BS ISO 21940-21:2012

BSI Standards Publication

Mechanical vibration — Rotor balancing

Part 21: Description and evaluation of balancing machines

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National foreword

This British Standard is the UK implementation of ISO 21940-21:2012. It supersedes BS ISO 2953:1999 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee GME/21/5, Mechanical vibration, shock and condition monitoring - Vibration of machines.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

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Mechanical vibration — Rotor balancing —

Part 21: Description and evaluation of balancing machines

Vibrations mécaniques — Équilibrage des rotors —

Partie 21: Description et évaluation des machines à équilibrer

Reference number
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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 21940-21 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 21940-21 cancels and replaces ISO 2953:1999, of which it constitutes an editorial revision. The main change is that for all definitions, reference is made to ISO 1925. Additionally, the Scope has been reworded in order to exactly reflect what this part of ISO 21940 is dealing with. Furthermore, some rough rounding in the numbers given in the Tables has been smoothened, and some Figures drawn more exactly.

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)]

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*

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

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

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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*

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*

Mechanical vibration — Rotor balancing —

Part 21: Description and evaluation of balancing machines

1 Scope

This part of ISO 21940 specifies requirements for evaluating the performance of machines for balancing rotating components by the following tests:

a) test for minimum achievable residual unbalance, U_{mar} test;

b) test for unbalance reduction ratio, URR test;

c) test for couple unbalance interference on single-plane machines;

d) compensator test.

These tests are performed during acceptance of a balancing machine and also later, on a periodic basis, to ensure that the balancing machine is capable of handling the actual balancing tasks. For periodic tests, simplified procedures are specified. Tests for other machine capacities and performance parameters, however, are not contained in this part of ISO 21940.

For these tests, three types of specially prepared proving rotors are specified, covering a wide range of applications on horizontal and vertical balancing machines. An annex describes recommended modifications of proving rotors prepared in acccordance with ISO 2953:1985.[2]

Moreover, this part of ISO 21940 also stresses the importance attached to the form in which the balancing machine characteristics are specified by the manufacturer. Adoption of the format specified enables users to compare products from different manufacturers. Additionally, in an annex, guidelines are given on the information by which users provide their data and requirements to a balancing machine manufacturer.

This part of ISO 21940 is applicable to balancing machines that support and rotate rotors with rigid behaviour at balancing speed and that indicate the amounts and angular locations of a required unbalance correction in one or more planes. Therefore, it is applicable to rotors with rigid behaviour as well as to rotors with shaft-elastic behaviour balanced in accordance with low-speed balancing procedures. It covers both soft-bearing balancing machines and hard-bearing balancing machines. Technical requirements for such balancing machines are included; however, special features, such as those associated with automatic correction, are excluded.

This part of ISO 21940 does not specify balancing criteria; such criteria are specified in ISO 1940-1[1] and ISO 11342[3] (only low-speed balancing procedures apply).

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)]

3 Terms and definitions

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

4 Capacity and performance data of the balancing machine

4.1 General

The manufacturer shall specify the data listed in 4.2 for horizontal or 4.3 for vertical balancing machines, as applicable, and in a similar format.

NOTE Information provided by the user to the balancing machine manufacturer is summarized in Annex A.

4.2 Data for horizontal balancing machines

4.2.1 Rotor mass and unbalance limitations

4.2.1.1 The maximum mass of a rotor, m, which can be balanced shall be stated over the range of balancing speeds (n_1, n_2, ...).

The maximum moment of inertia of a rotor with respect to the shaft axis, $m\,r^2$, where m is the rotor mass and r is the radius of gyration, which the machine can accelerate in a stated acceleration time shall be given for the range of balancing speeds (n_1, n_2, ...) together with the corresponding cycle rate (see Table 1).

4.2.1.2 Production efficiency (see Clause 7) shall be stated, as follows.

4.2.1.2.1 Time per measuring run:

a) Time for mechanical adjustment: .... s

b) Time for setting indicating system: .... s

c) Time for preparation of rotor: .... s

d) Average acceleration time: .... s

e) Reading time (including time to stabilize): .... s

f) Average deceleration time: .... s

g) Relating readings to rotor: .... s

h) Other necessary time: .... s

i) Total time per measuring run [a) to h) in the preceding]: .... s

11) To become ISO 21940-2 when revised.

4.2.1.2.2 Unbalance reduction ratio, URR, for inboard rotors: .... %

4.2.1.2.3 Unbalance reduction ratio for outboard rotors: .... %

Table 1 — Data for horizontal balancing machines

Manufacturer: .... **Model:** ....

Balancing speeds or speed ranges (see also 4.2.3.1)			n_1	n_2	n_3	n_4	…
Rotor mass (see Note 1)	kg	maximum, m_{max}					
		minimum					
Occasional overload force per support (see Note 1)	N						
Maximum negative force per support (see Note 1)	N						
Maximum rotor moment of inertia with respect to the shaft axis (see Note 2)	kg·m^2						
Cycle rate (see Note 2)							
Maximum unbalance (see Note 3)	g·mm/kg or g·mm	measurable					
		permissible					
a) For inboard rotors Minimum achievable residual specific unbalance, e_{mar} (see Note 4 and Clause 6)	g·mm/kg	maximum mass, m_{max}					
		0,2 m_{max}					
		minimum mass					
Corresponding deflection of analogue amount-of-unbalance indicator, mm or Number of digital units (see Note 4)		maximum mass, m_{max}					
		0,2 m_{max}					
		minimum mass					
b) For outboard rotors Minimum achievable residual specific unbalance, e_{mar} (see Note 4 and Clause 6)	g·mm/kg	maximum mass, m_{max}					
		0,2 m_{max}					
		minimum mass					
Corresponding deflection of analogue amount-of-unbalance indicator, mm or Number of digital units (see Note 4)		maximum mass, m_{max}					
		0,2 m_{max}					
		minimum mass					

NOTE 1 The occasional overload force is only stated for the lowest balancing speed. It is the maximum force per support that can be accommodated by the machine without immediate damage.

The negative force is the static upward force resulting from a rotor having its centre of mass outside the bearing support.

NOTE 2 Cycle rate for a given balancing speed is the number of starts and stops which the machine can perform per hour without damage to the machine when balancing a rotor of the maximum moment of inertia.

NOTE 3 In general, for rotors with rigid behaviour with two correction planes, one-half of the stated value pertains to each plane; for disc-shaped rotors, the full stated value holds for one plane.

NOTE 4 Limits for soft-bearing machines are generally stated in gram millimetres per kilogram (specific unbalance, g·mm/kg), since this value represents a measure of rotor displacement and, therefore, motion of the balancing machine bearings. For hard-bearing machines, the limits are generally stated in gram millimetres (g·mm), since these machines are usually factory calibrated to indicated unbalance in such units (see Clause 6). For two-plane machines, this is the result obtained when the minimum achievable residual unbalance is distributed between the two planes.

4.2.2 Rotor dimensions

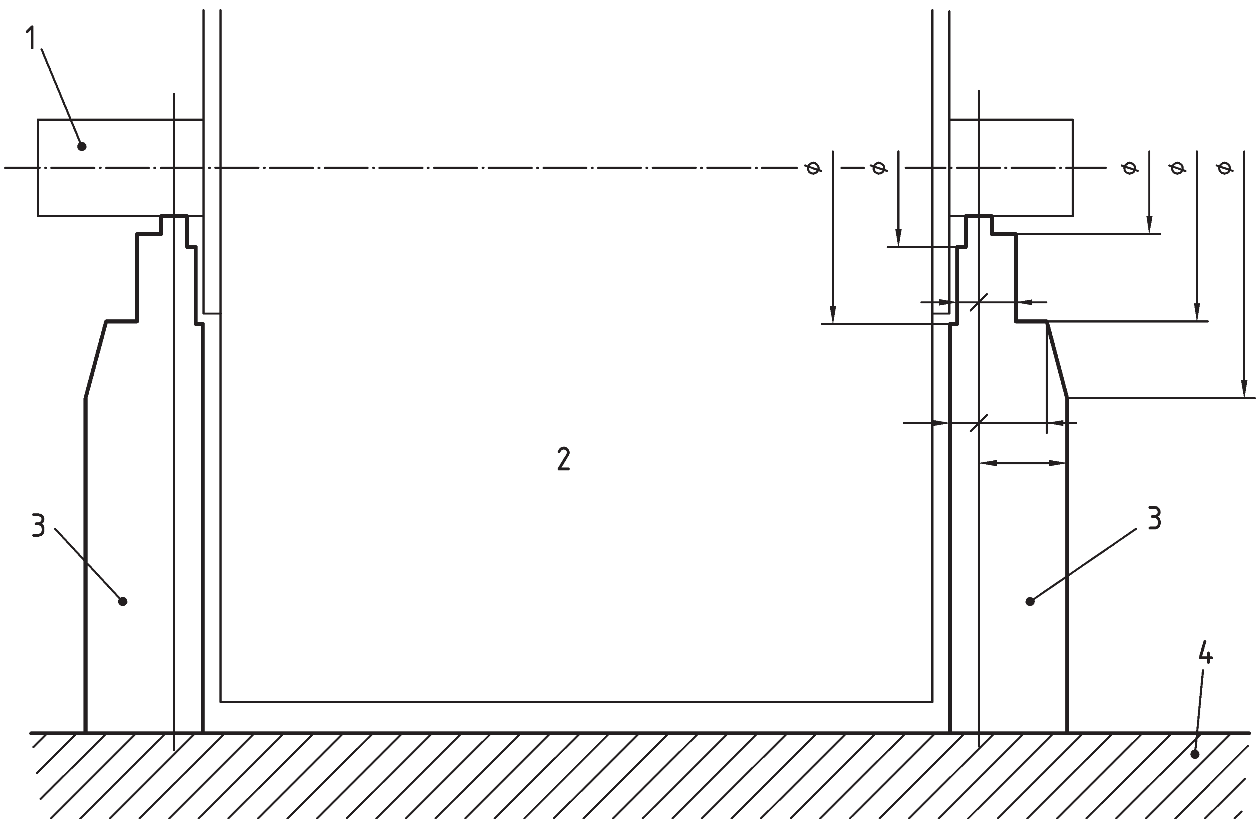
4.2.2.1 Adequate envelope drawings of the pedestals and of other obstructions, such as belt-drive mechanism, shroud mounting pads, thrust arms and tie bars, shall be supplied to enable the user to determine the maximum rotor envelope that can be accommodated and the tooling or adaptors required.

A combination of large journal diameter and high balancing speed can result in an excessive journal peripheral speed. The maximum journal peripheral speed shall be stated.

When belt drive is supplied, balancing speeds shall be stated for both the maximum and minimum diameters over which the belt can drive, or other convenient diameter.

The manufacturer shall state if the axial position of the drive can be adjusted.

4.2.2.2 Rotor envelope limitations shall be stated (see Figure 1).



Key

1 shaft

2 rotor

3 support

4 bed

If the left-hand support is not a mirror image of the right-hand support, separate dimensions shall be shown.

The profile of the belt-drive equipment shall be shown, if applicable.

Figure 1 — Example of a machine support drawing illustrating rotor envelope limitations

4.2.2.3 Rotor diameter:

a) Maximum diameter over bed: .... mm

b) Maximum diameter over which belt can drive: .... mm

c) Minimum diameter over which belt can drive: .... mm

4.2.2.4 Distance between journal centrelines:

a) Maximum: .... mm

b) Minimum: .... mm

c) Maximum distance from coupling flange to centreline of farthest bearing: .... mm

d) Minimum distance from coupling flange to centreline of nearest bearing: .... mm

4.2.2.5 Journal diameter:

a) Maximum: .... mm

b) Minimum: .... mm

Maximum permissible peripheral journal speed .... m/s

4.2.2.6 Correction plane limitations (consistent with the statements in 5.4) shall be stated.

4.2.2.7 Correction plane interference ratios (consistent with the statements in 5.4 and based on the proving rotor) shall be stated.

4.2.3 Drive

4.2.3.1

	Balancing speed r/min	Rated torque on rotor N·m
n_1	....	....
n_2	....	....
n_3	....	....
n_4	....	....
n_5	....	....
n_6	....	....
n_7	....	....
n_8	....	....
	or	or
	steplessly variable	steplessly variable
from	....	....
to	....	....

4.2.3.2 Torque:

a) Zero-speed torque: .... % of rated torque on rotor

b) Run-up torque adjustable from .... % to .... % of rated torque on rotor

c) Peak torque .... % of rated torque on rotor

NOTE In most cases, maximum torque is required for accelerating a rotor. However, in the case of a rotor with high windage or friction loss, maximum torque can be required at balancing speed. When there is axial thrust, it is necessary that provisions be made to take this into account.

4.2.3.3 Type of drive to rotor: ....

EXAMPLES End drive by universal joint driver, end drive by band, belt drive, magnetic field, driven bearing rollers, air jet.

4.2.3.4 Prime mover (type of motor): ....

a) Rated power: .... kW

b) Motor speed: .... r/min

c) Power supply, voltage/frequency/phase: .... / .... / ....

4.2.3.5 Brake

a) Type of brake: ....

b) Braking torque adjustable from .... % to .... % of rated torque

c) Can the brake be used as a holding device? Yes / No

4.2.3.6 Motor and controls in accordance with the following standard(s): ....

4.2.3.7 Speed regulation provided:

Accurate or constant within .... % of .... r/min, or .... r/min

4.2.4 Couple unbalance interference ratio: .... g·mm/(g·mm^2)

NOTE This value is only applicable for single-plane balancing machines. It describes the influence of couple unbalance in the rotor on the indication of resultant unbalance.

4.2.5 Air pressure requirements: .... Pa, ... m^3/s.

4.3 Data for vertical balancing machines

4.3.1 Rotor mass and unbalance limitations

4.3.1.1 The maximum mass of a rotor, m, which can be balanced shall be stated over the range of balancing speeds (n_1, n_2, ...).

The maximum moment of inertia of a rotor with respect to the shaft axis, $m\,r^2$, where m is the rotor mass and r is the radius of gyration, which the machine can accelerate in a stated acceleration time shall be given for the range of balancing speeds (n_1, n_2, ...) together with the corresponding cycle rate (see Table 2).

Table 2 — Data for vertical balancing machines

Manufacturer: .... **Model:** ....

Balancing speeds or speed ranges (see also 4.3.3.1)			n_1	n_2	n_3	n_4	…
Rotor mass (see Note 1)	kg	maximum, m_{max}					
		minimum					
Occasional overload force up to (see Note 1)	N						
Maximum rotor moment of inertia with respect to the shaft axis (see Note 2)	kg·m^2						
Cycle rate (see Note 2)							
Maximum unbalance (see Note 3)	g·mm/kg or g·mm	measurable					
		permissible					
Minimum achievable residual specific unbalance, e_{mar} (see Note 4 and Clause 6)	g·mm/kg	maximum mass, m_{max}					
		0,2 m_{max}					
		minimum mass					
Corresponding deflection of analogue amount-of-unbalance indicator, mm or Number of digital units (see Note 4)		maximum mass, m_{max}					
		0,2 m_{max}					
		minimum mass					

NOTE 1 The occasional overload force is only stated for the lowest balancing speed. It is the maximum force that can be accommodated by the machine without immediate damage.

NOTE 2 Cycle rate for a given balancing speed is the number of starts and stops which the machine can perform per hour without damage to the machine when balancing a rotor of the maximum moment of inertia.

NOTE 3 In general, for rotors with rigid behaviour with two correction planes, one-half of the state value pertains to each plane; for disc-shaped rotors, the full stated value holds for one plane.

NOTE 4 Limits for soft-bearing machines are generally stated in gram millimetres per kilogram (specific unbalance, g·mm/kg), since this value represents a measure of rotor displacement and, therefore, motion of the balancing machine bearings. For hard-bearing machines, the limits are generally stated in gram millimetres (g·mm), since these machines are usually factory calibrated to indicated unbalance in such units (see Clause 6). For two-plane machines, this is the result obtained when the minimum achievable residual unbalance is distributed between the two planes.

4.3.1.2 Production efficiency (see Clause 7) shall be stated, as follows.

4.3.1.2.1 Time per measuring run:

a) Time for mechanical adjustment: .... s

b) Time for setting indicating system: .... s

c) Time for preparation of rotor: .... s

d) Average acceleration time: .... s

e) Reading time (including time to stabilize): .... s

f) Average deceleration time: .... s

g) Relating readings to rotor: .... s

h) Other necessary time: .... s

i) Total time per measuring run [a) to h) in the preceding]: .... s

4.3.1.2.2 Unbalance reduction ratio, URR: .... %

4.3.2 Rotor dimensions

4.3.2.1 If the machine is equipped with two or more speeds, the information on rotor dimensions shall be stated for each speed. If the machine is equipped with steplessly variable balancing speeds, then the information shall be given in the form of a table, formula or graph.

Adequate drawings of the support surface of the spindle or mounting plate and of obstructions, such as drill heads and electrical control cabinets, above the mounting plate shall be supplied to enable the user to determine the maximum rotor envelope that can be accommodated and the tooling or adaptors required.

4.3.2.2 Maximum diameter: .... mm

4.3.2.3 Rotor height:

a) Maximum overall height: .... mm

b) Maximum height of centre of gravity: .... mm

at 100 % of maximum mass: .... mm

at 50 % of maximum mass: .... mm

at 25 % of maximum mass: .... mm

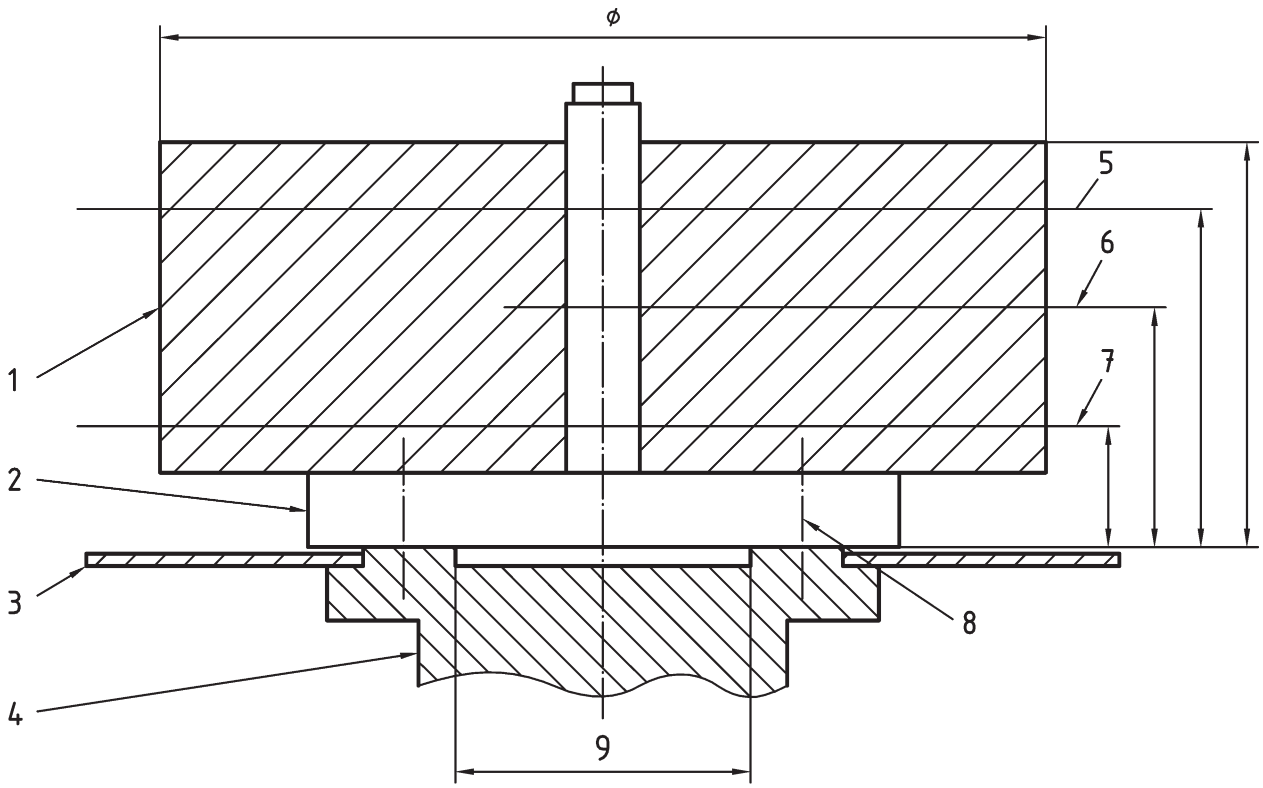
4.3.2.4 Rotor envelope limitations, including machine spindle or mounting plate interface, shall be stated (see Figure 2).

4.3.2.5 Correction plane limitations (consistent with the statements in 5.4) shall be stated.

4.3.3 Drive

4.3.3.1

	Balancing speed r/min	Rated torque on rotor N·m
n_1	....	....
n_2	....	....
n_3	....	....
n_4	....	....
n_5	....	....
n_6	....	....
n_7	....	....
n_8	....	....



Key

1 rotor
2 adaptor
3 protractor
4 spindle
5 upper correction plane
6 centre of mass plane
7 lower correction plane
8 mounting holes for adaptor
9 spigot diameter

Figure 2 — Example of vertical machine mounting interface illustrating rotor envelope limitations

4.3.3.2 Torque:

a) Zero-speed torque: .... % of rated torque on rotor

b) Run-up torque adjustable from .... % to .... % of rated torque on rotor

c) Peak torque: .... % of rated torque on rotor

NOTE In most cases, maximum torque is required for accelerating a rotor. However, in the case of rotors with high windage or friction loss, maximum torque can be required at balancing speed.

4.3.3.3 Prime mover (type of motor): ....

a) Rated power: .... kW

b) Motor speed: .... r/min

c) Power supply, voltage/frequency/phase: .... / .... / ....

4.3.3.4 Brake

a) Type of brake: ....

b) Braking torque adjustable from .... % to .... % of rated torque

c) Can the brake be used as a holding device? Yes / No

4.3.3.5 Motor and controls in accordance with the following standard(s): ....

4.3.3.6 Speed regulation provided:

Accurate or constant within .... % of .... r/min, or .... r/min

4.3.4 Couple unbalance interference ratio: .... g·mm/(g·mm^2)

NOTE This value is only applicable for single-plane balancing machines. It describes the influence of couple unbalance in the rotor on the indication of resultant unbalance.

4.3.5 Air pressure requirements: .... Pa, ... m^3/s.

5 Machine features

5.1 Principle of operation

An adequate description of the principle of operation of the balancing machine shall be given, e.g. motion measuring, force measuring, resonance, compensation.

5.2 Arrangement of the machine

5.2.1 The manufacturer shall describe the general configuration of the balancing machine and the principal features of design, e.g.:

- horizontal or vertical axis of rotation;
- soft- or hard-bearing suspension system;
- resonance-type machine with mechanical compensator.

5.2.2 The manufacturer shall provide details of the following, as applicable.

5.2.2.1 Components designed to support the rotor, e.g.:

- vee blocks;
- open rollers;
- plain half bearings;
- closed ball, roller or plain bearings;
- devices to accommodate rotors in their service bearings;
- devices to accommodate complete units.

Details of bearing lubrication requirements shall be given, where applicable.

5.2.2.2 The mechanical adjustment and functioning of the means provided to take up axial thrust from the rotor (horizontal machines only).

5.2.2.3 Type(s) of transducers used to sense unbalance effects.

5.2.2.4 The drive and its control.

5.3 Indicating system

5.3.1 General

A balancing machine shall have means to determine the amount of unbalance and its angular location; such means shall be described, e.g.:

- wattmetric indicating system;
- voltmetric indicating system with phase-sensitive rectifier (including systems with frequency conversion);
- voltmetric system with stroboscope and filter;
- voltmetric indicating system with marking of angular position on the rotor itself;
- compensator with mechanical or electrical indication.

5.3.2 Amount indicators

The manufacturer shall describe the means of amount indication provided, e.g.:

- wattmetric or voltmetric component meters;
- wattmetric or voltmetric amount meters;
- wattmetric or voltmetric vector meters;
- mechanical or optical indicators;
- analogue or digital readout.

5.3.3 Angle indicators

The manufacturer shall describe the means of angle indication provided, e.g.:

- wattmetric or voltmetric component meters;
- wattmetric or voltmetric vector meters;
- direct angle indication in degrees on a scale meter;
- oscilloscope, stroboscopic indicators;
- mechanical or optical indicators;
- analogue or digital readout.

5.3.4 Operation of the indicating system

The manufacturer shall describe the procedure by which readings are obtained, taking into account at least the following aspects.

a) How many measuring runs are required to obtain:
   - the two readings for single-plane balancing?
   - the four readings for two-plane balancing?

b) Is an indicator provided for each reading or is it necessary to switch over for each reading?

c) Are readings retained after the end of the measuring run?

d) Is an individual plus-and-minus switch provided for each plane which permits the indication of a heavy or light spot?

5.4 Plane separation system

5.4.1 This subclause is not applicable to single-plane balancing machines, for which see 5.4.2.

The manufacturer shall state whether plane separation is provided. If it is provided, at least the following details shall be given.

a) How is it operated for single rotors of a type not previously balanced?

b) How is it operated for single rotors in a series, with identical dimensions and mass?

c) The limits of rotor geometry over which plane separation is effective shall be defined with the effectiveness stated on the basis of the correction plane interference ratio, stating the following:

   — the ratio of bearing distance to plane distance for which plane separation is effective;

   — whether either or both correction planes can be between or outside the bearings;

   — whether the centre of mass can be between or outside the two selected correction planes or bearings.

d) Whether the indicator system can also be used to measure directly resultant unbalance and couple unbalance.

5.4.2 For single-plane horizontal or vertical machines, the manufacturer shall state to what extent the machine is able to suppress effects of couple unbalance (see 11.8).

5.5 Setting and calibration of indication

5.5.1 General

The manufacturer shall describe the means of setting and calibration and the means provided for checking these.

The manufacturer shall state whether setting is possible for indication in any desired unit, whether practical correction units or unbalance units.

The manufacturer shall state the number of runs required for calibrating the balancing machine:

— for single-plane balancing;

— for two-plane balancing.

The manufacturer shall state the maximum permissible change, in percentage terms, in repeatability of speed during calibration and operation.

5.5.2 Soft-bearing machines

The manufacturer shall state how calibration is accomplished on the first rotor of a particular mass and configuration (e.g. whether the rotor has to be balanced by a trial-and-error procedure or whether a compensator is provided, whether calibration masses are required), and whether total or partial recalibration is required when changing the balancing speed.

If a compensator is provided, the limits of initial unbalance, of rotor geometry and speed for which compensation is effective shall be stated.

5.5.3 Hard-bearing machines

The manufacturer shall state whether the balancing machine is permanently calibrated and can be set according to the rotor or whether it requires calibration by the user for different balancing speeds, rotor masses and dimensions.

5.6 Other devices

Special devices which influence the efficient functioning of the balancing machine shall be described in detail, e.g.:

- indication in components of an arbitrary coordinate system;
- indication of unbalance resolved into components located in limited sectors in more than two correction planes;
- correction devices;
- devices to correlate the measured angle or amount of unbalance with the rotor;
- suitable output for connection to a computer, printer or other peripherals.

6 Minimum achievable residual unbalance

The minimum residual unbalance that can be achieved with a balancing machine shall be specified in terms of specific unbalance, in gram millimetres per kilogram (g·mm/kg), together with the corresponding amount-of-unbalance indication.

This minimum achievable residual specific unbalance, e_{mar}, shall be stated for the full range of rotor masses and balancing speeds of the machine.

In achieving the stated residual unbalance, the manufacturer shall consider whether the accuracy of the following is adequate for this purpose:

- amount indication;
- angle indication;
- plane separation;
- scale multiplier;
- drive, bearings, etc.

It should be noted that the stated minimum achievable residual unbalance value applies to the balancing machine as delivered, but if out-of-round journals, excessively heavy or loose adaptors, or other tooling are employed by the user, the minimum achievable residual unbalance can be affected.

7 Production efficiency

7.1 General

Production efficiency is the ability of the machine to assist the operator in balancing a rotor to a given residual unbalance in the shortest possible time. It shall be assessed by using a proving rotor or, alternatively, a test rotor to be specified by the user.

To find the production rate for a specific rotor (number of pieces per time or the reciprocal of the floor-to-floor time), the time per measuring run, the necessary number of runs, the time for loading, unbalance correction and unloading have to be taken into consideration. The necessary number of measuring runs depends on the average initial unbalance, the balance tolerance and the unbalance reduction ratio (URR).

7.2 Time per measuring run

For the proving rotor or rotors specified by the user, the manufacturer shall describe the procedure in detail and state the average time normally used for each of the operations listed under a) to h):

a) mechanical adjustment of the balancing machine, including the drive, tooling or adaptor;

b) setting of the indicating system;

c) preparation of the rotor for the measuring run;

d) average acceleration time;

e) the reading time, i.e. the normal total time between the end of the acceleration run and the start of the deceleration run;

f) average deceleration time;

g) any further operations necessary to relate the readings obtained to the actual rotor being balanced;

h) time for all other required operations, e.g. safety measures.

Items a) and b) are of primary interest for single-rotor balancing.

The time per measuring run is the total time required for steps a) to h) for the first run, but for subsequent measuring runs on the same rotor, only steps d) to h) are required. In the case of mass production rotors, only steps c) to h) are required.

If special tools, not supplied as part of the standard equipment, are necessary to accommodate a rotor, this shall be specified, e.g. bearing inserts, couplings for drive shafts, and shrouds.

7.3 Unbalance reduction ratio

The manufacturer shall state the unbalance reduction ratio, URR. It shall be assumed that the addition or subtraction of mass is made without error and that normal skill and care are exercised in the operation of the balancing machine.

Where indicator systems that rely heavily on operator judgement are used, e.g. stroboscopes and mechanical indicators, realistic values based on experience and related to the rotor to be balanced shall be given.

8 Performance qualifying factors

The manufacturer shall state the range of the following factors within which the machine is capable of achieving the guaranteed performance, e.g.:

— temperature;

— humidity;

— balancing speed variation;

— line voltage and frequency fluctuations.

The manufacturer shall also state whether the performance of the machine is significantly changed by the use of ball bearings on the rotor journals.

In addition, the manufacturer shall state whether the unbalance indication of the rotor is significantly affected if the rotor bearing thrust face is not perpendicular to the rotor axis.

9 Installation requirements

9.1 General

In considering the siting of a balancing machine, the manufacturer shall state the precautions to be observed to obtain satisfactory performance in the presence of the following environmental factors:

— extraneous vibration;

— electromagnetic radiation;

— condensation, fungus and other factors, such as those referred to in Clause 8.

9.2 Electrical and pneumatic requirements

Balancing machines shall be provided with standard input connections that are plainly marked with the required supply voltage and frequency, air pressure, hydraulic pressure, etc.

9.3 Foundation

The manufacturer shall state the overall dimensions and mass of the balancing machine, and the type and size of foundation required for the machine under which its specified performance is assured, e.g. concrete blocks and workbench.

10 Proving rotors and test masses

10.1 General

This clause specifies technical requirements for a range of proving rotors for use in testing balancing machines. It specifies rotor masses, materials, dimensions, limits, tapped hole dimensions, rotor balancing requirements and details of test masses. The extent and costs of tests, as well as the rotor size(s), may be negotiated between the manufacturer and user.

If agreed between the manufacturer and user, production rotors may be used instead of the standardized proving rotors, provided they can be prepared in accordance with the principles of the standardized proving rotors and their balance errors are sufficiently small.

NOTE For balance errors, see ISO 21940-14.

10.2 Proving rotors

10.2.1 Three types of proving rotors are defined, designated A, B and C (see Figure 3). Typical rotors which are intended to be represented by the proving rotors are characterized as follows.

— Type A: Rotors without journals, balanced on a vertical machine (or balanced on a horizontal machine with integrated spindle), in one or two correction planes.

Service bearing planes may be anywhere; i.e. one on each side, or both on one side of the main rotor body. For the tests, however, it is assumed that one bearing is on each side of the rotor.

— Type B: Inboard rotors with journals, balanced on a horizontal machine, mostly with two correction planes between the bearings.

Service bearings are positioned on either side of the rotor.

— Type C: Outboard rotors with journals, balanced on a horizontal machine, with two overhung correction planes.

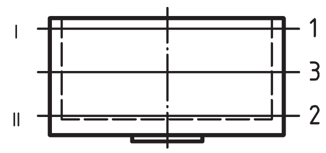
Service bearing positions are similar to those on the proving rotor.

NOTE 1 A type C proving rotor is composed of a shaft and a proving rotor of type A.

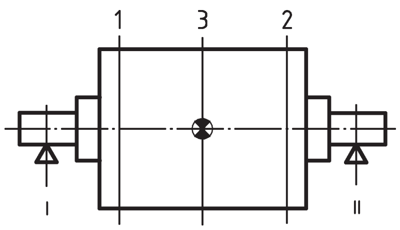
NOTE 2 Calculations for U_{mar} for a type C proving rotor are based on the total mass (shaft and proving rotor type A).

Each type of proving rotor has three planes for attachment of test masses.

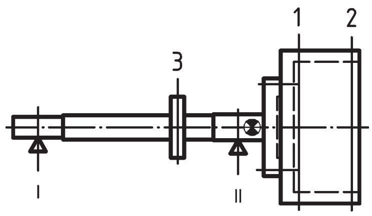
The same proving rotor and test masses are used for tests in one or two planes.



a) Proving rotor without journals — Type A



b) Inboard proving rotor with journals — Type B



c) Outboard proving rotor with journals — Type C

Key

1,2,3 test planes

I, II assumed bearing planes

NOTE Centre of mass position is inboard in types A and B but outboard in type C (shaft plus type A rotor).

Figure 3 — Proving rotors type A, B and C

10.2.2 The manufacturer shall state whether a proving rotor is supplied with the machine.

NOTE The shipment of proving rotors to the user is the subject of individual negotiation.

10.2.3 Proving rotors shall be manufactured of steel and shall be similar to those in Table 3 and Figure 4 for vertical machines, Table 4 and Figure 5 for horizontal machines (inboard rotor), and Table 5 and Figure 6 for outboard rotors (see 10.2.5).

NOTE Older style rotors with only eight holes per plane may be modified to comply with this part of ISO 21940 (see Annex D).

10.2.4 For machines covered by this part of ISO 21940, the manufacturer shall have available proving rotors that may be used to confirm the performance of each machine prior to shipment from the plant.

10.2.5 If a horizontal machine is to be used for balancing outboard rotors (or inboard rotors with correction planes overhanging on one side), additional tests have to be agreed upon (see 11.1). These require a proving rotor type C.

10.2.6 Clear and permanent angle markings shall be provided on every proving rotor every 10° and enumerated at intervals of 30°. Two such scales with a clockwise and counterclockwise enumeration may be provided.

For testing stroboscopic machines, the proving rotor shall be equipped with a numbered standard band delivered with the machine. The middle of the first number shall coincide with one set of tapped holes. Angle readout for the tests shall be made from the numbered band and recalculated in the 360° circle.

10.2.7 For multi-purpose machines, a standard proving rotor shall be used whose mass falls within the lower third of the mass capacity range of the machine.

10.2.8 For machines which are intended to be used near the lower limit of the mass capacity range, a proving rotor having a mass near the lower mass capacity limit is recommended for an additional test.

10.2.9 For special-purpose machines, or by agreement between the manufacturer and user, the user's own rotor may be used, provided the balance errors introduced by such rotors are negligible.

10.3 Test masses

10.3.1 General

Test masses are used to create defined unbalances in the proving rotor test planes.

Since the test positions have threaded holes, the test masses may be in the form of bolts, screws, etc. A recommended solution is to have studbolts permanently fixed into all positions, protruding from the surface of the rotor by a certain height, and to screw the test masses on to them. In this case, test masses are rings and the precise location of their centres of mass (radius) can be easily identified.

The unbalance value of a test mass is always expressed in units of U_{mar}, i.e. multiples of the minimum achievable residual unbalance.

If the claimed minimum achievable residual unbalance is specified per plane, U_{mar} is calculated as follows:

$$U_{\mathrm{mar}} = 2\ U_{\mathrm{mar\ per\ plane}}$$

If e_{mar}, the claimed minimum achievable residual specific unbalance, is stated, U_{mar} is obtained by multiplying e_{mar} by the total mass of the proving rotor, m:

$$U_{\mathrm{mar}} = e_{\mathrm{mar}}\ m$$

NOTE The required value for a particular test mass is derived from the required unbalance and the radius of its centre of mass, when attached to the proving rotor.

Table 3 — Recommended dimensions, masses and speeds for proving rotors type A for tests on vertical machines (see Figure 4)

Rotor No.	Rotor mass m	Major diameter D	Minor diameter d ≈ 0,9 D	Height H ≈ 0,5 D	X ≈ 0,075 D	Y[a] ≈ 0,175 D	Z[a] ≈ 0,175 D	F ≈ 0,06 D	G	I[b]	J[b]	K[b]	R[b]	T	Highest test speed[c]
Metric values															
	kg	mm	mm	mm	mm	mm	mm	mm		mm	mm	mm	mm	mm	r/min
1	1,1	110	99	55	8	20	20	6,5	M3	50,8	0,4 × 45°	4,2	76,2	6,6	20 000
2	3,5	160	144	80	12	30	30	9,5	M4	50,8	0,4 × 45°	4,2	76,2	6,6	14 000
3	11	230	206	127	19	45	45	13	M5	114,3	0,4 × 45°	4,2	133,35	10,3	10 000
4	35	345	310	170	25	60	60	20	M6	114,3	0,4 × 45°	4,2	133,35	10,3	6 000
5	110	510	460	255	38	90	90	30	M8	114,3	0,4 × 45°	4,2	133,35	10,3	4 000
Inch and pound values															
	lb	in	in	in	in	in	in	in		in	in	in	in	in	r/min
1	2,5	4,3	3,875	2,2	0,375	0,75	0,75	0,250	No.5 UNF	2	0,015 × 45°	0,165	3	0,266	20 000
2	8	6,3	5,650	3,2	0,5	1,125	1,125	0,375	No.8 UNF	2	0,015 × 45°	0,165	3	0,266	14 000
3	25	9	8,125	5	0,75	1,75	1,75	0,510	No.10 UNF	4,5	0,015 × 45°	0,165	5,25	0,406	10 000
4	80	13,5	12,125	7	1	2,375	2,375	0,800	1/4 UNC	4,5	0,015 × 45°	0,165	5,25	0,406	6 000
5	250	20	18	10	1,5	3,5	3,5	1.186	5/16 UNC	4,5	0,015 × 45°	0,165	5,25	0,406	4 000

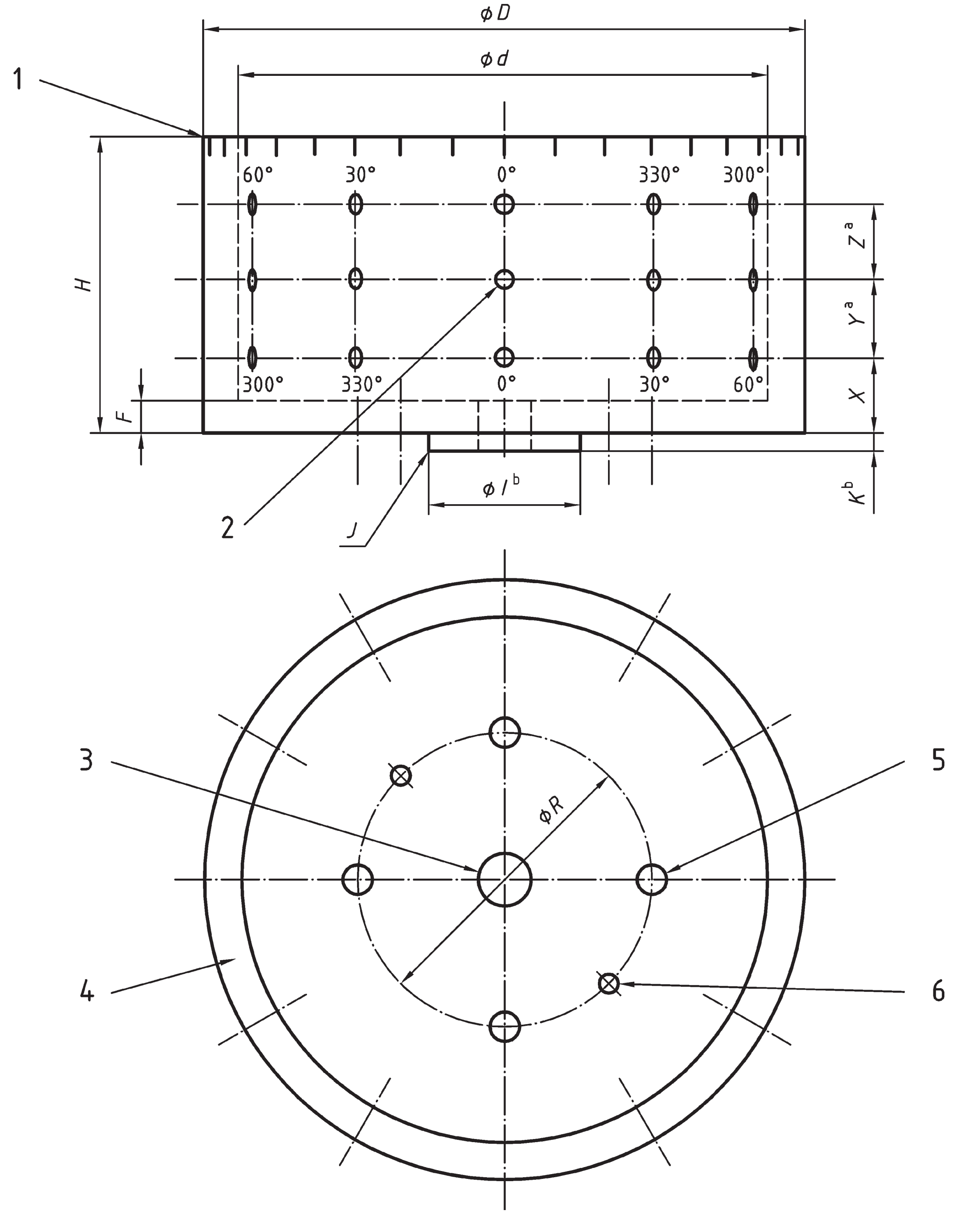
All tolerances and residual unbalance shall be in accordance with the test aims.

Proving rotors from SAE ARP 4162A[4] may be used instead with test masses modified to suit the ISO tests.

[a] Dimensions may be varied, except Y and Z.

[b] Interface (spigot) dimensions comply with SAE ARP 4162A[4] proving rotors (Rotor Nos. 2 to 5).

[c] Refers to rotors. Test mass design can limit highest speed.



Key

1 36 equal divisions of 10°, enumerated at 30° intervals, clockwise, counterclockwise
2 12 equally spaced threaded holes G in each of the three test planes
3 threaded hole for lifting eye
4 holes in this face to balance rotor (optional)
5 four through holes T, equally spaced
6 two threaded holes G

All tolerances and residual unbalance shall be in accordance with the test aims.

Proving rotors from SAE ARP 4162A[4] may be used instead with test masses modified to suit the ISO tests.

NOTE For dimensions, see Table 3.

a Dimensions may be varied, except Y and Z.
b Interface dimensions (spigot) comply with SAE ARP 4162A[4] proving rotors (where existing).

Figure 4 — Proving rotors type A for tests on vertical machines

Table 4 — Recommended dimensions, masses and speeds for proving rotors type B for inboard tests on horizontal machines (see Figure 5)

Rotor No.	Rotor mass m	Major diameter D	Overall length $L \approx 2{,}5D$	Shaft diameter $d \approx 0{,}3D$[b]	Bearing distance $A+B+C \approx 2D$	A[a], C[a] $\approx 0{,}5D$	B[a] $\approx D$	E $\approx 0{,}25D$	F $\approx 0{,}5D$	P_1	H[b]	K[b]	P_2[b]	N	Resonance speed[c] $\approx 7\,600\,000/D$	Highest test speed[d] $\approx 760\,000/D$
Metric values																
	kg	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm		r/min	r/min
1	0,5	38	95	11	76	19	38	9,5	19	31	—	—	—	M2	200 000	20 000
2	1,6	56	140	17	112	28	56	14	28	46	—	—	—	M3	140 000	14 000
3	5	82	205	25	164	41	82	20,5	41	72	—	—	—	M4	95 000	9 500
4	16	120	300	36	240	60	120	30	60	108	4	7	30	M5	65 000	6 500
5	50	176	440	58	352	88	176	44	88	160	1,4	30	47	M6	45 000	4 500
6	160	260	650	78	520	130	260	65	130	240	1,8	42	62	M8	30 000	3 000
7	500	380	950	114	760	190	380	95	190	350	2,2	57	84	M10	20 000	2 000
Inch and pound values																
	lb	in	in	in	in	in	in	in	in	in	in	in	in		r/min	r/min
1	1,1	1,5	3,75	0,433	3	0,75	1,5	0,375	0,75	1,25	—	—	—	No. 2 UNF	200 000	20 000
2	3,5	2,2	5,5	0,669	4,4	1,1	2,2	0,55	1,1	1,8	—	—	—	No. 5 UNF	140 000	14 000
3	11	3,2	8	0,984	6,4	1,6	3,2	0,8	1,6	2,8	—	—	—	No. 8 UNF	95 000	9 500
4	35	4,8	12	1,417	9,6	2,4	4,8	1,2	2,4	4,25	0,157	0,276	1,181	No.10 UNF	65 000	6 500
5	110	7	17,5	2,283	14	3,5	7	1,75	3,5	6,25	0,05	1,181	1,850	1/4 UNC	45 000	4 500
6	350	10,2	25,5	3,071	20,4	5,1	10,2	2,55	5,1	9,25	0,071	1,654	2,441	5/16 UNC	30 000	3 000
7	1 100	15	37,5	4,488	30	7,5	15	3,75	7,5	13,75	0,087	2,244	3,307	3/8 UNC	20 000	2 000

All tolerances and residual unbalance shall be in accordance with the test aims.

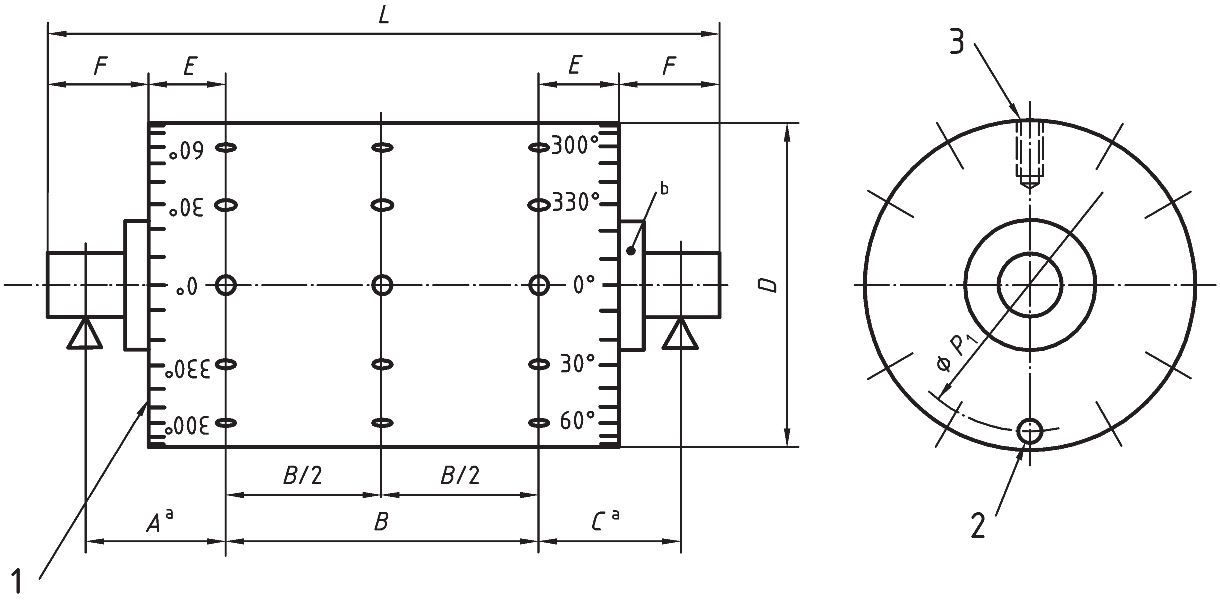
Proving rotors from SAE ARP 4162A[4] may be used instead with test masses modified to suit the ISO test.

a Dimensions A, B and C may be varied, provided they meet the requirements: $A \approx B/2$, $C \approx B/2$.

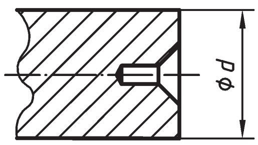
b End-drive interface dimensions comply with typical drive shafts.

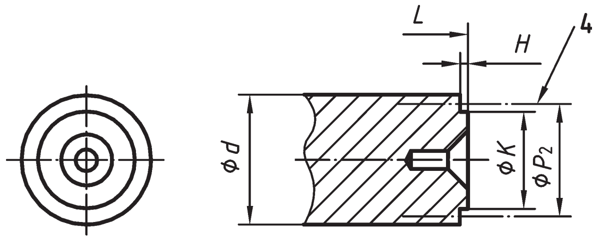
c Resonance speeds are calculated for rotors running in rigid bearings.

d Refers to rotors. Test mass design can limit highest speed.



a) Proving rotor type B





b) Details of journal ends for rotors for belt drive **c) Details of journal ends for rotors for end drive**

Key

1 36 equal divisions of 10°, enumerated at 30° intervals, clockwise, counterclockwise

2 12 equally spaced threaded holes N on each end for trim balancing

3 12 equally spaced threaded holes N in each of the three test planes

4 number and size of threads as requested

End-drive interface dimensions comply with typical drive shafts.

All tolerances and residual unbalance shall be in accordance with the test aims.

Proving rotors from SAE ARP 4162A[4] may be used instead, with test masses modified to suit the ISO tests.

Older style rotors with only eight holes per plane may be modified to comply with this part of ISO 21940 (see Annex D).

NOTE For dimensions, see Table 4.

a Dimensions A, B and C may be varied, provided they meet the requirements: $A \approx B/2$, $C \approx B/2$.

b If the shafts are used as ball bearing seatings, a shoulder should be provided so that bearings are perpendicular to the rotor axis and the centres are at the prescribed axial location.

Figure 5 — Proving rotors type B for inboard tests on horizontal machines

Table 5 — Recommended dimensions, masses and speeds for proving rotors type C for outboard tests on horizontal machines (see Figure 6)

Shaft No.	Proving rotor type A No.	Assembly													
		No.	Mass m	Bearing load on rotor[a] A	Bearing load on rotor[a] B	y [b]	d_1 [c]	d_2	d_4	N[b]	Major diameter d_6	Bearing distance L	A	B	Resonance speed[d]	Highest test speed[e]
Metric values																
			kg	N	N	mm	mm	mm	mm		mm	mm	mm	mm	r/min	r/min
1	1	1	2,2	– 3	24	20	17	21	50	M3	110	164	41	40	25 000	4 000
2	2	2	6,2	– 8	70	30	25	30	72	M4	160	240	62[f]	60	17 000	2 800
3	3	3	19,5	– 25	220	45	36	45	106	M5	230	352	93[f]	90	14 500	1 900
4	4	4	60	– 75	670[f]	65	58	65	156	M6	345	520	140	120	8 000	1 300
5	5	5	190	– 230	2 100	95	78	95	230	M8	510	760	203	180	5 500	900
Inch and pound values																
			lb	lbf	lbf	in	in	in	in		in	in	in	in	r/min	r/min
1	1	1	5	– 0,6	5,6	0,8	0,67	0,83	2	No.5 UNF	4,3	6,4	1,68	1,5	25 000	4 000
2	2	2	14	– 1,8	16	1,2	0,98	1,2	2,8	No.8 UNF	6,3	9,6	2,45	2,25	17 000	2 800
3	3	3	45	– 6	51	1,75	1,42	1,8	4,2	No.10 UNF	9	14	3,68[f]	3,5	14 500	1 900
4	4	4	135	– 17	150	2,55	2,28	2,55	6,2	1/4 UNC	13,5	20,4	5,55	4,75	8 000	1 300
5	5	5	430	– 54	480	3,75	3,07	3,7	9	5/16 UNC	20	30	8	7	5 500	900

All tolerances and residual unbalance shall be in accordance with the test aims.

Proving rotors from SAE ARP 4162A[4] may be used instead of proving rotor type A with test masses modified to suit the ISO tests.

[a] For indication, see Figure A.1.

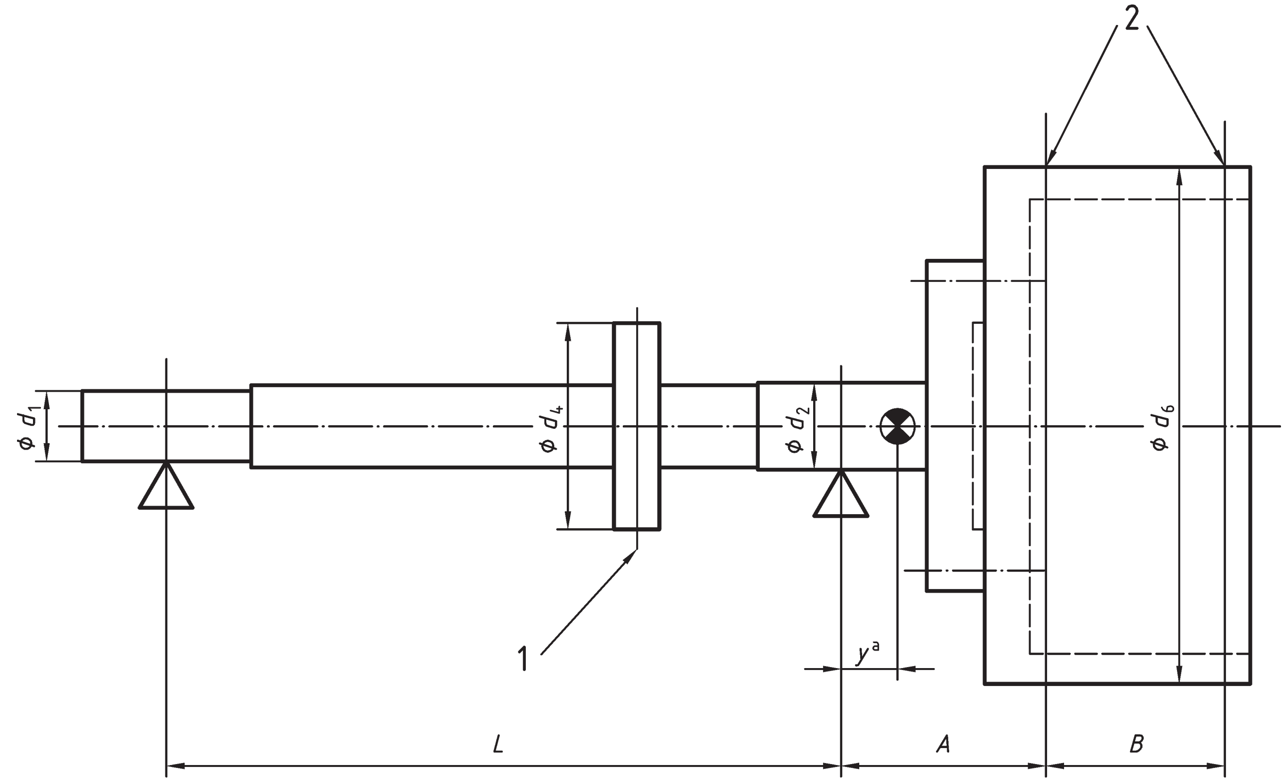
[b] Dimensions may be varied, provided the centre of mass stays outboard with the same overhung, y, and the position of holes N between bearings is maintained.

[c] End-drive interface dimensions for Nos. 3 to 5 are in accordance with proving rotors type B, Nos. 4 to 6.

[d] Resonance speeds are calculated for rotors running in rigid bearings.

[e] Refers to rotors. Test mass design can limit highest speed.

[f] Number adjusted.



Key

1 12 equally spaced threaded holes N

2 12 equally spaced threaded holes N

End-drive interface dimensions for Nos. 3 to 5 are in accordance with proving rotors type B, Nos. 4 to 6.

All tolerances and residual unbalance shall be in accordance with the test aims.

Proving rotors from SAE ARP 4162A[4] may be used instead of proving rotor type A with test masses modified to suit the ISO tests.

NOTE 1 For dimensions, see Table 5.

NOTE 2 Proving rotor type C is made up from a shaft (see Figure C.1 and Table C.1) and a proving rotor type A.

NOTE 3 Recommended dimensions of shafts (for end-drive) fitting proving rotors type A are given in Annex C.

NOTE 4 Interface dimensions (spigot) comply with proving rotors type A.

[a] Dimension may be varied, provided the centre of mass stays outboard with the same overhang and the position of holes N between bearings is maintained.

Figure 6 — Proving rotors type C for outboard tests on horizontal machines

10.3.2 Test mass for U_{mar} test

10.3.2.1 For the U_{mar} test (see 11.6), one test mass producing 10 U_{mar} is required for plane 3 (see Table 7).

NOTE For proving rotors type A or type B, two test masses of 5 U_{mar} each for planes 1 and 2 could be used instead. There is no recommended alternative for proving rotors type C.

10.3.2.2 For proving rotors type A and type B, U_{mar} shall be calculated in accordance with 10.3.1 using the values given

— in Table 3 for vertical machines and for horizontal machines with integrated spindles (type A);

— in Table 4 for horizontal machines for inboard rotors (type B).

EXAMPLE Horizontal machine, proving rotor type B as in Table 4, No. 5: m = 50 kg.

Claimed in Table 1: e_{mar} = 0,5 g·mm/kg.

Calculation according to 10.3.1: U_{mar} = 0,5 g·mm/kg × 50 kg = 25 g·mm

The U_{mar} test mass is to produce $10U_{mar}$ = 250 g·mm.

10.3.2.3 For proving rotors type C on horizontal machines for outboard tests, perform the same calculation (principle) for U_{mar} as above but use the values given in Table 5.

NOTE This leads to test masses different from the inboard test because:

— the mass of rotor type C is different from type B;

— the value claimed in Table 1 as e_{mar} for inboard rotors may differ from that for outboard rotors;

— the mass is attached to a different rotor diameter and thus has a different effective radius.

EXAMPLE Horizontal machine, outboard proving rotor type C as in Table 5, No. 3: m = 19,5 kg.

Claimed in Table 1: e_{mar} = 2 g·mm/kg.

Calculation according to 10.3.1: U_{mar} = 2 g·mm/kg × 19,5 kg = 39 g·mm

The U_{mar} test mass is to produce $10U_{mar}$ = 390 g·mm.

10.3.3 Test masses for URR test

10.3.3.1 For the URR test (see 11.7), two test masses (a stationary and a travelling mass) per test plane are required.

10.3.3.2 For proving rotors type A and type B, these test masses are:

— one (for a single-plane test) or two (for a two-plane test) stationary masses, each producing $20U_{mar}$ to $60U_{mar}$:

$$U_{station} = 20U_{mar} \text{ to } 60U_{mar}$$

— one (for a single-plane test) or two (for a two-plane test) travelling masses, each producing five times the unbalance of the stationary masses:

$$U_{travel} = 5U_{station}$$

EXAMPLE Using the same proving rotor and claimed value of e_{mar} as in 10.3.2.2, and stationary test masses producing 30 times the minimum achievable residual unbalance, U_{mar}, leads to:

The URR stationary test masses are to produce $U_{station}$ = 30 U_{mar} = 30 × 25 g·mm = 750 g·mm.

The URR travelling test masses are to produce U_{travel} = $5U_{station}$ = 3 750 g·mm.

10.3.3.3 For proving rotors type C, perform the same calculation (principle) as above. However, in order to use the same URR evaluation diagram $U_{station}$ should be:

$$U_{station} = 60U_{mar} \text{ to } 100U_{mar}$$

NOTE The test masses differ from those for proving rotor type A.

On proving rotors type C (outboard), as an alternative the URR test can be performed with resultant or couple test masses. The following is recommended, based on the principles and rules given in ISO 1940-1.[1]

For resultant, use

— one stationary mass, producing $U_{\text{res station}} = 20U_{\text{mar}}$ to $60U_{\text{mar}}$

— one travelling mass, producing $U_{\text{res travel}} = 5U_{\text{res station}}$

For couple, use

— two stationary masses, each producing $U_{\text{c station}} = 4U_{\text{res station}}$

— two travelling masses, each producing $U_{\text{c travel}} = 5U_{\text{c station}}$

10.3.4 Permissible errors of test masses

10.3.4.1 Mass

The permissible error in the test mass is directly related to the task and should not influence the test by more than 10 %.

a) For the U_{mar} test, the permissible mass error is ±1 %.

b) For the URR test, the permissible mass error (percentage) is directly related to the claimed URR. The percentage is equal to:

±0,1(100 % – URR)

EXAMPLE For a test with a claimed URR of 95 %, the permissible mass error is:

±0,1(100 % – 95 %) = ±0,5 %

10.3.4.2 Position

The mounting position for test masses shall be at 30° intervals in each plane.

NOTE Older style rotors with only eight holes per plane may be modified to comply with this part of ISO 21940 (see Annex D).

The 0° reference in each test plane shall be at the same angular orientation (in the same plane through the axis of rotation).

The mounting positions shall be located relative to the true position in each of three directions with the following permissible errors:

a) in the axial direction: within the same percentage as determined for the mass tolerance in 10.3.4.1 for the URR test (e.g. ±0,5 %), but applied to the correction plane distances;

b) in the radial position: within the same percentage as above (e.g. ±0,5 %), but applied to the radius;

c) in the angular position: within the same percentage as above, but applied to the unit of angle (1 rad = 57,3°); e.g. ±0,5 % is equivalent to ±0,3°.

In order to facilitate tests with proving rotors type B and type C, it is advisable to line up the thread pattern for the end drive to the 0° position of the proving rotor.

10.3.5 Material

For medium and small proving rotors, some test masses may become difficult to design and inconvenient to handle because of their small size. In these cases, it is preferable to make the test masses from low-density material (e.g. aluminium or plastics).

11 Verification tests

11.1 Requirements for performance and parameter verification

To verify the claimed performance of a balancing machine in general, two to four separate tests are required:

— the U_{mar} test (test for minimum achievable residual unbalance);

— the URR test (test for unbalance reduction ratio);

— the ISC test (test for interference from couple unbalance with resultant unbalance indication), required only for single-plane machines;

— the test of the compensator used for index balancing.

These tests are described in 11.6 to 11.9 and shall be conducted by the manufacturer either at their plant or after installation on site; the location is to be agreed between the manufacturer and user.

The tests shall be performed during acceptance of a balancing machine and should also be performed later on a periodic basis to ensure that the machine is capable of handling the actual balancing tasks.

Proving rotors type A and type B are chosen according to the type of balancing machine (see 10.2). Proving rotors type C shall be used only if outboard rotors are to be balanced on a horizontal machine and upon prior agreement between the manufacturer and user.

NOTE Tables 6 and 7 give an overview of the U_{mar} and URR tests for proving rotors types A, B, and C.

These tests represent a minimum test procedure designed to establish essential compliance with the requirements for:

— minimum achievable residual unbalance (U_{mar});

— combined accuracy of amount-of-unbalance indication, angle indication and plane separation (URR);

— suppression of couple unbalance (ISC);

— accuracy of the compensator.

The test procedures do not prove compliance with all requirements over the full range of variables, nor do they define the exact reason when the machine fails to comply.

In addition, equipment parameters shall be verified. This includes physical inspection of various dimensions, features, instrumentation, tooling and accessories.

11.2 Duties of manufacturer and user

11.2.1 Examiner

For these tests, the user shall provide an examiner trained in the use of balancing machines. The manufacturer shall instruct the examiner in the use of the machine. The examiner may either operate the machine or satisfy him/herself that he/she could obtain the same results as the operator. The manufacturer shall ensure that the written instructions are followed by the examiner.

11.2.2 Readings

The examiner shall print or read off the unbalance indication from the machine's instrumentation, log the values, convert them into units of U_{mar} and subsequently plot them. The manufacturer shall be entitled to check the accuracy of the examiner's work.

11.2.3 Condition of proving rotor and test masses

The manufacturer is responsible for the condition of the proving rotor, the correctness of the test masses and the location of the test masses. The examiner shall be entitled to verify this.

NOTE Older style rotors with only eight holes per plane may be modified to comply with this part of ISO 21940 (see Annex D).

11.3 Requirement for weighing scale

A weighing scale shall be available having sufficient accuracy to meet the requirements of 10.3.4.1.

11.4 Test and rechecks

When a balancing machine fails to conform in a test, the manufacturer shall be entitled to adjust or modify the machine, after which the complete test shall be repeated and the machine shall conform in that test in order to qualify as being acceptable.

11.5 Test speed

The appropriate test speed for the proving rotor may be determined in the following ways and agreed upon between manufacturer and user:

a) a typical speed of the balancing machine to be tested, based on specification data of the manufacturer;

b) 10 % to 20 % of the highest permissible test speed of the proving rotor (see Tables 3 to 5), adapted to the specification data of the manufacturer;

c) a typical speed at which the user intends to balance rotors;

d) when the user's own rotor is prepared as a proving rotor, the intended balancing speed of this rotor.

11.6 Test for minimum achievable residual unbalance, U_{mar}

11.6.1 General

This test is intended to check the ability of the machine to balance a rotor to the claimed minimum achievable residual unbalance, U_{mar}.

A two-plane test is described in detail, deviations for a single-plane test are mentioned.

11.6.2 Starting-point

11.6.2.1 Plane setting for balancing

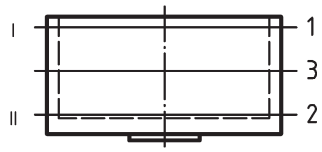
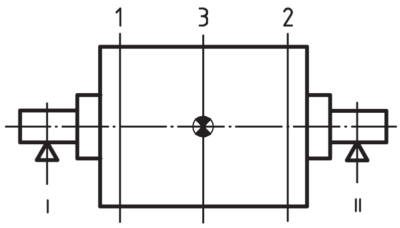
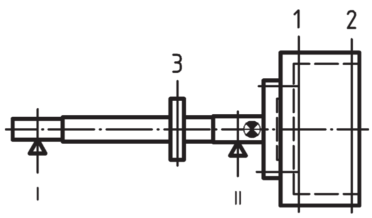
For the particular rotor under consideration, perform the mechanical adjustment of the balancing machine. Calibration or setting is done for balancing in plane(s) (which are not the test planes); see Tables 6 and 7.

11.6.2.2 Initial unbalance

Make sure that the unbalance in each plane of the proving rotor is smaller than five times the claimed minimum achievable residual unbalance (10 times for a single-plane test). If necessary, correct for these unbalances. Use locations which do not interfere with the following test steps.

EXAMPLE Correction planes on a proving rotor type B: rotor body end-faces (see Key 2 in Figure 5).

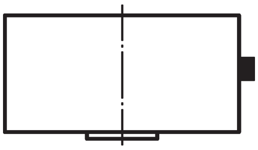
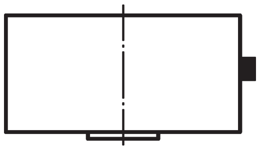
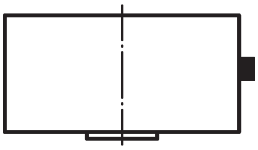
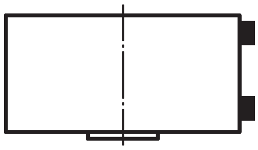
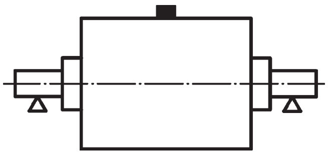
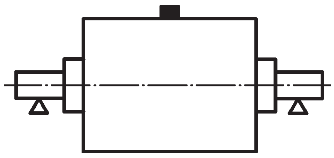
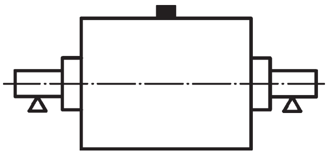
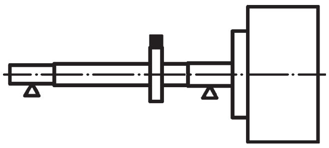
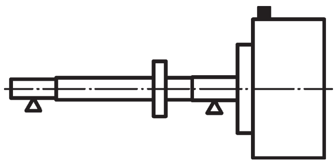
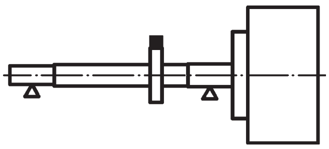
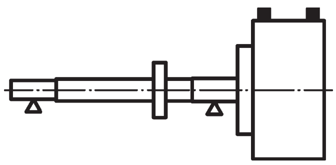
Table 6 — Proving rotors and their planes for the tests of Table 7

Balancing machine axis	Centre of mass location	Proving rotor (see 10.2)	Type of test
Vertical	—	 Type A	single-plane → two-plane →
Horizontal	inboard	 Type B	single-plane → two-plane →
	outboard	 Type C	single-plane → two-plane →

1, 2, 3 test planes

I, II measuring planes for U_{mar}

Table 7 — Overview of U_{mar} and URR tests with proving rotors of Table 6

U_{mar} **test** (see 11.6)	**URR test** (see 11.7)
Balancing with plane setting: resultant unbalance  Test mass producing $10U_{mar}$ in plane 3 Measuring: resultant unbalance	Test mass in plane 3  $U_{station}$ = (20 to 60)U_{mar} U_{travel} = 5$U_{station}$ Measuring: resultant unbalance
Balancing with plane setting: to correction planes near to 1, 2  Test mass producing 10 U_{mar} in plane 3 Measuring: in planes I, II	Test masses in each plane 1, 2  $U_{station}$ = (20 to 60)U_{mar} U_{travel} = 5$U_{station}$ Measuring: planes 1, 2
Balancing with plane setting: resultant unbalance  Test mass producing $10U_{mar}$ in plane 3 Measuring: resultant unbalance	Test mass in plane 3  $U_{station}$ = (20 to 60)U_{mar} U_{travel} = 5$U_{station}$ Measuring: resultant unbalance
Balancing with plane setting: to correction planes near to 1, 2  Test mass producing $10U_{mar}$ in plane 3 Measuring: in planes I, II	Test masses in each plane 1, 2  $U_{station}$ = (20 to 60)U_{mar} U_{travel} = 5$U_{station}$ Measuring: planes 1, 2
Balancing with plane setting: resultant unbalance  Test mass producing $10U_{mar}$ in plane 3 Measuring: resultant unbalance	Test mass in plane 1  $U_{station}$ = (20 to 60) U_{mar} U_{travel} = 5$U_{station}$ Measuring: resultant unbalance
Balancing with plane setting: to correction planes near to 1, 2  Test mass producing $10U_{mar}$ in plane 3 Measuring: in planes I, II	Test masses in each plane 1, 2  $U_{station}$ = (20 to 60)U_{mar} U_{travel} = 5$U_{station}$ Measuring: planes 1, 2
1, 2, 3 test planes I, II measuring planes for U_{mar}	

11.6.3 Unbalance added

Add two unbalance masses (such as balancing clay) to the rotor. They shall be equivalent to $5U_{mar}$ to $10U_{mar}$ each. The unbalance masses shall not be:

a) in the same radial plane;

b) in a correction plane;

c) in a test plane;

d) at the same angle;

e) displaced by 180°.

EXAMPLE For planes on a proving rotor type B to add these unbalances: rotor body surface near to the test planes.

NOTE In the case of a single-plane test, one unbalance mass of $10U_{mar}$ to $20U_{mar}$ is used.

11.6.4 Readings

Readings of these initial unbalances (and after each correction step, see 11.6.5) are recorded in Table 8.

11.6.5 Correction

Balance the rotor as well as possible (following the standard procedure for the machine) in a maximum of four runs. Apply corrections in the correction plane(s). Take readings and record them in Table 8.

EXAMPLE Correction planes on a proving rotor type B: rotor body end-faces (see Key 2 in Figure 5).

NOTE If residual unbalance is not well below $0{,}5U_{mar}$ in each plane (two-plane test) or below U_{mar} (single-plane test), the machine will probably not pass the test.

11.6.6 Reference change

In the case of horizontal machines, after performing the actions specified in 11.6.2 to 11.6.5, change the angular reference system of the machine by 60°:

— on end-drive machines, turn the drive shaft with respect to the rotor;

— on belt-drive machines, shift the angle reference.

If a 60° change is not possible, a 90° change may be made.

If, after the reference system has been changed, the next reading (run 6) is unsatisfactory (see Note to 11.6.5), the problems should be remedied before continuing the test.

11.6.7 Plane setting for U_{mar} test

Set the instrument to read in measuring plane(s) according to Tables 6 and 7.

11.6.8 Test runs

Attach in test plane 3 a test mass producing $10U_{mar}$ (see 10.3.2). Run rotor, measure and record unbalance readings (amounts only) in Table 9.

Attach this mass in all available holes in plane 3 using a sequence that is arbitrary.

Run rotor, measure and record readings in both planes for each position of the mass in Table 9.

11.6.9 U_{mar} evaluation

11.6.9.1 Calculation

Calculate the arithmetic mean value per plane by adding the values of all readings per plane, and dividing the result by 12. Record the arithmetic mean value in Table 9 under "Mean value".

Divide each reading by the "Mean value" of the respective plane and record the results in Table 9 under "Multiples of mean value".

11.6.9.2 Plot

Plot the calculated values (multiples of mean value) in Figure 7.

11.6.9.3 Lines

In Figure 7, the horizontal middle-line represents the arithmetic mean of the readings in each plane. Two dashed lines (0,88 and 1,12) represent the limit lines: ±12 % of the arithmetic mean for each plane, which account for 1 times the claimed U_{mar} + 20 % for the effects of variation in the position of the masses and scatter of the test data.

11.6.9.4 Assessment

The machine is considered to have passed the U_{mar} test, i.e. the claimed minimum achievable residual unbalance has been reached, if the following condition is met.

All points plotted on Figure 7 are within the range given by the two dashed lines (0,88 and 1,12), with one exception allowed.

11.7 Test for unbalance reduction ratio, URR

11.7.1 URR tests on single-plane balancing machines

On horizontal and vertical single-plane balancing machines designed to indicate resultant unbalance only, the unbalance reduction test is intended to check only the combined accuracy of amount-of-unbalance indication and angle indication.

11.7.2 URR tests on two-plane balancing machines

On horizontal and vertical two-plane balancing machines designed to indicate dynamic unbalance, the unbalance reduction test is intended to check the combined accuracy of amount-of-unbalance indication, angle indication and plane separation.

NOTE On outboard proving rotors type C, as an alternative the URR test can be performed with resultant or couple unbalance test masses. Deviations from the two-plane test are described in the following subclauses.

11.7.3 General

The test and the method of recording the machine indications are designed to prevent machine operators from knowing in advance what the readings should be, and thereby prevent them from influencing the outcome.

The test consists of a set of 11 measuring runs. The test is run with a stationary test mass and a travelling test mass (see 10.3.3) in each test plane.

Unbalance readings are recorded on the test sheet and subsequently plotted and evaluated.

There are different URR test data sheets for two-plane (Table 10) and single-plane (Table 11) tests. Prepare the test data sheet prior to making the actual test runs so that test data are entered in the proper order.

Table 8 — Data sheet for balancing the proving rotor

Date of test: ....
Location of test: ....
Balancing machine operated by: ....
Readings taken and recorded by: ....

Balancing machine tested, make: ....
Model: ....

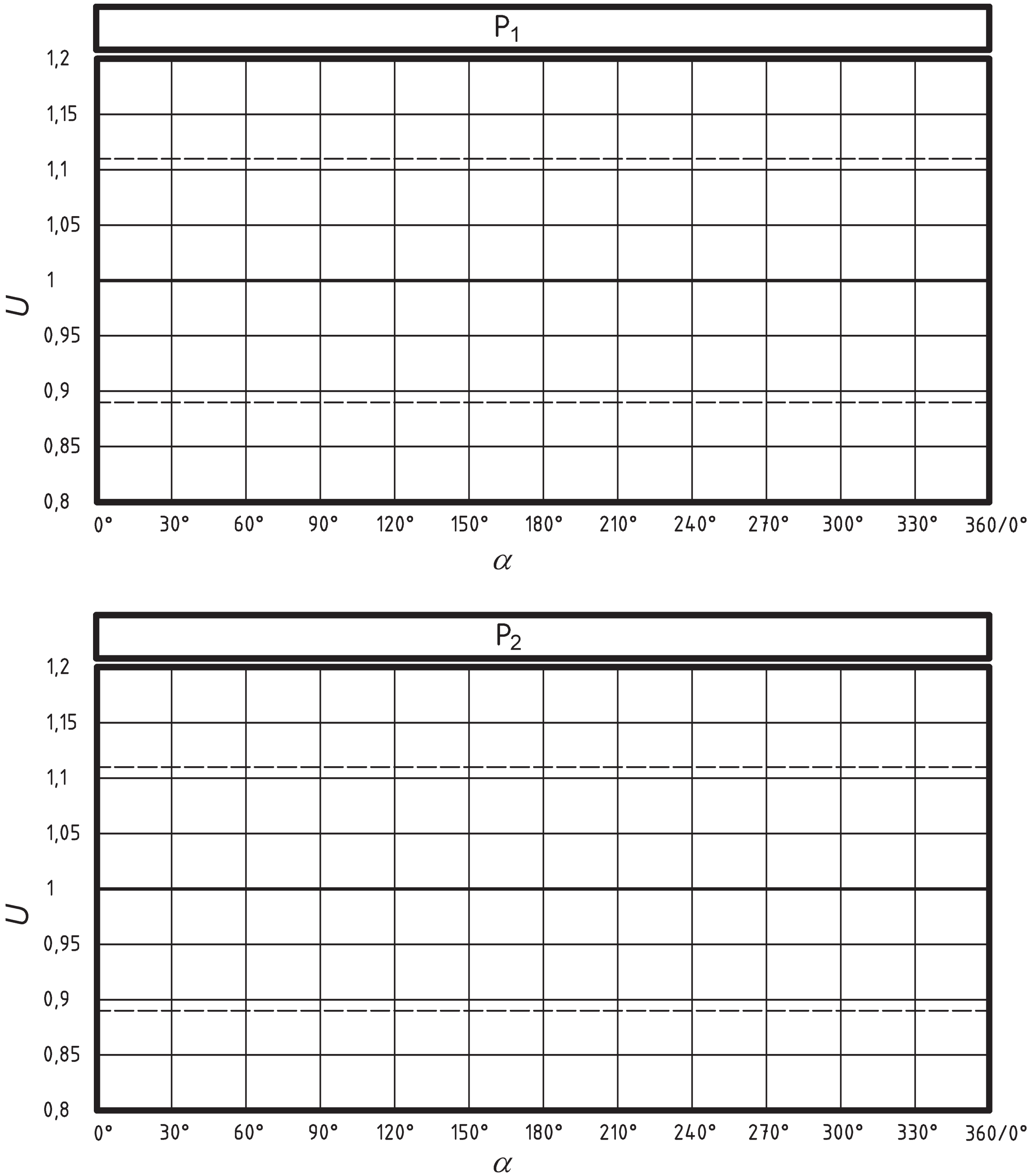
Proving rotor, type: ....
No.: .... Mass: .... kg
U_{mar} = ... g·mm 10 U_{mar} = ... g·mm
Test mass: .... g Effective radius: .... mm
Test speed: .... r/min

	Plane 1 reading		Plane 2 reading		Correction
	Amount U_{mar}	Angle °	Amount U_{mar}	Angle °	
Run 1 initial unbalance					
Run 2					
Run 3					
Run 4					
Run 5 residual unbalance					not allowed
Run 6 after 60° reference change					not allowed

Table 9 — Test data sheet for U_{mar} test

Position of test mass	Amount of unbalance	Amount of unbalance	Multiples of mean value	Multiples of mean value
°	Plane 1	Plane 2	Plane 1	Plane 2
0				
30				
60				
90				
120				
150				
180				
210				
240				
270				
300				
330				
Sum				
Mean value				

NOTE For single-plane machines, use plane 1 columns to record the readings for the resultant unbalance.



Key

U unbalance readout

α position of test masses

P_1 plane 1

P_2 plane 2

NOTE Unbalance readout is in multiples of arithmetic mean values.

Figure 7 — Diagram for evaluation of U_{mar} test

11.7.4 Preparation of test sheets

11.7.4.1 Two-plane test

Preparation of a test data sheet (see Table 10) entails the following steps.

a) Enter at the top of the data sheet the requested data so that the test conditions are permanently recorded.

b) Arbitrarily choose in plane 1 one of the 12 possible test mass positions for the stationary test mass and enter the degree value in the "Run No. 1" row on the "Plane 1, stationary" column of the data sheet.

c) Choose in plane 2 a position for the stationary test mass. This should neither be the same position nor opposite to the stationary test mass in plane 1. Enter the degree value in the "Run No. 1" row on the "Plane 2, stationary" column of the data sheet.

d) Arbitrarily choose in plane 1 one of the remaining 11 positions as the starting position for the travelling test mass and enter the degree value in the "Run No. 1" row on the "Plane 1, travelling" column of the data sheet.

e) Arbitrarily choose in plane 2 a starting position for the travelling test mass. Enter the degree value in the "Run No. 1" row on the "Plane 2, travelling" column of the data sheet.

f) Enter successive positions for successive runs in the data sheet for both travelling test masses, letting them travel:

   — in plane 1 in ascending 30° intervals;

   — in plane 2 in descending 30° intervals.

   Skip the stationary test mass positions, since two test masses cannot occupy the same position.

For a resultant or couple test, use Table 10 with the following modifications.

— Mark plane 1 as the left-hand couple plane. This means positions and readings for couple test masses in plane 1 (couple test masses in plane 2 are always 180° apart).

— Mark plane 2 as the middle plane (between planes 1 and 2). This means positions and readings for resultant test masses.

11.7.4.2 Single-plane test

Table 11 is for only one plane. The rules to chose positions for the stationary and travelling test masses are identical to plane 1 of the two-plane test (see 11.7.4.1).

11.7.5 Plane setting

The machine shall be set to read in the test planes (see Tables 6 and 7).

For a resultant or couple test on a proving rotor type C, the machine shall be set to read the couple unbalance in planes 1 and 2 and resultant unbalance in the middle plane (between planes 1 and 2).

11.7.6 URR test runs

11.7.6.1 Starting-point

Unless a U_{mar} test has immediately preceded this one, perform steps specified in 11.6.2 to 11.6.6.

11.7.6.2 Test planes

Test planes shall be according to Table 6.

For a resultant or couple test, planes 1 and 2 are used for the couple test masses, and the middle plane (between planes 1 and 2) for the resultant test masses.

11.7.6.3 Procedure

Add the stationary and travelling test masses in starting position (Run No. 1 row) to the test planes of the proving rotor as shown in the data sheet.

Make a run, measure and record the amount and angle readings for the planes on the data sheet.

Advance the travelling test masses to the next positions as shown in the data sheet, make a run, measure and record the amount and angle readings for the planes in the data sheet, until 11 successive runs have been performed.

Divide amount readings by the unbalance value of the stationary mass (both in terms of unbalances) to obtain values in multiples of the stationary unbalance, U_{station}. Enter these values in the appropriate columns of the data sheet.

11.7.7 Plotting URR test data

11.7.7.1 Evaluation diagrams

Each evaluation diagram (Figure 8 for two-plane test and Figure 9 for single-plane test) contains a diagram with 11 sets of concentric URR limit circles. From the inside outwards, the concentric circles designate the limits for URR values of 95 %, 90 %, 85 %, and 80 %.

Instructions for drawing these diagrams are given in Annex B.

11.7.7.2 Two-plane test

See Figure 8.

a) Enter the angular position of plane 1 stationary test mass on the short line above the arrow in the appropriate URR evaluation diagram. Mark radial lines in 20° intervals by entering degree markings in 20° increments (rising clockwise) on all short lines around the periphery of the diagram.

b) Since the stationary test mass in plane 2 has a different angular position, enter a second angular reference system into the diagram for plane 2. To avoid interference with the degree markings for plane 1, enter the degree markings for plane 2 in the oval circles provided halfway between the degree markings for plane 1.

c) Using the amount (multiples of U_{mar}) and angle values from the data sheet, plot the plane 1 readings in the form of test points (dots) on the appropriate URR diagram, using the amount scale as shown next to the vertical arrow.

d) Next, plot the plane 2 readings, but in order to avoid confusing plane 1 test points with plane 2 test points, circle all test points for plane 2.

For a resultant or couple test, plane 1 means couple unbalance, plane 2 means resultant unbalance (see 11.7.4.1).

11.7.7.3 Single-plane test

See Figure 9.

Enter only one angular reference system into the diagram.

Table 10 — URR test data sheet for two-plane test

Company: ....

Location of test: ....

Balancing machine tested, make: .... Model: ....

Balancing machine operated by: ....

Readings taken and logged by: .... Date of test: ....

Proving rotor, type: .... No.: .... Mass: .... kg

Claimed e_{mar} = ... g·mm/kg

Claimed U_{mar} = ... g·mm

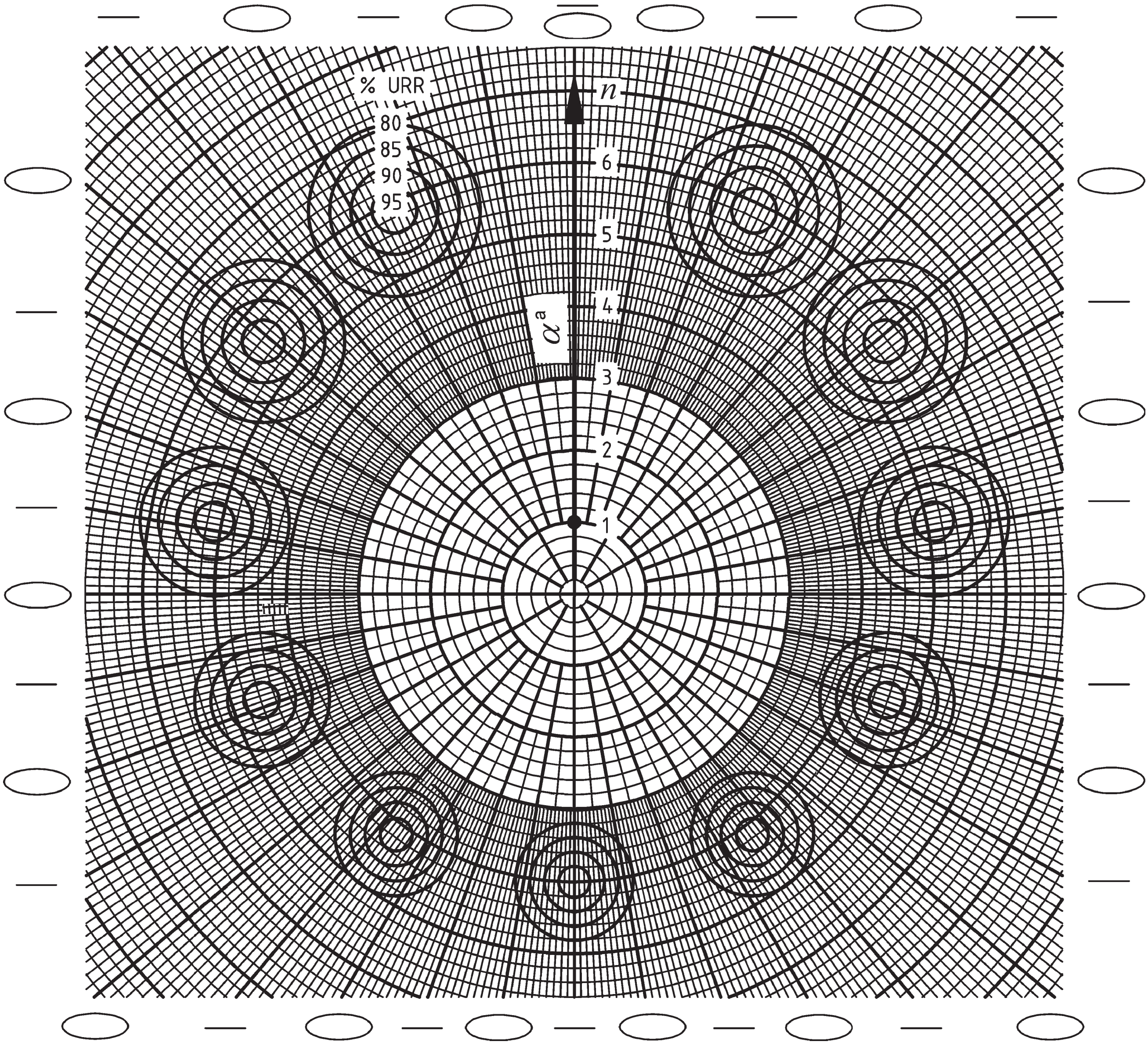
$U_{station}$ = ... × U_{mar} = ... g·mm

Effective radius: .... mm Stationary mass: .... g

U_{travel} = 5 $U_{station}$ = ...g·mm

Effective radius: .... mm Travelling mass: .... g

Run No.	**Test mass positions (angles)** Plane 1 Stationary °	Plane 1 Travelling °	Plane 2 Stationary °	Plane 2 Travelling °	**Unbalance readout** Plane 1 Amount g·mm	Angle °	**Amount** Reading plane 1 divided by $U_{station}$ Multiple of $U_{station}$	**Unbalance readout** Plane 2 Amount g·mm	Angle °	**Amount** Reading plane 2 divided by $U_{station}$ Multiple of $U_{station}$
1										
2	″		″							
3	″		″							
4	″		″							
5	″		″							
6	″		″							
7	″		″							
8	″		″							
9	″		″							
10	″		″							
11	″		″							



URR achieved: ....

Test points plotted by: ....

Key

n	amount scale in multiples, n, of stationary test mass unbalance, $U_{station}$
α [a]	position of stationary test mass (indicated by the vertical arrow)
% URR	unbalance reduction ratio as percentage

[a] Insert angular reference system according to position of stationary mass:

——— plane 1, use •

⬭ plane 2, use ⊙

Figure 8 — URR evaluation diagram for two-plane test

Table 11 — URR test data sheet for single-plane test

Company: ....

Location of test: ....

Balancing machine tested, make: .... Model: ....

Balancing machine operated by: ....

Readings taken and logged by: .... Date of test: ....

Proving rotor, type: .... No.: .... Mass: .... kg

Claimed e_{mar} = ... g·mm/kg

Claimed U_{mar} = ... g·mm

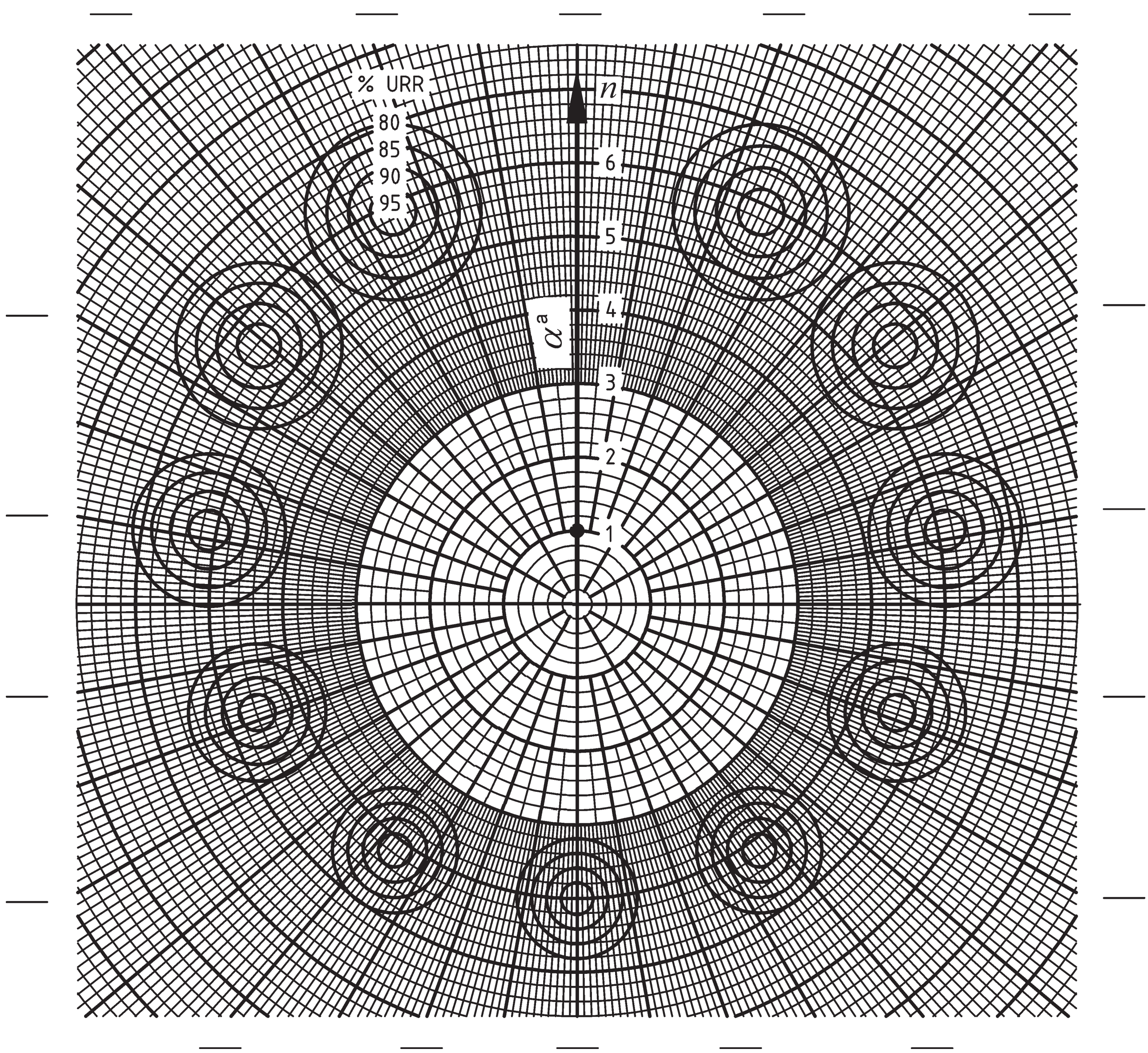
$U_{station}$ = ... $\times U_{mar}$ = ... g·mm

Effective radius: .... mm Stationary mass: .... g

$U_{travel} = 5\ U_{station}$ = ... g·mm

Effective radius: .... mm Travelling mass: .... g

Run No.	**Test mass positions (angles)** Plane 3		**Unbalance readout** Plane 3		**Amount** Reading plane 3 divided by $U_{station}$
	Stationary °	Travelling °	Amount g·mm	Angle °	Multiple of $U_{station}$
1					
2	″				
3	″				
4	″				
5	″				
6	″				
7	″				
8	″				
9	″				
10	″				
11	″				



URR achieved: ....

Test points plotted by: ....

Key

n amount scale in multiples, n, of stationary test mass unbalance, $U_{station}$

α [a] position of stationary test mass (indicated by the vertical arrow)

% URR unbalance reduction ratio as percentage

[a] Insert angular reference system according to position of stationary mass:

——— resultant plane

Figure 9 — URR evaluation diagram for single-plane test

11.7.8 Evaluation

If a test point falls within the innermost circle (or on its line), the reading qualifies for a 95 % circle. If a test point falls between the 95 % circle and the 90 % circle (or on its line), the reading qualifies for a URR of 90 %, and so on.

NOTE If a URR value other than 95 %, 90 %, 85 % or 80 % is specified, an intermediate circle of appropriate diameter may be inserted (see Annex B).

All test points on a URR evaluation diagram shall fall within the URR limit circles that correspond to the claimed value for the URR, with one exception per correction plane allowed. If not, the machine fails the test, in which case the rules given in 11.4 apply.

11.8 Test for couple unbalance interference on single-plane machines

11.8.1 Starting point

On horizontal and vertical single-plane balancing machines, the ability to suppress indication of couple unbalance shall be checked.

Balance the rotor as stated in 11.6.5.

11.8.2 Procedure

Add one test mass each (e.g. the travelling mass of the URR test) in planes 1 and 2 of the rotor, exactly 180° apart, and take a reading of the resultant unbalance. Shift the couple unbalance test masses by 90° three times in succession, each time taking a new reading.

11.8.3 Evaluation

None of the four readings may exceed the value of the attached couple unbalance multiplied by the claimed couple unbalance interference ratio, plus the claimed minimum achievable residual unbalance.

11.9 Compensator test

11.9.1 Starting-point

The compensator (used for the index balancing procedure) shall provide a consistent readout at the end of the test procedure.

NOTE This test checks the compensator by simulating the indexing of the rotor by only moving the test masses.

Use the balanced proving rotor (see 11.6.5) or ensure that the unbalance is smaller than $5U_{mar}$ in each plane (see 11.6.2.2).

11.9.2 Procedure

Add in plane 1:

— a stationary test mass at 30° producing $U_{station}$;

— a travelling test mass at 150° producing U_{travel}.

Add in plane 2:

— a stationary test mass at 150° producing $U_{station}$;

— a travelling test mass at 30° producing U_{travel}.

Run the balancing machine and set the compensator for the first step according to the manufacturer's manual.

To simulate the indexing, move:

— in plane 1 the travelling test mass from the 150° position to 330° (180° shift);

— in plane 2 the travelling test mass from the 30° position to 210° (180° shift).

Run the balancing machine and set the compensator for the second step according to the manufacturer's manual.

Remove:

— in plane 1 the travelling test mass (located at 330°);

— in plane 2 the travelling test mass (located at 210°).

NOTE The stationary test masses in plane 1 at 30° and in plane 2 at 150° are still in place.

Run the machine and set the compensator to read rotor unbalance.

11.9.3 Evaluation

The compensator passes the test if the reading in each plane does not exceed $0{,}02U_{\text{station}}$.

11.10 Simplified tests

11.10.1 General

If a balancing machine has been type tested thoroughly before, or a machine in operation periodically is undergoing tests, a reduced effort is sufficient.

Both the U_{mar} and the URR tests may be simplified in reducing the number of test runs.

11.10.2 Simplified U_{mar} test

a) Follow the procedures in 11.6.2 to 11.6.7.

b) In 11.6.8, skip every second angular position, thus reducing the number of runs to six.

NOTE The remaining angles are evenly spread around the rotor, e.g. 0°, 60°, 120°, 180°, 240°, 300°.

c) Follow 11.6.9.1 to 11.6.9.3 but calculate the arithmetic mean value per plane by dividing the sum by six.

d) The balancing machine has passed the test if all plotted points are within the range given by the two dashed lines in Figure 7 (0,88 and 1,12). No exception is allowed.

11.10.3 Simplified URR test

a) Follow 11.7.4 to 11.7.8 but skip all positions being 60° or multiples apart from the stationary test mass in each plane. This reduces the number of runs to six.

b) Enter for the travelling test masses 60° ascending or descending intervals in the log, see 11.7.4.1 f).

c) Make six successive runs in accordance with 11.7.6.3.

d) All test points on the test sheet shall fall within the URR limit circles (or on their perimeter lines) that correspond to the claimed value for the unbalance reduction ratio, URR. No exception is allowed.

Annex A
(informative)

Information provided by the user to the balancing machine manufacturer

A.1 General

This annex comprises minimum information that users should provide to the balancing machine manufacturer in order to enable the manufacturer to meet users' requirements.

A.2 Rotor to be balanced

A.2.1 Essential rotor data

Give data on limiting factors, such as mass, dimensions and tolerances.

If the balancing machine is to be used for many types of rotors, Table A.1 should be completed for each type. The maximum and minimum sizes of rotors that the machine is required to balance should be indicated.

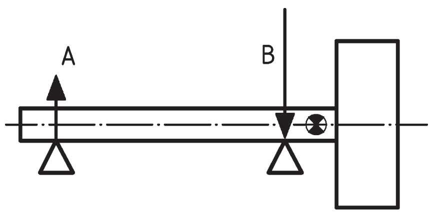
If the machine is to be used for series balancing of a limited number of specific rotors, detailed information, including rotor manufacturer's drawings, should be supplied in lieu of Table A.1.

A.2.2 Other rotor data

A.2.2.1 Include detailed drawings. If possible, the user should send drawings of typical rotors to be balanced. This is particularly important for rotors with unusual geometry.

A.2.2.2 If correction planes are located other than between the journals, describe their locations.

A.2.2.3 Is the balancing machine to be used with outboard rotors? If so, what is load B and negative load A? (See Figure A.1.)



Key

A, B loads

Figure A.1 — Loads

Table A.1 — Data of typical rotors with rigid behaviour to be balanced

Parameter	Rotor type[a]					Unit
	1	2	3	4	…	
Mass						kg
Quantity[b]						
Production rate required[c]						per hour/per day[d]
Dimensions (See Figures A.2 and A.3.)						
Maximum diameter, D						mm
Belt-drive diameter, Q[e,f]						mm
Maximum length, L						mm
Journal diameters, d[e]						mm
Distance between journal centres, W[e]						mm
Correction plane location A						mm
B						mm
C						mm
End clearance on driven end, P[f]						mm
Service speed						r/min
Resonance speed[g]						r/min
Moment of inertia[h]						$kg \cdot m^2$
Air resistance[i]						
Power and speed						kW; r/min
Maximum initial unbalance[j]						g·mm
Unbalance tolerance[k]						g·mm
Number of correction planes[l]						
Drive[e,m]						
Correction means[n]						

[a] Type(s) of rotor(s) and use: e.g. 4-cylinder crankshaft, flywheel, ventilator, electric rotor, fan.

[b] Approximately how many rotors of the same type are to be balanced in succession before changing over to another type.

[c] If applicable, state the desired production rate in pieces per hour or pieces per day at 100 % efficiency.

[d] Delete the unit not used.

[e] Generally applicable only to horizontal machines.

[f] If applicable, state the diameter over which the belt shall drive.

[g] For multi-bearing rotors, e.g. crankshafts, state the approximate frequency value of the first flexural resonance speed of the rotor, simply supported in rigid bearings on the two end journals.

[h] Moment of inertia is $\int r^2 \, dm$ over the entire rotor body, where dm is an increment of mass and r is its distance from the shaft axis.

[i] Does the rotor offer substantial air resistance during the balancing operation? If so, give expected power required and the corresponding speed.

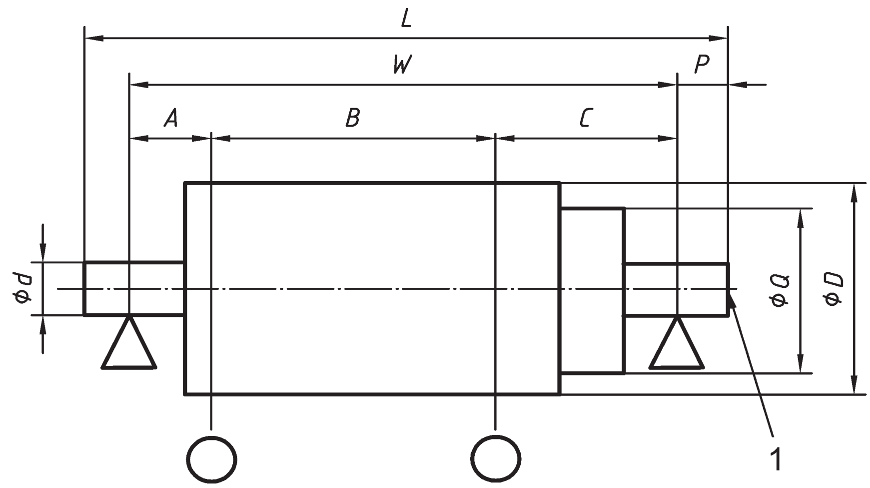
[j] Maximum initial unbalance (g·mm) in each correction plane.

[k] Unbalance tolerance (g·mm) in each correction plane.

[l] State the number of planes in which correction is to be made. If correction in more than two planes is required, explain separately.

[m] State the means by which the rotor may be rotated: belt drive, end drive, either belt or end drive, air drive, roller drive, self-powered drive, band drive, etc.

[n] State the means of correction intended, e.g. drilling, milling or addition of correction masses.



Key

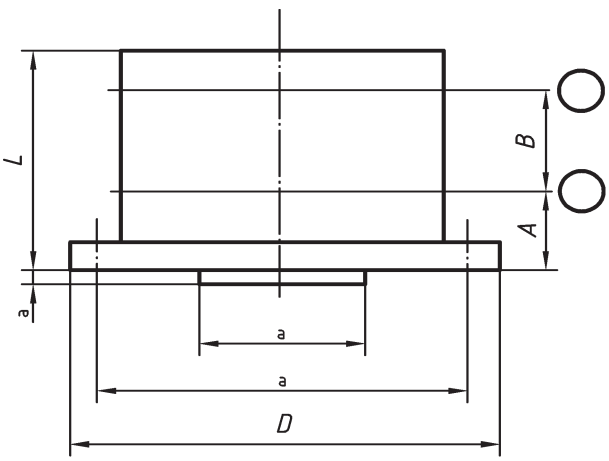
1 driven end

○ correction planes

△ bearing planes

NOTE For dimensions, see Table A.1.

Figure A.2 — Example of a rotor for a horizontal balancing machine



Key

○ correction planes

NOTE For dimensions, see Table A.1.

[a] Mounting dimensions, including number of bolt holes and their diameter, or central bore or taper used to mount the rotor in assembly should be stated.

Figure A.3 — Example of a rotor for a vertical balancing machine

A.2.2.4 Is there a thrust load? If so, give value and direction expected during balancing operation (applicable to horizontal machines only).

A.2.2.5 Does the user require the balancing machine manufacturer to supply the necessary fixtures and attachments, such as driving adaptors, pulleys, mounting adaptors and mandrels?

A.2.2.6 What is the journal finish, roundness and hardness?

A.2.2.7 Are the rotors to be balanced in their own bearings? If so, give details, e.g. type of bearings and maximum outside diameter of bearings.

A.2.2.8 Is a specific balancing speed desired? If so, explain.

A.2.2.9 Does the user expect the balancing machine manufacturer to supply the means of correction (drills, milling cutters, etc.)?

A.2.2.10 Are there any other special rotor properties, e.g. rotating magnetic fields and aerodynamic effects?

A.3 Other technical information and requirements

A.3.1 Is the main electrical supply three- or single-phase voltage? Give frequency and maximum possible deviation, expressed as a percentage. If the three-phase system is earthed (grounded), is there a neutral lead available? Should the electrical equipment meet any particular standard or specification?

A.3.2 Is tropical insulation required?

A.3.3 Is compressed air available? At what pressure? With what maximum variation?

A.3.4 Is the floor rigid where the machine is to be located, i.e. equivalent to a concrete slab laid on compacted earth? How thick is the concrete floor?

A.3.5 State possible sources of vibration in the vicinity, e.g. hammers and heavy vehicles. State their average rate of occurrence.

A.3.6 What units should be marked on indicating devices?

A.3.7 In which language should the operating instructions and leaflets accompanying the balancing machine preferably be written? What other languages are also acceptable?

A.4 Administrative information and requirements

A.4.1 Does the user require the services of a balancing machine service engineer to install and calibrate the machine?

A.4.2 Does the user require the services of a balancing machine service engineer to instruct the personnel?

A.4.3 Does the user intend to send an operator to be trained by the manufacturer?

A.4.4 What are the names and addresses of people in the user's organization in charge of balancing?

A.4.5 Who inspects and accepts the machine and where? Where are the applicable specifications?

A.4.6 Is the user interested in a maintenance contract?

A.4.7 To whom shall the quotation be addressed?

A.4.8 State address to which the machine is to be shipped.

A.4.9 Give any box markings.

A.4.10 Give insurance instructions.

A.4.11 State, as applicable:

— FOB (free on board) plus indication of loading port;

— FAS (free alongside ship) plus indication of loading port;

— CIF (cost insurance freight) plus indication of designation port; etc.

A.4.12 Requested delivery date.

Annex B
(informative)

URR limit diagrams

B.1 Basic data

Underlying data for the URR limit diagrams shown in Figures 8 and 9 are listed in Tables B.1 and B.2. Even though they are calculated for $U_{station} = 30U_{mar}$, they may be used with sufficient accuracy in the range of $U_{station} = 20U_{mar}$ to $60U_{mar}$.

Table B.1 — Two-plane URR limit diagram data (see Figure 8)

Origin of URR limit circles			Radii r^c of URR limit circles			
α^a °	γ^b °	R^c	80 %	85 %	90 %	95 %
30	25,1	5,89	1,19	0,900	0,605	0,311
60	51,1	5,57	1,13	0,852	0,573	0,295
90	78,7	5,10	1,04	0,782	0,527	0,272
120	109,1	4,58	0,93	0,704	0,475	0,246
150	143,1	4,16	0,85	0,641	0,433	0,225
180	180	4,00	0,82	0,617	0,417	0,217

[a] Angle between the stationary mass and the travelling mass as defined in Figure B.1.

[b] Angle of the resultant vector R.

[c] In multiples of $U_{station}$.

Table B.2 — Single-plane URR limit diagram data (see Figure 9)

Origin of URR limit circles			Radii r^c of URR limit circles			
α^a °	γ^b °	R^c	80 %	85 %	90 %	95 %
30	25,1	5,89	1,21	0,916	0,622	0,328
60	51,1	5,57	1,15	0,868	0,590	0,312
90	78,7	5,10	1,05	0,798	0,543	0,288
120	109,1	4,58	0,95	0,721	0,492	0,262
150	143,1	4,16	0,87	0,658	0,450	0,242
180	180	4,00	0,83	0,633	0,433	0,233

[a] Angle between the stationary mass and the travelling mass as defined in Figure B.1.

[b] Angle of the resultant vector R.

[c] In multiples of $U_{station}$.

B.2 Instructions for drawing URR limit circle diagrams

Proceed as follows (see Figure B.1):

a) use commercially available polar diagram paper or design your own;

b) select a suitable scale so that all circles are within the diagram part of the paper;

c) determine the URR limit circle origin; it is a distance equivalent to 1 ($1U_{station}$) vertically above the graph paper origin;

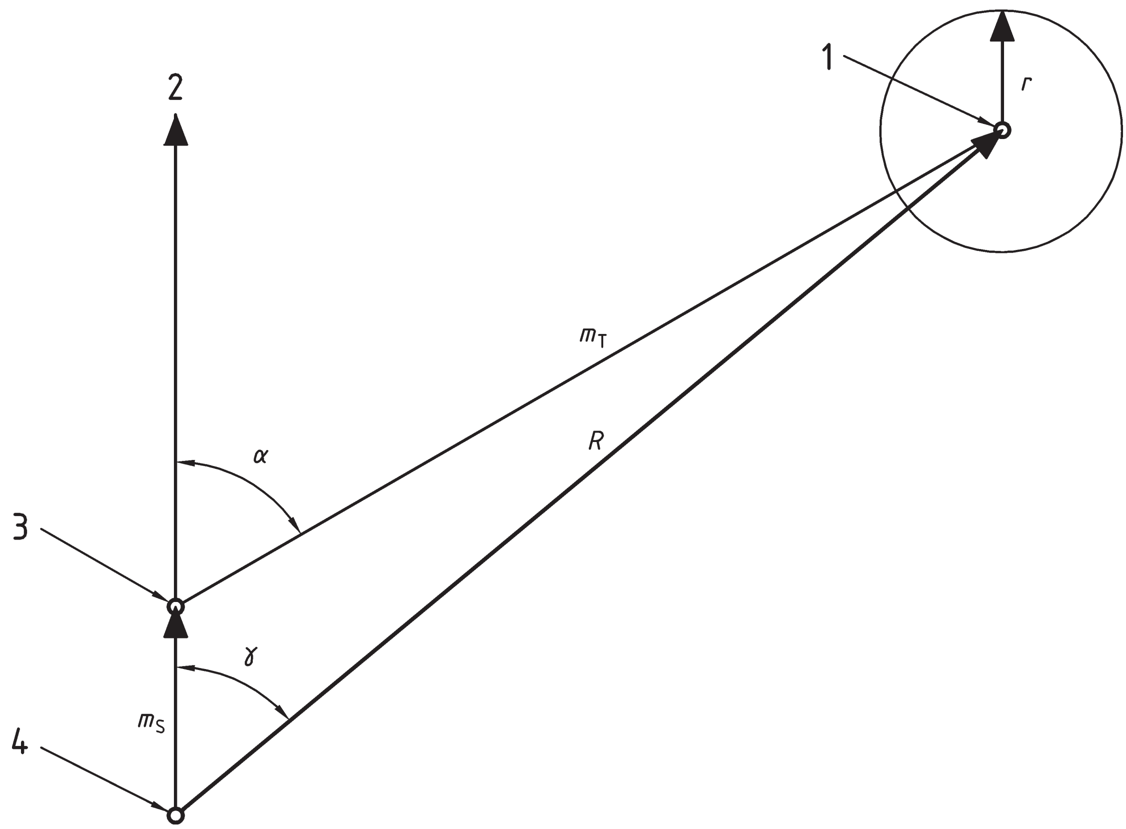
d) draw 12 equally spaced radial lines (30° apart) from the URR limit circle origin outwards;

e) determine the centre of each URR limit circle, omitting the one in the vertical direction (towards the top of the page); the centres are located on each radial line, a distance equivalent to 5 ($5U_{station}$) from the URR limit circle origin;

f) draw concentric circles around each URR limit circle centre, with radii r (in units of $U_{station}$) as shown in the columns of the selected URR values in Tables B.1 or B.2;

g) insert an arrow from the graph origin in a vertical direction to designate the position of the stationary test masses;

h) along the arrow, mark off the amount-of-unbalance scale in multiples, n, of $U_{station}$ and insert the appropriate values 1 to 6; the diagram is now ready for evaluating the logged URR test data.



Key

1 centre of URR limit circles

2 0° axis

3 URR limit circle origin (origin of travelling test mass m_T)

4 graph origin (origin of stationary test mass m_S)

NOTE For dimensions, see Table B.1.

Figure B.1 — Graphical determination of R and γ from m_S, m_T, and α

B.3 Other URR limits

If the URR limit diagrams given in Figures 8 and 9 are insufficient, i.e. a balancing machine with another unbalance reduction ratio is to be tested, an appropriate URR limit diagram can be made up with the help of the instructions given in B.4.

B.4 Calculation of URR limit circles

B.4.1 The radii and positions of URR limit circles for commonly used unbalance reduction ratios may be taken directly from Tables B.1 and B.2. The equations given in the following may serve mainly to substantiate the data in Tables B.1 and B.2, but may also be used to calculate values for R, r and γ if different URR values or angles between test masses are used.

B.4.2 The equation for determining the distance, R, i.e. the magnitude of the resultant vector of m_S and m_T (given as amount-of-unbalance indication), between the graph origin and the centre of a URR limit circle is:

$$R = \sqrt{m_S^2 + m_T^2 + 2 m_S m_T \cos \alpha}$$

where

m_S is the stationary test mass ($1 U_{station}$);

m_T is the travelling test mass ($5 U_{station}$);

α is the angle between the stationary and travelling test masses as defined in Figure B.1.

B.4.3 The equation for determining the angle, γ, between the stationary test mass, m_S, and the resultant, R, is:

$$\cos \gamma = \frac{m_S^2 + R^2 - m_T^2}{2 m_S R}$$

B.4.4 For dimensions of m_S, m_T, R, and r in multiples of $U_{station}$ and $m_T = 5 m_S$, the equations for R and γ are:

$$R = \sqrt{26 + 10 \cos \alpha}$$

$$\cos \gamma = \frac{R^2 - 24}{2R}$$

B.4.5 The equation for determining the radius of a URR limit circle, r, is:

a) For two-plane test

$$r = R\,(1 - \text{URR}) + \frac{U_{mar}}{2 U_{station}}$$

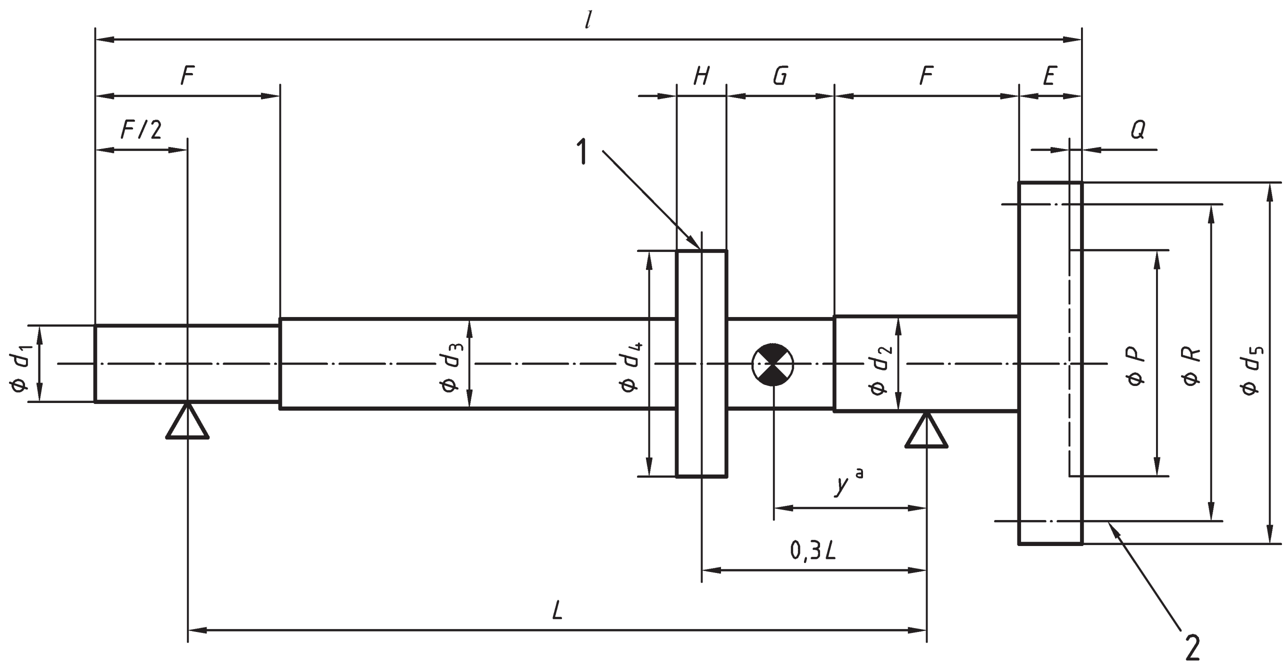
b) For single-plane test

$$r = R\,(1 - \text{URR}) + \frac{U_{mar}}{U_{station}}$$

where URR is given as absolute value, e.g. 0,925.

Annex C
(informative)

Shafts of outboard proving rotors type C



Key

1 12 equally spaced threaded holes N

2 4 equally spaced threaded holes O

End-drive interface dimensions for Nos. 3 to 5 shall be in accordance with proving rotors type B, Nos. 4 to 6.

All tolerances and residual unbalance shall be in accordance with the test aims.

NOTE 1 For dimensions, see Table C.1. Dimensions may be varied (e.g. by addition of a belt pulley), provided the mass, position of centre of mass, y, and position of N between bearings are maintained.

NOTE 2 Interface dimensions (spigot) comply with proving rotors type A.

[a] Distance of centre of mass to right-hand bearing plane.

Figure C.1 — Shafts of proving rotors type C for outboard tests on horizontal machines

Table C.1 — Recommended dimensions and masses of shafts of proving rotors type C for outboard tests on horizontal machines (see Figure C.1)

Shaft	Mass	Overall length	Bearing distance	Journals				Major diameter		Journal length				Flange[b]				
No.	m	l	L	d_1[a]	d_2	d_3	d_4	d_5	E	F	G	H	N	O	P	Q	R	y
				≈ 0,1 L	≈ 0,125 L		≈ 0,3 L			≈ 0,25 L								
Metric values																		
	kg	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm			mm	mm	mm	mm
1	1,1	217	164	17	21	20	50	85	12	41	24	11	M3	M6	50,8	5	76,2	30
2	2,7	320	240	25	30	28	72	85	20	60	34	16	M4	M6	50,8	5	76,2	60
3	8,5	460	352	36	45	42	106	156	30	88	50	24	M5	M10	114,3	6	133,35	90
4	25	700	520	58	65	62	156	156	50	130	74	34	M6	M10	114,3	6	133,35	135
5	80	1 020	760	78	95	91	230	230	70	190	108	50	M8	M10	114,3	6	133,35	200
Inch and pound values																		
	lb	in	in	in	in	in	in	in	in	in	in	in			in	in	in	in
1	2,5	8,5	6,4	0,67	0,83	0,8	2	3,4	0,5	1,6	0,9[c]	0,4	No.5 UNF	1/4 UNC	2	0,2	3	1,2
2	6	12,75	9,6	0,98	1,2	1,1	2,8	3,4	0,75	2,4	1,4[c]	0,6	No.8 UNF	1/4 UNC	2	0,2	3	2,4
3	20	18,25	14	1,42	1,8	1,65	4,2	6,2	1,18	3,5	2	0,9	No.10 UNF	3/8 UNC	4,5	0,25	5,25	3,5
4	55	27,5	20,4	2,28	2,55	2,4	6,2	6,2	2	5,1	3	1,3	1/4 UNC	3/8 UNC	4,5	0,25	5,25	5,3
5	180	40,25	30	3,07	3,7	3,5	9	9	2,75	7,5	4,25	2	5/16 UNC	3/8 UNC	4,5	0,25	5,25	8

All tolerances and residual unbalance shall be in accordance with the test aims.

Dimensions may be varied, provided the mass, m, position of centre of mass, y, and position of N between bearings are maintained.

[a] End-drive interface dimensions for Nos. 3 to 5 shall be in accordance with proving rotors type B, Nos. 4 to 6.

[b] Interface dimensions (spigot) comply with proving rotors type A.

[c] Number adjusted.

Annex D
(informative)

Modifications of proving rotors prepared in accordance with ISO 2953:1985[2] to this part of ISO 21940

D.1 Proving rotors type A

The main differences are the size of threads and test masses.

The easiest adaptation to this part of ISO 21940 is to use bolts with stepped threads: one end for the tapped holes in the proving rotor, the other end for the test masses (rings) with the thread recommended in this part of ISO 21940.

D.2 Proving rotors type B

D.2.1 General

The main differences are threads, middle plane (3), number of holes, test masses, shaft diameter and interfaces to universal joint shafts. See the recommendations in D.2.2 and D.2.3.

D.2.2 Test planes

It is recommended that all holes in the three planes be machined in one setup.

The new test planes (1 and 2) are best arranged adjacent to and inside of old planes (old holes may be closed by set screws). Add middle plane (3).

D.2.3 Interfaces to end drives

The interface may be adapted to this part of ISO 21940 by an adaptor which becomes an integral part of the proving rotor.

NOTE Too large a mass on the universal joint shaft side, however, may jeopardize the U_{mar} test.

D.3 Proving rotors type C

The main differences are the special shaft and modifications of the proving rotor type A. The shaft is a new item (see Annex C); for modification of proving rotor type A, see D.1.

Bibliography

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

[2] ISO 2953:1985, *Balancing machines — Description and evaluation*[13)]

[3] ISO 11342, *Mechanical vibration — Methods and criteria for the mechanical balancing of flexible rotors*[14)]

[4] SAE ARP 4162A, *Balancing machine proving rotors*

12) To become ISO 21940-11 when revised.

13) Withdrawn.

14) To become ISO 21940-12 when revised.

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