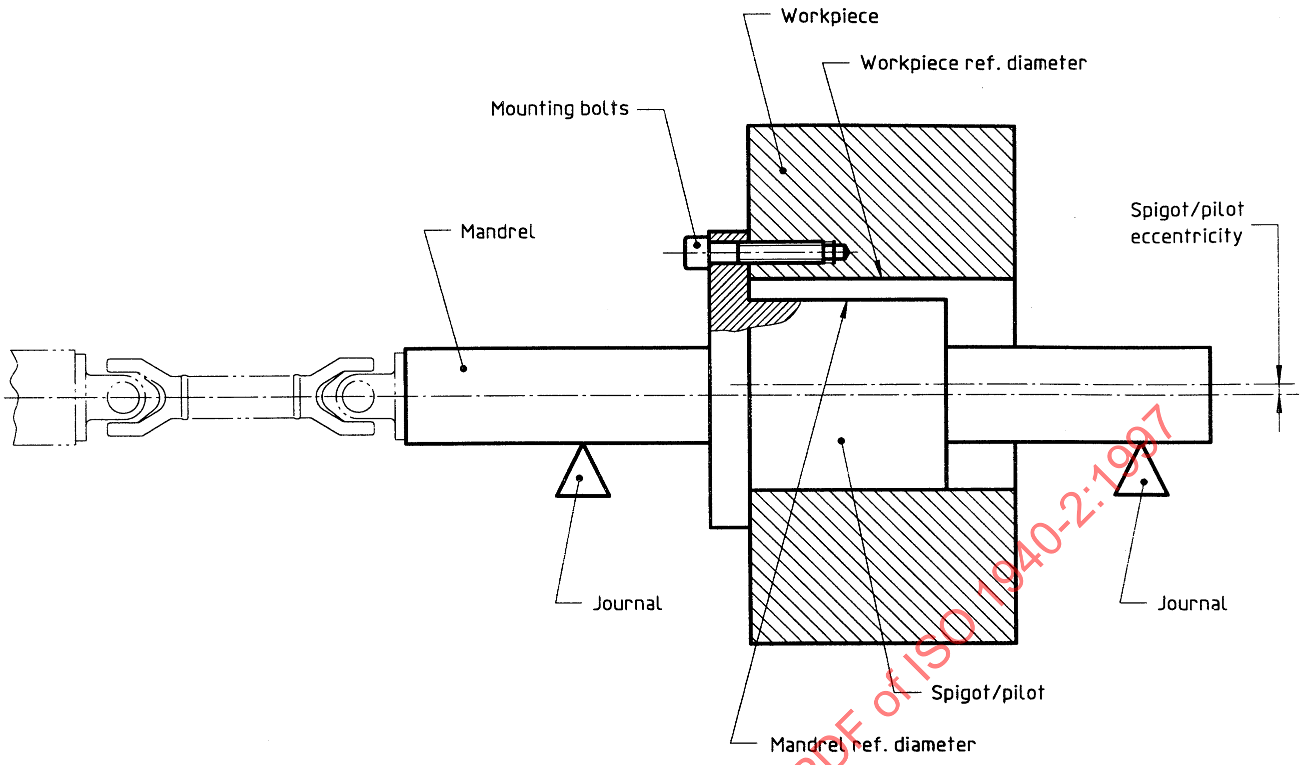


Figure A.1 — Workpiece located on mandrel

A.2.1 Errors originating from loose parts

The error caused by loose parts can be obtained by starting and stopping the rotor, ensuring that the angular position of the rotor is different at the start of each run, and taking a reading for each run. The error and mean unbalance can be found using the method described in subclause 5.5. Changing the direction of rotation may be helpful in certain cases, but should be undertaken with caution. It should be noted that on certain machines the effect of loose parts may only become apparent under actual service conditions.

A.2.2 Errors originating from presence of entrapped liquids or small loose particles

Where the presence of entrapped liquids or loose particles is suspected and cannot be avoided, the rotor should be left standing with 0° at the top for a period of time, started again, and then a reading taken. This is repeated having the 90°, 180° and 270° position of the rotor successively at the top. The method of subclause 5.5 can then be applied to find the error and the mean unbalance.

Results should be examined to avoid confusion with thermal effects (see A.2.3) e.g. due to the rotor standing still for some time.

A.2.3 Errors originating from thermal effects

Distortion and the resulting unbalance caused by non-uniform temperatures is particularly noticeable in long or tubular rotors.

These errors can be reduced by not allowing the rotor to remain stationary in the balancing machine for even relatively short periods or by running the rotor until the unbalance vector has stabilized. This may be done at a very low speed, e.g. 5 r/min to 10 r/min.

Welding or heat-generating machining operations for unbalance correction may result in significant rotor distortion. Dissipation of the localized heat and/or certain stabilizing running periods are usually required to equalize the temperature in the rotor and restore it to its normal shape.

A.2.4 Errors originating from bearings

The rotating bearing races should, in operation, retain the angular relationship to the rotor they had during the balancing operation. Otherwise errors similar to those described in A.1.2 can occur.

Spurious couple unbalance readings in both soft and hard bearing balancing machines can, for example, result from axial runout of the rotating thrust face, from a ball bearing being tilted relative to the shaft axis, or from a bent rotor etc.

These effects can be demonstrated and the error evaluated by running the rotor at different speeds, n_1 and n_2, as follows:

a) For a hard bearing balancing machine, the axial runout effects may be found in unbalance units, as $\Delta\vec{U}_{1L}$, $\Delta\vec{U}_{1R}$ at speed n_1:

$$\Delta\vec{U}_{1L} = \frac{1}{1-(n_1/n_2)^2}\left(\vec{U}_{1L} - \vec{U}_{2L}\right) \quad \text{... (7)}$$

$$\Delta\vec{U}_{1R} = \frac{1}{1-(n_1/n_2)^2}\left(\vec{U}_{1R} - \vec{U}_{2R}\right) \quad \text{... (8)}$$

where $\vec{U}_{1L}, \vec{U}_{1R}, \vec{U}_{2L}, \vec{U}_{2R}$ are the readings caused by the sum of the unbalance-simulating effects of axial runout and the (residual) unbalances $\vec{U}_L$, $\vec{U}_R$ in the left and right planes at the speeds n_1 and n_2 respectively.

The machine should be calibrated in the same unbalance units for each of these speeds and planes.

b) For a soft bearing machine the unbalance simulating effect depends on the vibratory masses in the soft bearing machine suspension system and is, therefore, inversely proportional to the square of the speed. Thus the same formulae result.

In these calculations, it is assumed that the <u>forces on the bearings</u> of a hard bearing balancing machine caused by axial runout of a rotating thrust face are independent of speed, whereas in a soft bearing machine, the <u>bearing vibrations</u> caused by unbalance are independent of speed.

The above formulae hold true only if measurements are taken at a speed far enough away from the resonance speed of the rotor and/or the balancing machine.

Similar effects can be observed at very low balancing speeds when bent rotor journals are mounted on open rollers or when the supports of a balancing machine with flat roller surfaces lack vertical axis freedom. These errors can be minimized by appropriate design of the balancing machine support structure. In some cases the error caused by axial runout of the thrust face can be avoided by adjustment of the thrust bearing.

A.2.5 Errors originating from mechanical fits

Unbalance may change in operation owing to the design or improper assembly of a fit. It may also change if the rotor is partially disassembled after balancing and re-assembled (refer also to A.1.3.)

A.2.6 Errors originating from runout of end-drive mounting surface

Where the balancing machine end-drive shaft is attached to an eccentric spigot/pilot at the end of the rotor, an error will be introduced which cannot be detected by index balancing. It can only be calculated knowing the effective drive mass and the spigot/pilot eccentricity vector relative to the rotor shaft axis. If necessary, temporary compensation can be applied at the appropriate angle during balancing.

A.2.7 Errors originating from magnetic effects

Magnetic effects may primarily manifest themselves in the balancing machine by causing an erroneous unbalance read-out if their frequency is at or near the rotational frequency.

For instance, this may be due to the rotor's magnetic field wiping across the balancing machine's pick-ups at a once-per-revolution frequency. The influence of a magnetized rotor is best eliminated either by shielding the pick-ups or by selecting, on a hard bearing balancing machine, a sufficiently higher balancing speed, where the influence is no longer significant. The presence of magnetic effects is best discovered by taking unbalance readings at different speeds at which the rotor is rigid.

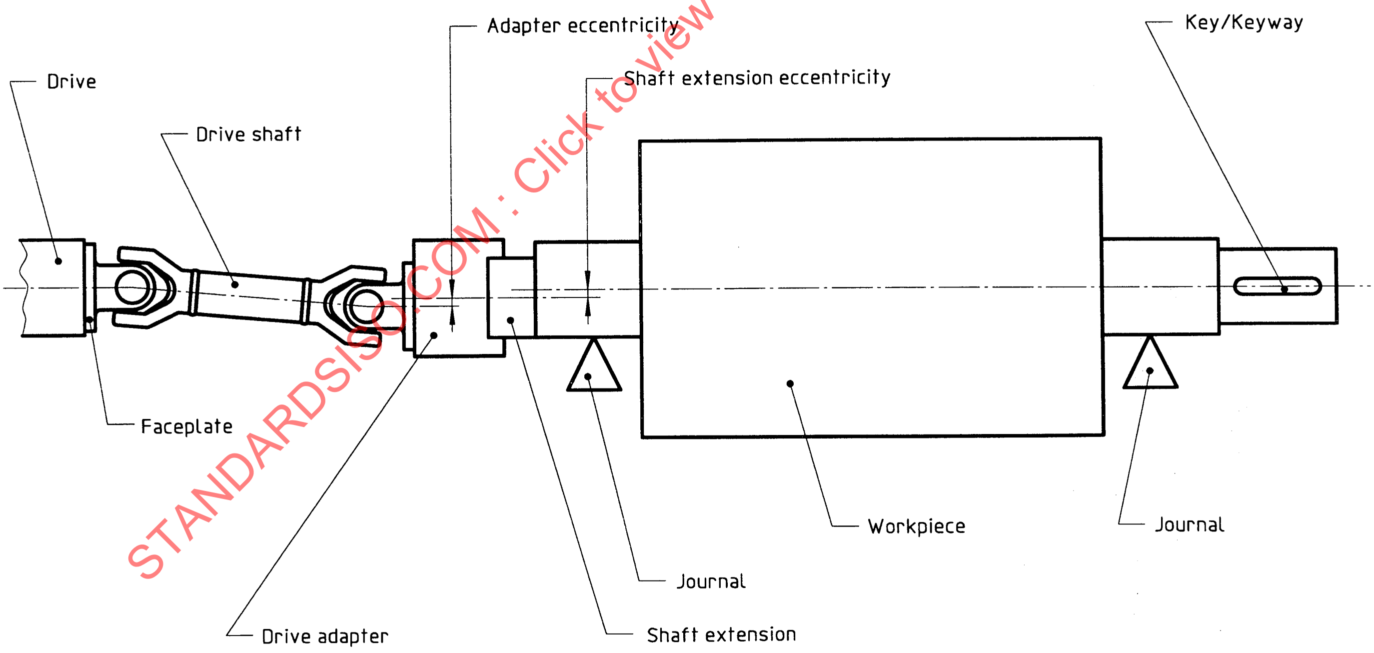


Figure A.2 — Workpiece located on its own journals

Table A.1 — Examples of errors and methods for reduction and assessment

Origin of the error	Description of the source of error	Method for reduction of the unbalance error	Assessment of the unbalance error			Refer to clause
			Experiment (for systematic error)	Experiment (for random error)	Other method(s)	
Balancing machine	Measuring equipment systematic and random errors	Check machine calibration and operation; correct if necessary. Recalibrate or repair machine			Refer to ISO 2953[1)]	5.2 5.4 to 5.6
Auxiliary equipment	Unbalance in drive element	Balance auxiliary equipment	Applicable, rotor being shifted 180° relative to drive element or mandrel. Error amount and phase obtained are global	Possible, but index balancing more economical	Measure error amount and phase by separate balancing of item[2)]	A.1.1 A.1.3
	Unbalance in mandrel (or stub shaft)	Balance mandrel (or stub shaft) or other auxiliary equipment more finely. Reduce mass of auxiliary equipment				
	Radial and axial runout in drive element	Balance or repair drive element				
	Radial and axial runout in mandrel (or stub shaft)	Repair or compensate with bias mass or compensator				
	Eccentricity of slave rolling element bearing	Balance with service bearing in place. If removal is required for rotor assembly into housing match mark bearing inner races to shaft	Applicable, refitting one bearing at the time after turning 180°			A.1.2
Rotor	Loose parts, e.g. compressor rotor blades	Make several start-and-stop runs and take average unbalance readings; correct average unbalance		Applicable, starting the rotor from a different stopping position for each run		A.2.1
	Presence of entrapped liquids or solids	Remove the liquids or solids; if not possible make several start-and-stop runs and correct the average unbalance		Applicable, but approximately half an hour stop between each run[3)]		A..2.2
	Thermal and gravitational effects	Run rotor until stabilized before balancing. Do not allow the rotor to remain stationary in the balancing machine for long periods		Applicable, but these effects are to be reduced as much as possible[3)]		A.2.3

Table A.1 *(end)*

Origin of the error	Description of the source of error	Method for reduction of the unbalance error	Assessment of the unbalance error			Refer to clause
			Experiment (for systematic error)	Experiment (for random error)	Other method(s)	
Rotor	Windage effects	Enclose rotor or cover intake openings, or run rotor backwards			Compare measurements at different running speeds	
	Magnetic effects (i.e. magnetized rotor)	Demagnetize rotor, select higher balancing speed to minimize magnetic effects			Measure error amount and phase in low-speed run	A.2.7
	Tilted service ball bearings	Straighten out races on shaft, remachine shaft shoulders. Reduce these effects by reducing the resistance of the saddle to spherical movements, if possible			Compare measurement at different running speeds	A.2.4
	Poor journal surface finish; inadequate lubrication	Remachine journals, lubricate				
	Misalignment (rotors with more than two bearings)	Balance in two bearings only (one per support), or mount rotor in a rigid frame with multiple bearings				
	Keys and keyways	Insert proper half key per ISO 8821				
	Axial and radial runout of the drive attachment interface	Remachine surface or use belt drive				A.2.6
Assembly	Clearance in mechanical joints of universal shaft	Tighten universal joints, replace drive shaft or switch to belt drive	Possible, if zero clearance can be assessed for each run	Applicable, disassembling and re-assembling suspect joints between runs (rotor stopped in different angular positions)		A.1.3 A.2.5
	Incorrect shrink fits in assembly	Dismantle and re-assemble shrink fit	Measure axial runout			
		Reconsider dimensioning		Check repeatability		

1) Where the workpiece mass or measuring plane positions differ significantly from those of the proving rotor used in the tests described in ISO 2953, further tests should be carried out to determine the minimum achievable residual unbalance at the specified measuring planes on the workpiece/rotor itself.

2) In general, it is possible to apply corrections for errors of known amount and phase. However, if these errors are in excess of U_{per} it may be advisable to take other steps to reduce their magnitude before proceeding with the balancing process.

3) Results should be examined to avoid confusion between entrapped material effect and thermal effects.

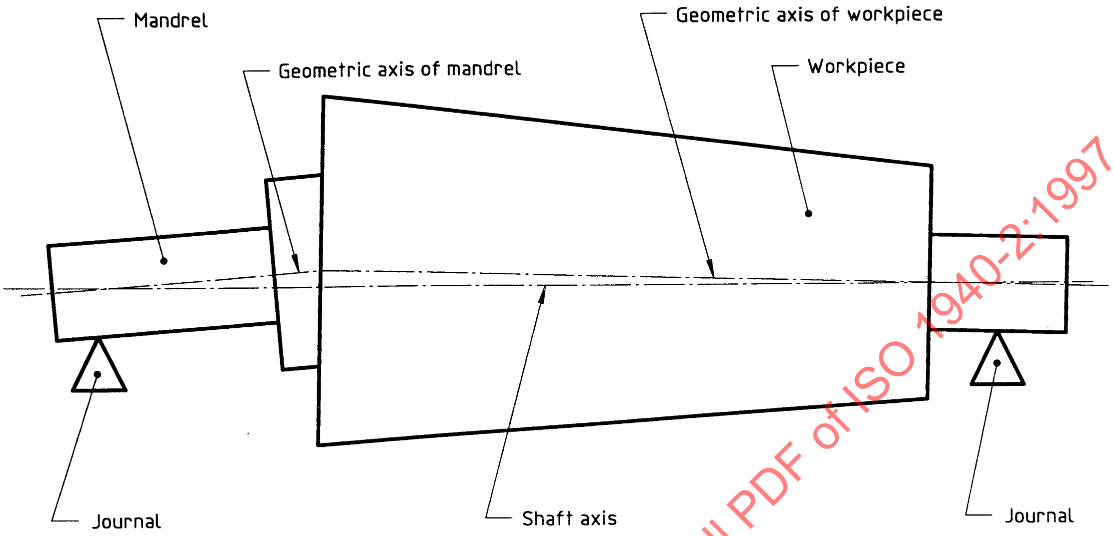


Figure A.3 — One journal on mandrel and one on workpiece

Annex B
(informative)

Typical data for checking the algorithm referred to in clause 8 b)

Table B.1 — Typical data for checking the algorithm referred to in clause 8 b)

Transducer No.	**Without test mass**		**With test mass in plane No. 1** 30 000 g·mm, 0°		**With test mass in plane No. 2** 20 000 g·mm, 0°	
	Amplitude	Phase	Amplitude	Phase	Amplitude	Phase
1	1,50	0°	3,10	60°	2,11	320°
2	2,10	130°	1,90	250°	2,09	90°

The resulting residual unbalances are:

— plane No. 1: 6 500 g·mm (213°);
— plane No. 2: 18 900 g·mm (108°).

NOTE — The phase of the residual unbalance vector is normally not needed to determine the balance quality.