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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

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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.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

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 second edition cancels and replaces the first edition (ISO 21940-21:2012), which has been technically revised.

The main changes are as follows:

— the introduction of new computer based technology into balance machine indication systems;

— the introduction of additional tests for repeatability and speed range (see Annex F and Annex G);

— the introduction of greater clarification for use with automated and special purpose machines.

A list of all parts in the ISO 21940 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The purpose of this document is to provide a common framework for the specification, comparison and evaluation of balancing machines.

It describes a proforma on which the baseline balancing machine characteristics can be presented by the manufacturer enabling users to compare products from different manufacturers. Additionally, guidelines are given on the information by which users provide their data and requirements to a balancing machine manufacturer.

This document describes the tests to be performed during the acceptance testing of a balancing machine and 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.

Methods and requirements for preparing proving rotors (which can be of Type A, Type B or Type C, or a user defined proving rotor e.g. based on a user supplied part) are specified, allowing a wide range of applications to be covered.

The accuracy of all balance machines is inherently non-linear over their mass and speed range. In normal practice, a hard bearing balance machine is calibrated over a particular part of its speed and mass range, but outside that its accuracy cannot be assumed. As a consequence, a rotor specific calibration should be performed to establish the machine accuracy at a specific speed and for a rotor of a particular mass. This is normal practice for soft bearing machines or where the manufacturer states that rotor specific calibration should be carried out.

Mechanical vibration — Rotor balancing —

Part 21:
Description and evaluation of balancing machines

1 Scope

This document sets out the requirements for evaluating hard and soft bearing balancing machines that support and rotate:

a) rotors with rigid behaviour at balancing speed (as described in ISO 21940-11);

b) rotors with shaft elastic behaviour and balanced in accordance with low speed balancing procedures (as described in ISO 21940-12).

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 21940-2, *Mechanical vibration — Rotor balancing — Part 2: Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 21940-2 apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

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. Information to be 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

The maximum rotor mass, 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 (given by, $m\,r^2$ where m is the rotor mass and r the radius of gyration) with respect to the shaft axis, 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, Note 2).

4.2.2 Production efficiency

The production efficiency (further requirements are described in Clause 7) is the total time taken to carry out the individual steps necessary to perform a balance measuring run.

The individual steps to be measured are:

a) time for mechanical adjustment (s);

b) time for setting indicating system (s);

c) time for preparation of rotor (s);

d) acceleration time for a stated rotor (s);

e) time taken for the balance reading to stabilize and for it to be recorded (s);

f) deceleration time for a stated rotor (s);

g) identifying unbalance readings taken (s);

h) any other times to be taken into account for operations to be carried out but not included in 4.2.2 a) to 4.2.2 g) (s).

Total time per measuring run is given by adding the individual times measured in steps 4.2.2 a) to 4.2.2 h) (s).

Table 1 — Horizontal balancing machine data

<table>
<tr><td colspan="2">Manufacturer:</td><td colspan="6">Model:</td></tr>
<tr><td colspan="3">Balancing speeds or speed ranges</td><td>n_1</td><td>n_2</td><td>n_3</td><td>n_4</td><td>...</td></tr>
<tr><td colspan="2" rowspan="2">Rotor mass (kg) (see Note 1)</td><td>maximum, m_{max}</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>minimum</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="3">Occasional overload force per support (N) (see Note 1)</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="3">Maximum negative force per support (N) (see Note 1)</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="3">Maximum rotor moment of inertia with respect to the shaft axis (kg m^2)</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="3">Cycle rate per hour (see Note 2)</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2" rowspan="2">Maximum unbalance (g mm/kg or g mm) (see Note 3)</td><td>measurable</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>permissible</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="3">a) For inboard rotors minimum achievable residual specific unbalance, e_{mar}, (g mm/kg) (see Note 4)</td><td rowspan="3">Rotor mass (kg) (see Note 1)</td><td>maximum mass, m_{max}</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>0,2 m_{max}</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>minimum mass</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="3">b) For outboard rotors minimum achievable residual specific unbalance, e_{mar}, (g mm/kg) (see Note 4)</td><td rowspan="3">Rotor mass (kg) (see Note 1)</td><td>maximum mass, m_{max}</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>0,2 m_{max}</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>minimum mass</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="8">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 The cycle rate per hour 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 planes, the stated value is distributed proportionally to each tolerance plane. For disc-shaped rotors with only one tolerance plane, the full stated value holds for one plane.

NOTE 4 This is the machine's ability to measure the smallest amount of unbalance for a rotor (see 5.5.3).</td></tr>
</table>

4.2.3 Rotor dimensions

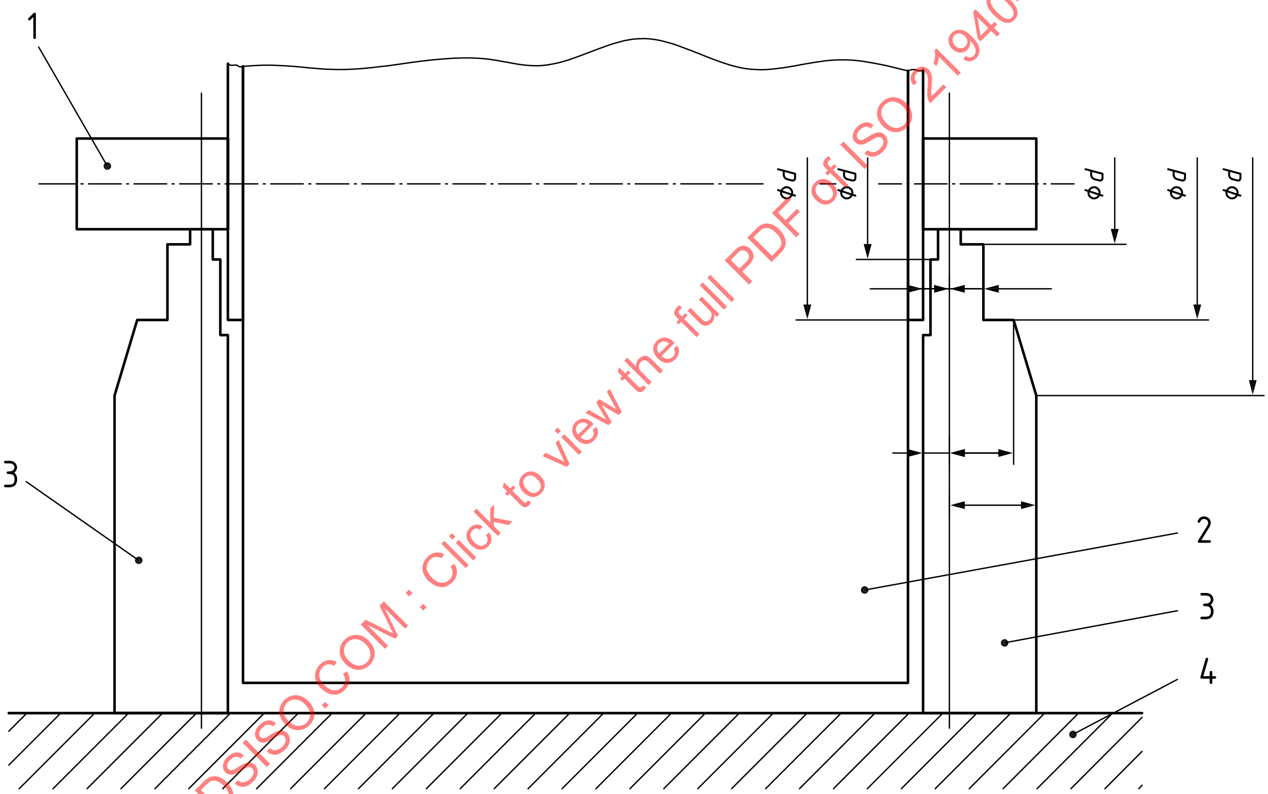
General arrangement drawings of the pedestals and other obstructions (e.g. belt-drive mechanism, shroud mounting pads, thrust arms and tie bars) shall be supplied to enable the user to determine the maximum rotor envelope that can be accommodated and the tooling or adaptors required to support and or drive the rotor.

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 the rotor.

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

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



Key

1 shaft
2 rotor
3 supports
4 bed
d diameter

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

If the left-hand support is not a mirror image of the right-hand support, separate dimensions for each shall be shown. All maximum rotor swing diameters shall be dimensioned along with the pedestal widths as indicated in the right hand pedestal.

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

In addition, these dimensions shall be recorded:

a) maximum diameter over bed (mm);

b) maximum diameter over which the belt can drive (mm);

c) minimum diameter over which the belt can drive (mm);

d) distance between journal centrelines:

   1) maximum (mm);

   2) minimum (mm);

   3) maximum distance from coupling flange to centreline of farthest bearing (mm);

   4) minimum distance from coupling flange to centreline of nearest bearing (mm).

e) journal diameter:

   1) maximum (mm);

   2) minimum (mm).

f) maximum permissible peripheral journal speed (m s^{-1});

g) correction plane limitations (consistent with the requirements of 5.4);

h) correction plane interference ratios (consistent with the requirements of 5.4 and based on the proving rotor used).

4.2.4 Balancing machine drive data

Balancing machine drive parameters shall be recorded as shown in Table 2.

Table 2 — Balancing machine drive parameters

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

4.2.5 Torque

The balancing machine torque parameters to be recorded are

a) zero-speed torque (% of rated torque on rotor),

b) adjustable run-up torque (from ...... % to ...... % of rated torque on rotor), and

c) peak torque (% of rated torque on rotor).

In most cases, the 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 are made to take this into account.

4.2.6 Type of rotor drive

The type of rotor drive shall be recorded (e.g. end drive by band, belt drive, magnetic field, driven bearing rollers, air jet).

In addition, these drive motor parameters shall be recorded:

a) rated power (kW);

b) motor speed (r/min);

c) power supply, voltage (V), frequency (Hz) and phase (single or three phase).

4.2.7 Brake

These brake parameters shall be recorded:

a) type of brake;

b) adjustable braking torque (from ...... % to ...... % of rated torque on rotor);

c) if the brake can be used as a holding device.

4.2.8 Motor and controls

The standards against which the drive motor and its controls have been manufactured and tested shall be recorded.

4.2.9 Speed regulation

It shall be recorded whether or not motor speed regulation has been incorporated and if it has, what its specifications are (range within ...... % of ...... r/min, or constant at ...... r/min).

4.2.10 Couple moment interference ratio, I_{sc}

The couple moment interference ratio (g mm/(g mm^2)) shall be recorded.

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 a resultant unbalance.

4.2.11 Air pressure requirements

The air pressure requirements for the balancing machine shall be recorded in Pa and volume flow rate in m^3 s^{-1}.

4.3 Data for vertical balancing machines

4.3.1 Rotor mass and unbalance limitations

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

The maximum moment of inertia of a rotor (given by, $m\,r^2$ where, *m*, is the rotor mass and, *r*, is the radius of gyration) with respect to the shaft axis, 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 3).

Table 3 — Vertical balancing machine data

Manufacturer:	**Model:**					
Balancing speeds or speed ranges		n_1	n_2	n_3	n_4	...
Rotor mass (kg) (see Note 1)	maximum, m_{max}					
	minimum					
Occasional overload force per support (N) (see Note 1)						
Maximum rotor moment of inertia with respect to the shaft axis (kg m^2) (see Note 2)						
Cycle rate per hour (see Note 2)						
Maximum unbalance (g mm/kg or g mm) (see Note 3)	measurable					
	permissible					
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.						
NOTE 2 Cycle rate per hour 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 planes, the stated value is distributed proportionally to each tolerance plane. For disc-shaped rotors with only one tolerance plane, the full stated value holds for one plane.						
NOTE 4 This is the machine's ability to measure the smallest amount of unbalance for a rotor (see 5.5.3).						

4.3.2 Production efficiency

The production efficiency (further requirements are described in Clause 6) is the total time taken to carry out the individual steps necessary to perform a balance measuring run.

The individual steps to be measured are

a) any mechanical adjustment of the balancing machine needed, including to the drive, tooling or adaptor,

b) preparation of any other devices and systems needed,

c) setting the indicating system,

d) preparation of the rotor for the measuring run,

e) balance cycle acceleration time,

f) reading time (e.g. the total time between the end of the acceleration run and the start of the deceleration run),

g) deceleration time,

h) any further operations necessary to relate the readings obtained to the rotor being balanced,

i) loading and unloading times, and

j) time taken for any other relevant operations to be completed (e.g. safety measures).

4.3.3 Rotor dimensions

If the machine has two or more speeds, the rotor dimensions shall be stated for each speed. If the machine has continuously variable balancing speeds, then the information shall be presented in the form of a table, formula or graph.

Drawings of the spindle support surface or mounting plate and of any obstructions (e.g. 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.

In addition, these rotor dimensions shall be recorded:

a) maximum diameter (mm);

b) height:

   1) maximum overall height (mm);

   2) maximum centre of mass height (mm):

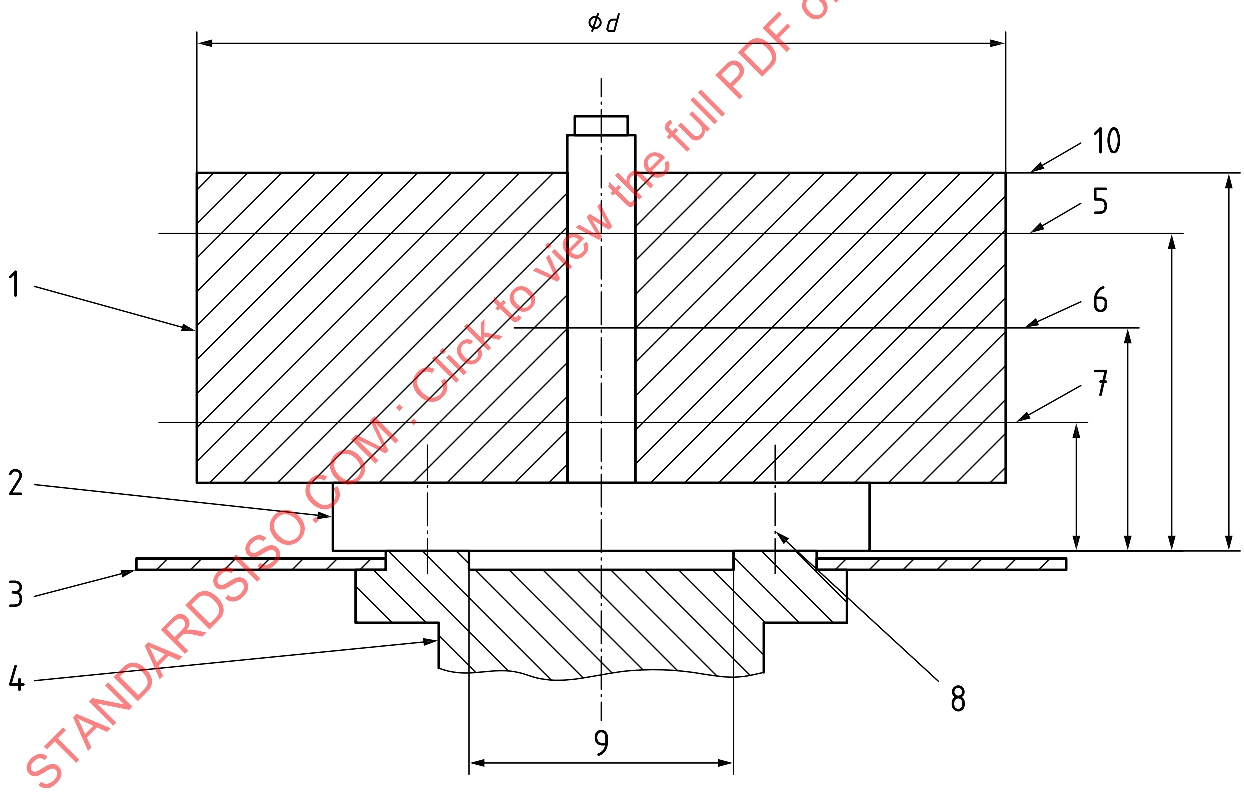
      i) at 100 % of maximum mass (mm);

      ii) at 50 % of maximum mass (mm);

      iii) at 25 % of maximum mass (mm).

c) envelope limitations (including machine spindle or mounting plate interface (see Figure 2));

d) correction plane limitations (consistent with the requirements of 5.4).



Key

1	rotor	5	upper correction plane	9	spigot diameter
2	adaptor	6	centre of mass plane	10	maximum height above spindle
3	protractor	7	lower correction plane	*d*	diameter
4	spindle	8	mounting holes for adaptor		

Figure 2 — Example of vertical machine mounting interface and rotor envelope

4.3.4 Balancing machine drive data

Balancing machine drive parameters shall be recorded as shown in Table 2.

4.3.5 Torque

See 4.2.5.

4.3.6 Type of drive to rotor

See 4.2.6.

4.3.7 Brake

See 4.2.7.

4.3.8 Motor and controls

See 4.2.8.

4.3.9 Speed regulation

See 4.2.9.

4.3.10 Couple moment interference ratio

See 4.2.10.

4.3.11 Air pressure requirements

See 4.2.11.

5 Machine features

5.1 Principle of operation

A description of the principle of operation of the balancing machine shall be given (e.g. motion measuring, force measuring).

5.2 Machine arrangement

The manufacturer shall describe the configuration of the balancing machine and its principal design features (e.g. horizontal or vertical axis of rotation, soft or hard bearing suspension system).

In addition, and as applicable, the manufacturer shall provide details of:

a) components designed to support the rotor, for instance:

   1) vee blocks;

   2) open rollers;

   3) plain half bearings;

   4) closed ball, roller or plain bearings;

   5) devices to accommodate rotors in their service bearings;

6) devices to accommodate complete units.

b) bearing lubrication requirements;

c) for horizontal machines only, the mechanical adjustment and functioning of the means provided to take up axial thrust from the rotor;

d) the type(s) of transducer(s) used to sense unbalance effects;

e) the drive method and the means to control it.

5.3 Measuring system

5.3.1 General

A balancing machine shall have the means to determine the amount of unbalance and its angular location.

The balancing machine manufacturer shall describe the measuring system used in their machine, for instance:

a) whether it is computer based (to include type and size of visual display used, data entry method, software architecture and communication and compatible operating system and PC minimum requirements);

b) whether it is electronically based;

c) the number of unbalance channels included and the phase or encoder inputs included;

d) the type of unbalance pickup used and the signal given.

5.3.2 Unbalance indicators

The manufacturer shall describe the means by which the amount and angle of the unbalance is provided, for instance by using

a) a display showing vectors in polar coordinates,

b) a numerical digital display with number of decimal places and significant digits,

c) any display showing the position and amount of the balance correction(s) needed (e.g. the position, depth and shape of the material to be removed or the position and amount of the material to be added), and

d) a means of displaying any tooling (e.g. a holding device for the rotor under test) compensation needed.

5.3.3 Additional features

Additional features, which influence the functioning of the balancing machine shall be described.

For information, additional features, which can be included in the machine are, but not limited to

a) whether an arbitrary coordinate system is used (e.g. geometric centring),

b) an indication of the unbalance resolved into components (which can be in more than two correction planes),

c) any correction devices installed,

d) any device used to show the position and/or amount of the correction to be applied to the rotor,

e) whether a suitable output for connection to a computer, network, printer or other peripheral is provided, and

f) any error proofing system(s) installed.

5.3.4 Operation of the indicating system

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

a) how many runs are required to obtain the unbalance measurements,

b) how the unbalance measurements are displayed,

c) if there are readings retained at the end of the measuring run and if readings from previous runs can be recalled,

d) if readings can be made and displayed in real time during the measurement run, averaged over time,

e) if readings can be made and displayed, as an average, after several runs have been completed, and

f) how the addition or subtraction angle of unbalance is selected.

5.4 Plane separation system

5.4.1 Multi-plane balancing machines

The manufacturer shall state whether plane separation is included and if it is, at least these details shall be provided:

a) how is it operated for single rotors of a type not previously balanced;

b) how is it operated for single rotors, in series, with identical dimensions and masses;

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:

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

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

   3) 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 directly measure the resultant and couple unbalances.

5.4.2 Single-plane horizontal or vertical balancing machines

The manufacturer shall state to what extent the machine is able to suppress the effects of the couple moment (see 10.6).

5.5 Setting and calibration of the measuring system

5.5.1 General

The manufacturer shall describe the means of setting and calibrating their machine and the methods provided for evaluating them.

The manufacturer shall state whether the machine can be set to display any desired unit, whether SI units or unbalance units.

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

a) for single-plane balancing,

b) for two-plane balancing, and

c) for three or more plane balancing.

The manufacturer shall state the maximum permissible change in speed during calibration and operation.

5.5.2 Soft-bearing machines

The manufacturer shall state how calibration and elimination of cross plane influence is to be accomplished on the first rotor of a particular mass and configuration, whether total or partial recalibration is required when changing the balancing speed and if the calibration factors are stored within the measuring system and can be recalled.

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 to be balanced, whether it requires re-calibration by the user for different balancing speeds, rotor masses and dimensions and whether these calibration factors are stored within the measuring system and can be recalled.

The minimum achievable residual specific unbalance, e_{mar}, that can be achieved with the balancing machine shall be specified in terms of specific unbalance (g mm/kg). The value of e_{mar} shall be stated for the full range of rotor masses and balancing speeds of the machine.

In achieving the stated e_{mar}, the manufacturer shall consider whether the accuracy of

a) amount indication,

b) angle indication,

c) plane separation, and

d) drive, bearings are adequate for the intended use of the machine.

It should be noted that the stated e_{mar} applies to the balancing machine as delivered. Other variables that can affect the e_{mar} and which may need to be taken into account are:

e) out-of-round journals;

f) excessively heavy or loose adaptors;

g) any other tooling employed by the user.

6 Production efficiency

6.1 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 specified by the user.

To find the production efficiency for a specific rotor (e.g. the number of pieces per time or the reciprocal of the floor-to-floor time), the time taken per measuring run, the number of runs, the time for loading and unloading and the unbalance correction shall be taken into account. The number of measuring runs required depends on the average initial unbalance, the specified balance tolerance and the unbalance reduction ratio, R_{UR}.

6.2 Time per balance cycle

For the proving rotor or rotors specified by the user (e.g. mass produced parts) the procedure to be used shall be described in detail and state, where applicable, the average time used for each of the operations.

When any operation is performed by an operator, this shall be noted and any correction time needed stated as averaged or specified criteria (e.g. based on the number and size and depth of holes).

At least these points shall be taken into account when establishing production efficiency:

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

b) preparation of any other devices and systems needed;

c) setting the indicating system;

d) preparation of the rotor for the measuring run;

e) balance cycle acceleration time;

f) the reading time (e.g. the total time between the end of the acceleration run and the start of the deceleration run);

g) deceleration time;

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

i) loading and unloading times;

j) time taken for any other relevant operations to be completed (e.g. safety measures).

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).

For automated machines with many operations that cannot be carried out in series, a timing chart (e.g. as shown in Table 4) may be used to record individual operation and overall times. Timings that vary due to non-controllable influences shall be highlighted and defined (e.g. human intervention).

Table 4 — Possible timings chart

			Total time taken s																
Sequence	**Operation time** s	**Criteria**	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	etc.
Operator loads part and starts cycle	4	Human																	
Clamp part	1	Machine																	
Measure part diameter and run-out	4	Machine																	
Accelerate	3	Machine																	
Measure unbalance	4	Machine																	
Decelerate	1	Machine																	
Index to correction angle	1	Machine																	
Hydraulic clamp	1	Machine																	
Mill feed to depth	3	3 mm																	
Carry out milling correction	6	120°																	
Unclamp rotary table from spindle	1	Machine																	
Accelerate	1	Machine																	
Measure	4	Machine																	
Decelerate	1	Machine																	
Orientate spindle for next part	1	Machine																	
Unclamp	1	Machine																	
Operator unloads part	4	Human																	

6.3 Unbalance reduction ratio, R_{UR}

The manufacturer shall state the R_{UR} for the machine that shall include R_{UR} percentage for both inboard and outboard rotors.

It is assumed in stating the R_{UR} that the addition or subtraction of mass is made without error and in accordance with the operating instructions for the balancing machine.

In ISO 21940-2, R_{UR} is defined as the ratio of the reduction in unbalance by a single unbalance correction to the initial unbalance and is given by Formula (1):

$$R_{UR} = \frac{U_1 - U_2}{U_1} = 1 - \frac{U_2}{U_1} \quad (1)$$

where:

U_1 is the amount of initial unbalance;

U_2 is the amount of unbalance remaining after one correction.

7 Performance qualifying factors

The manufacturer shall state the range of factors within which the machine is capable of achieving the guaranteed performance, for example

a) temperature,

b) humidity,

c) balancing speed variation, and

d) line voltage and frequency fluctuations.

The manufacturer shall also state

e) whether the performance of the machine is significantly changed by the use of ball bearings in the rotor journals, and

f) whether the unbalance indication of the rotor is significantly affected if the rotor bearing thrust face is not perpendicular to the rotor axis.

8 Installation requirements

8.1 General

In considering the siting of the balancing machine, the manufacturer shall state the precautions to be observed to obtain satisfactory performance in the presence of, at least

a) extraneous vibration,

b) electromagnetic radiation, and

c) condensation, cleanliness and any other relevant factors (e.g. those referred to in Clause 7).

8.2 Supply requirements

Balancing machines shall be provided with input connections that are plainly marked with at least, and where applicable

a) the required electrical supply voltage and frequency,

b) whether the machine requires 3 or 4 wire electrical supply,

c) the pressure (Pa) and volume flow rate ($m^3 s^{-1}$) of the required compressed air supply,

d) the pressure (Pa) and volume flow rate ($m^3 s^{-1}$) of the required hydraulic supply, and

e) the pressure (Pa), volume flow rate ($m^3 s^{-1}$) and temperature (°C) of the required water supply.

8.3 Foundation

The manufacturer shall state the overall dimensions and mass of the balancing machine and the type and size of foundation required for it under which its specified performance is assured (e.g. whether it requires installation on concrete blocks or a workbench).

9 Proving rotors and test masses

9.1 General

This clause specifies the 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 for standardized proving rotors (see 9.2). The extent and cost of the tests required as well as the rotor size(s) to be used, may be negotiated between the manufacturer and the user of the machine.

For special purpose machines and for machines dedicated to the testing of a particular part, a specialized proving rotor (see Annex D) may be used instead of a standardized proving rotor, provided that the production rotor can be prepared in accordance with the principles of the standardized proving rotor.

9.2 Standardized proving rotors

To evaluate and compare the performance of balancing machines, it is possible to manufacture a proving rotor of a similar configuration, mass and moment of inertia to simulate the range of rotors to be balanced.

Proving rotors can also be used for machine calibration.

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.

Proving rotors shall be manufactured of steel and shall be similar to those described in Table 3 and Figure 4 for vertical machines, Table 6 and Figure 5 for horizontal machines (inboard rotor), or Table 7 and Figure 6 for horizontal machines (outboard rotor).

Proving rotors with only 8 holes per plane may be modified to comply with the requirements of this document (see Annex D).

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

If a horizontal machine is to be used for balancing outboard rotors (or inboard rotors with correction planes overhanging on one side), additional tests shall be agreed upon (see Clause 10) and require the use of a Type C or user defined proving rotor.

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

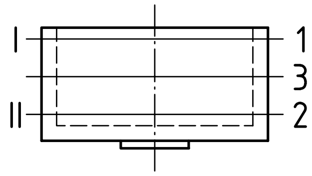
For machines to be used over their mass capacity range, two proving rotors shall be used, one with a mass in the lower third of the machine mass capacity range and one with a mass in the top third of the machine mass capacity range.

However, after successfully carrying out a machine performance evaluation (e.g. after installation) and if agreed, it is acceptable to revaluate machine performance after that (e.g. by carrying out an annual evaluation) using only one proving rotor having a mass anywhere in the machines mass capacity range. Often a single proving rotor having a mass in the lower third of the balance machines mass capacity range is used, once the balance machine performance has been successfully initially evaluated.

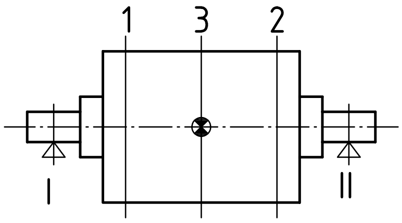
For machines intended to be used only over a particular part of their mass capacity range, a single proving rotor shall be used with a mass in the middle of the rotor masses to be tested.

Each type of proving rotor has three planes for test mass attachment. Where it is not practical to have a centre plane, suitable mass sets can be added to undertake the minimum achievable residual unbalance test, U_{mar} test, in two planes.

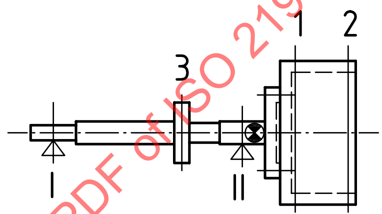
The same proving rotor and test masses shall be used for tests carried out in one or two planes.



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 correction planes

1, 2, 3 test planes

I, II assumed bearing planes

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

Figure 3 — Proving rotors Type A, Type B and Type C

The proving rotor types covered by the requirements of this document are:

a) **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 (see Figure 3 a)).

Service bearing planes may be anywhere (e.g. one on each side, or both on one side of the main rotor body). However, for the tests described in this document, it is assumed that one bearing is on each side of the rotor.

b) **Type B:** Inboard rotors with journals, balanced on a horizontal machine, mostly with two correction planes between the bearings (see Figure 3 b)).

Service bearings are positioned on either side of the rotor.

c) **Type C:** Outboard rotors with journals, balanced on a horizontal machine, with two overhung correction planes (see Figure 3 c)).

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 mounted to it.

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

9.3 User defined proving rotors

User defined rotors are used to meet the requirements of a specific application or where a Type A, Type B or Type C rotor is not suitable. The user defined proving rotor shall replicate the mass, geometry and inertia of the rotor to be balanced and can be manufactured to replicate a typical rotor to be balanced or be a modified production rotor.

Where the user defined rotor is mounted in a housing, its mass shall be similar to the one it is replicating along with the overall non-rotating housing being of a similar mass to the one it replicates.

Where there is the possibility of the user defined rotor deteriorating during testing, it shall have hardened and ground mating surfaces. The surface finish and roundness of any journals shall be of a quality to enable the machine to pass the tests described in this document.

There shall be a means of attaching test masses to the user defined rotor so as to be able to conduct the machine evaluation tests described in this document. Test masses are usually attached to the rotor by means of tapped holes and screws or threaded studs and nuts, but it can also be by other means (e.g. a method of clipping a test mass to the rotor or a hole to insert a non-locking test mass). The radii where the test masses are to be added shall be measured with sufficient accuracy to pass the tests described in this document (typically ±0,025 mm).

12 equally spaced positions for attaching the test weights shall be identified unless otherwise agreed between the machine manufacturer and user. If such an agreement is made, then the evaluation sheets shall be modified accordingly. The angular positioning tolerance shall be adequate to pass the tests described in this document (typically ±0,1°).

As far as is practical, test masses shall be manufactured in accordance with the requirements of 9.4. When a rotor is connected to another driveline item (e.g. tooling), these additional driveline masses shall be included when calculating the test mass.

9.4 Test masses

9.4.1 General

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

Since the test positions have threaded holes, test masses may be in the form of bolts and screws. One solution is to have stud bolts permanently fixed in all test mass mounting positions, protruding from the surface of the rotor by a fixed height, and to fix the test masses 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} (e.g. multiples of e_{mar}).

If the U_{mar} is specified per plane, U_{mar} is calculated using Formula 2.

$$U_{mar} = 2\ U_{mar} \quad \text{per plane} \tag{2}$$

If e_{mar} is stated, U_{mar} is obtained by using Formula 3.

$$U_{mar} = e_{mar} \cdot n \tag{3}$$

where n are multiples.

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 5 — Recommended dimensions, masses and speeds for vertical machine Type A proving rotors (see Figure 4)

	Metric values														
	Rotor mass m	Major diameter D	Minor diameter $d \approx 0{,}9\,D$	Height $H \approx 0{,}5\,D$	$X \approx 0{,}075\,D$	Y[a] $\approx 0{,}175\,D$	Z[a] $\approx 0{,}175\,D$	$F \approx 0{,}06\,D$	G	I[b]	J[b]	K[b]	R[b]	T	Highest test speed[c]
Rotor no.	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														
	Rotor mass m	Major diameter D	Minor diameter $d \approx 0{,}9\,D$	Height $H \approx 0{,}5\,D$	$X \approx 0{,}075\,D$	Y[a] $\approx 0{,}175\,D$	Z[a] $\approx 0{,}175\,D$	$F \approx 0{,}06\,D$	G	I[b]	J[b]	K[b]	R[b]	T	Highest test speed[c]
Rotor no.	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

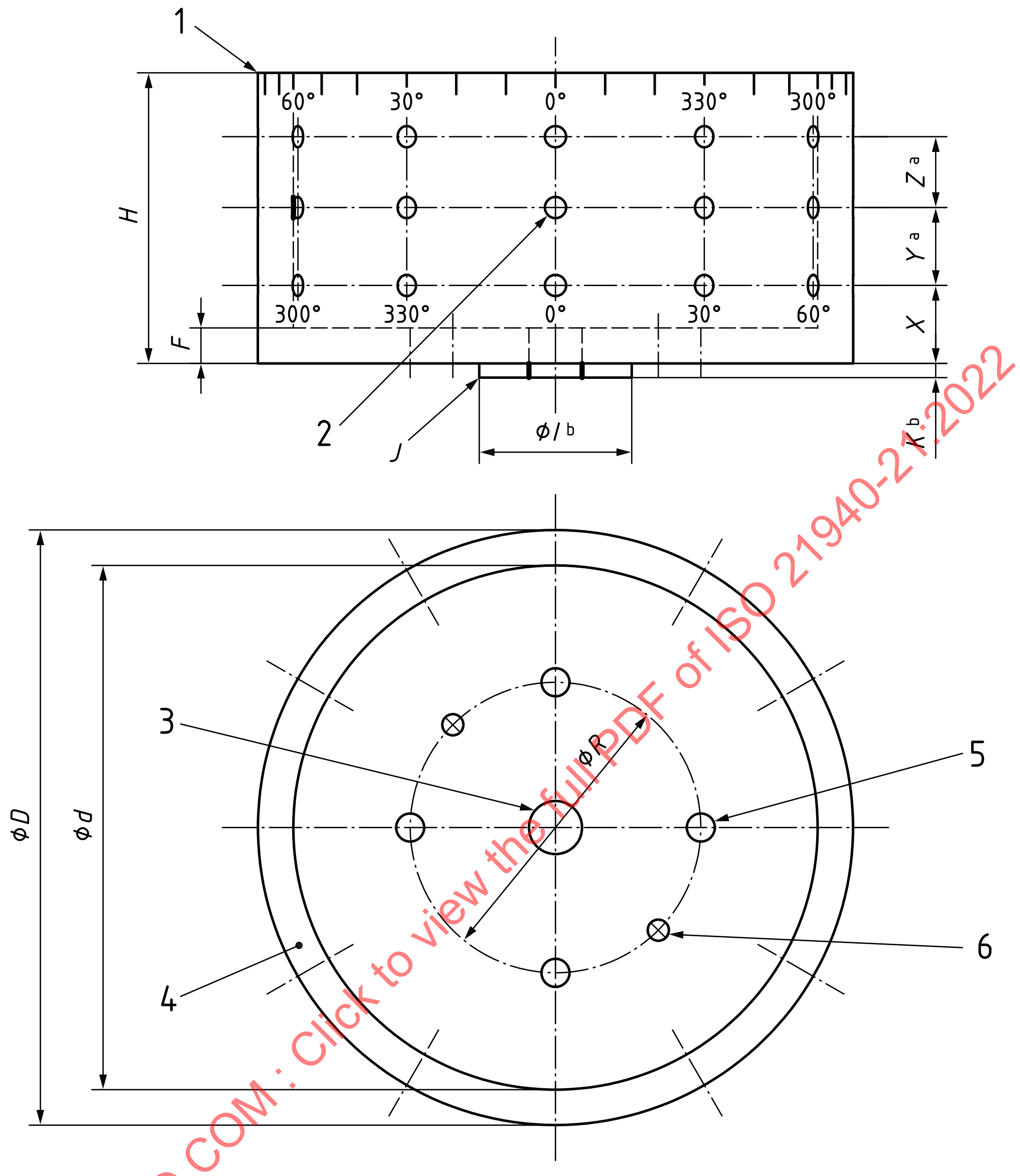
All tolerances and residual unbalance shall be in accordance with the test aims.

Proving rotors from SAE ARP 4162A[6] may be used instead of those described in this document with test masses modified to suit the tests to be performed as described in this document.

[a] Except for Y and Z, dimensions may be varied.

[b] Interface (spigot) dimensions shall comply with the requirements of SAE ARP 4162A[6] proving rotors (rotor no. 2 to no. 5).

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



Key

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

2 12 equally spaced threaded holes *G* (see Table 5) in each of the three test planes

3 threaded hole for lifting eye

4 holes in this face are used to balance the rotor (optional)

5 four equally spaced through holes *T* (see Table 5)

6 two equally spaced threaded holes *G* (see Table 5)

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

Proving rotors meeting the requirements of SAE ARP 4162A[6] may be used instead of those described in this document with test masses modified to suit the tests to be performed as described in this document.

NOTE For dimensions, see Table 5.

a Except for *Y* and *Z*, dimensions may be varied.

b Interface dimensions (spigot) shall comply with the requirements of SAE ARP 4162A[6] proving rotors (where existing).

Figure 4 — Type A proving rotors for tests on vertical balancing machines

Table 6 — Recommended dimensions, masses and speeds for horizontal machines with inboard bearings and Type B proving rotors (see Figure 5)

Rotor no.	Rotor mass m	Major diameter D	Overall length L » 2,5 D	Shaft diameter d » 0,3 D[b]	Bearing distance $A+B+C$ » 2 D	A[a], C[a] » 0,5 D	B[a] » D	E »0,25 D	F »0,5 D	P_1	H[b]	K[b]	P_2[b]	N	Resonance speed[c] »7 600 000/D	Highest test speed[d] »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																
Rotor no.	Rotor mass m	Major diameter D	Overall length L » 2,5 D	Shaft diameter d » 0,3 D[b]	Bearing distance $A+B+C$ » 2 D	A[a], C[a] » 0,5 D	B[a] » D	E »0,25 D	F »0,5 D	P_1	H[b]	K[b]	P_2[b]	N	Resonance speed[c] »7 600 000/D	Highest test speed[d] »760 000/D
	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.

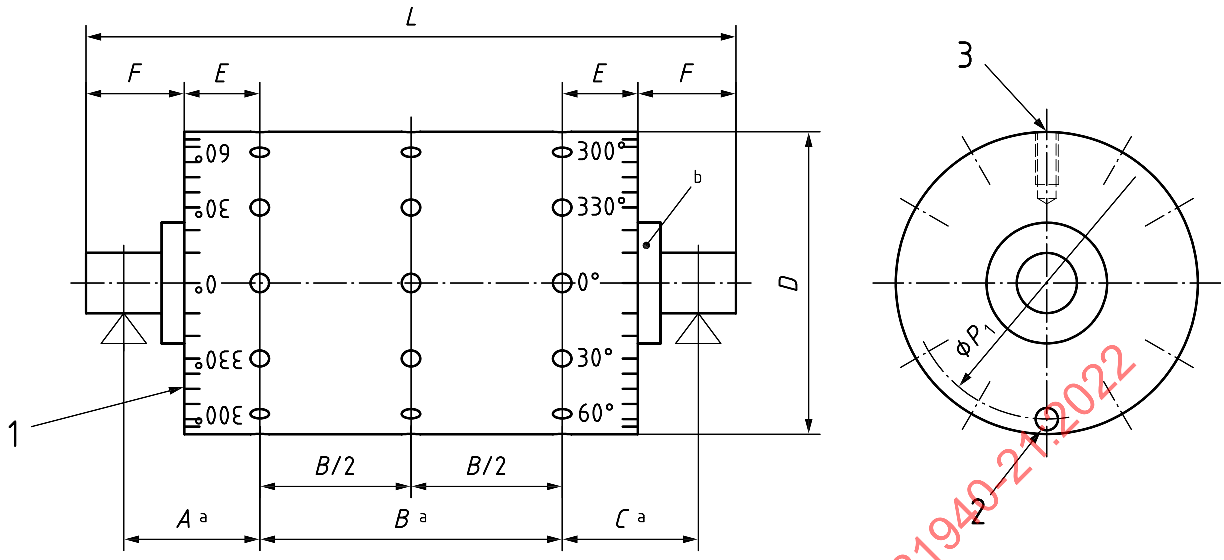
Proving rotors meeting the requirements of SAE ARP 4162A[6] may be used instead of those described in this document with test masses modified to suit the requirements of the tests to be carried out as described in this document.

[a] Dimensions A, B and C may be varied, provided that: $A \approx B/2$, $C \approx B/2$.

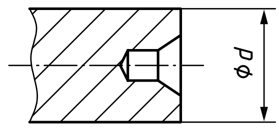
[b] End-drive interface dimensions comply with typical drive shafts.

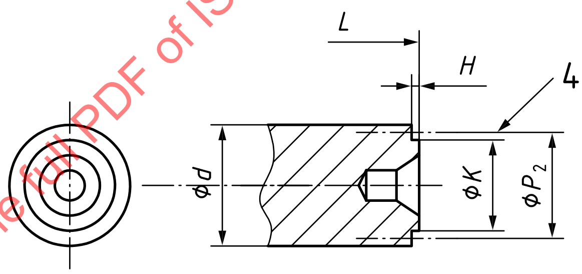
[c] Resonance speeds are calculated for rotors running in rigid bearings.

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



a) Type B proving rotor





b) Journal end details for belt drive rotors

c) Journal end details for end drive rotors

Key

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

2 12 equally spaced threaded holes *N* (see Table 6) on each end for trim balancing

3 12 equally spaced threaded holes *N* (see Table 6) in each of the three test planes

4 number and size of threads

End-drive interface dimensions shall comply with those of the drive shaft used.

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

Proving rotors from SAE ARP 4162A[6] may be used instead, with test masses modified to suit the requirements of the tests described in this document.

Rotors with only 8 holes per plane may be modified to comply with the requirements of this document (see 9.4.4.2).

NOTE For dimensions, see Table 6.

a Dimensions *A*, *B* and *C* may be varied, provided that: $A \approx B/2$, $C \approx B/2$.

b If the shafts are used as ball bearing seats, 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 — Type B proving rotors for inboard tests on horizontal machines

Table 7 — Recommended dimensions, masses and speeds for horizontal machines with outboard bearings and Type C proving rotors (see Figure 6)

Shaft no.	Proving rotor Type A no.	No.	Mass M	Bearing load on rotor[a] Left bearing	Bearing load on rotor[a] Right bearing	y[a]	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

a For indication, see Figure C.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 no. 3 to no. 5 meet the requirements described for proving rotors Type B, no. 4 to no. 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.

Table 7 *(continued)*

Shaft no.	Proving rotor Type A no.	No.	Metric values													
			Mass M	Bearing load on rotor[a]		y[a]	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]
				Left bearing	Right bearing											
			kg	N	N	mm	mm	mm	mm		mm	mm	mm	mm	r/min	r/min
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 meeting the requirements of SAE ARP 4162A[6] may be used instead of proving rotor Type A with test masses modified to suit the requirements of the tests described in this document.

a For indication, see Figure C.1.

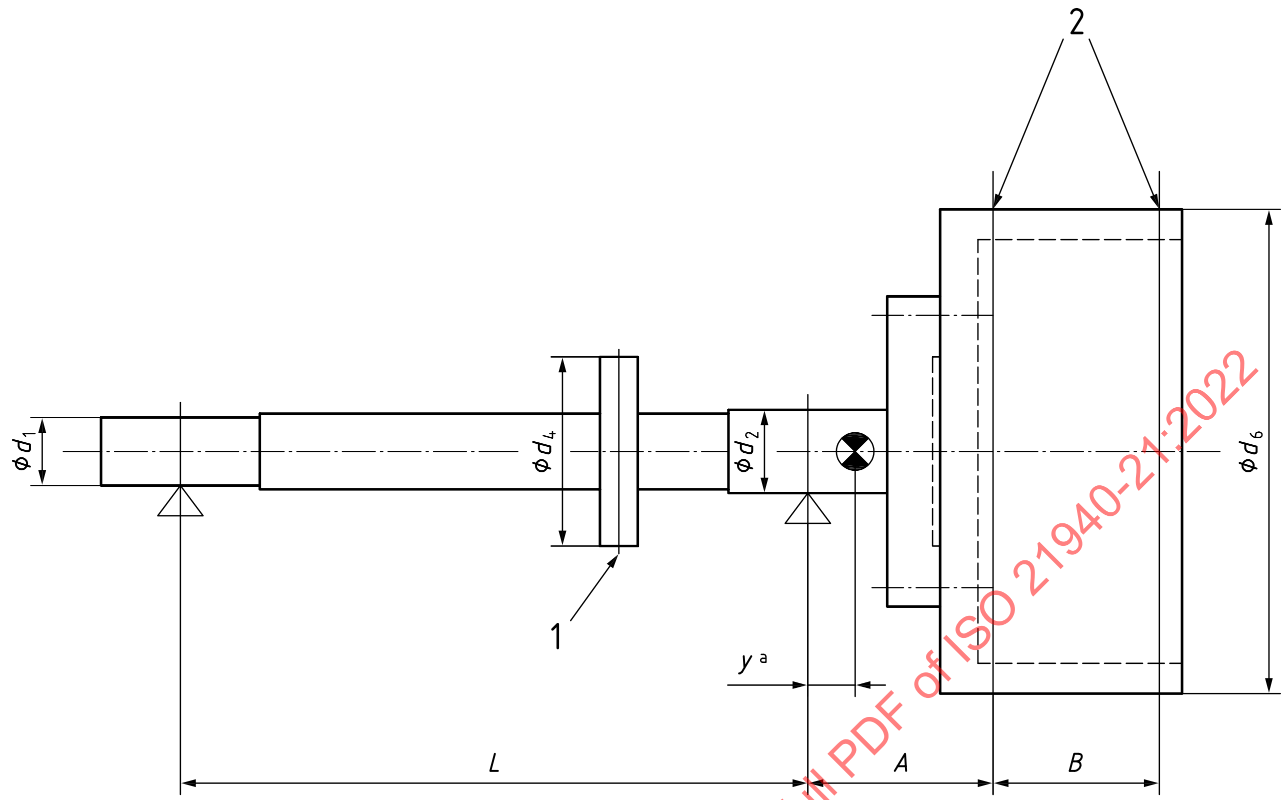
b Dimensions may be varied, provided the centre of mass stays outboard with the same overhung, y, and the position of holes N between bearings is maintained.

c End-drive interface dimensions for no. 3 to no. 5 meet the requirements described for proving rotors Type B, no. 4 to no. 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* (see Table 7). The axial position is required to be in between the bearings.

2 12 equally spaced threaded holes *N* (see Table 7)

End-drive interface dimensions for shaft no. 3 to no. 5 (see Table 7) are in accordance with Type B proving rotor no. 4 to no. 6.

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

A proving rotor meeting the requirements of SAE ARP 4162A[6] may be used instead of a Type A proving rotor with test masses modified to suit the requirements of the tests to be performed and to meet the requirements of this document.

NOTE 1 For dimensions, see Table 7. The distance of the centre of gravity to the right hand bearing is *y*[a].

NOTE 2 Type C proving rotors are made of a shaft (see Figure C.1 and Table C.1) and a Type A proving rotor.

NOTE 3 Recommended dimensions of shafts (for end-drive) fitting Type A proving rotors see E.3.

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

[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 balance plane tests on horizontal machines

9.4.2 U_{mar} test masses

9.4.2.1 General

For the U_{mar} test (see 10.4), one test mass producing $10U_{mar}$ is required for Plane 3 (see Table 6).

For Type A or Type B test masses of $5U_{mar}$ each for Plane 1 and Plane 2 can be used instead. There is no recommended alternative for Type C proving rotors.

9.4.2.2 Type A and B proving rotors

For Type A and Type B proving rotors, U_{mar} shall be calculated in accordance with the requirements of Clause 9 using the values given in:

a) Table 5 for vertical machines and for horizontal machines with integrated spindles (Type A); or

b) Table 6 for horizontal machines for inboard rotors (Type B).

EXAMPLE Horizontal machine, Type B proving rotor as in Table 6, no. 5 where m = 50 kg.

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

Calculation in accordance with the requirements of 10.4: if U_{mar} = 0,5 g mm/kg and m = 50 kg, then U_{mar} = 25 g mm.

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

9.4.2.3 Type C proving rotors

For Type C proving rotors on horizontal machines for outboard tests, perform the same calculation for U_{mar} as described in 9.4.1 but using the values given in Table 7.

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

a) the mass of a Type C proving rotor is different from a Type B proving rotor;

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

c) the mass is attached to a different rotor diameter and thus has a different effective measurement radius.

EXAMPLE Horizontal machine, outboard Type C proving rotor as in Table 7, no. 3 and m = 19,5 kg.

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

Calculation in accordance with the requirements of 9.4.2.2: U_{mar} = 2 g mm/kg and m = 19,5 kg, then U_{mar} = 39 g mm.

So the U_{mar} test mass is to produce 10 U_{mar} = 390 g mm.

9.4.3 R_{UR} test masses

9.4.3.1 General

For the R_{UR} test (see 10.5) two test masses (a stationary and a travelling mass) per test plane are required.

9.4.3.2 Type A and B proving rotors

For Type A and B proving rotors, the test masses are:

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

b) one (for a single-plane test) or two (for a two-plane test) travelling masses, U_{travel}, each producing five times the unbalance of the stationary masses.

EXAMPLE Using the same proving rotor and claimed value of e_{mar} as is shown in the example in 9.4.2.3, and stationary test masses producing 30 times the U_{mar} leads to:

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

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

9.4.3.3 Type C proving rotors

For Type C proving rotors, perform the same calculation as described in 9.4.3.2. However, in order to use the same R_{UR} evaluation diagram, $U_{station} = 60\ U_{mar}$ to $U_{station} = 100\ U_{mar}$.

NOTE The test masses differ from those for Type A proving rotors.

For Type C proving rotors (outboard) and as an alternative, the R_{UR} test can be performed using resultant or couple test masses.

Based on the requirements of ISO 21940-11, for resultant test masses use

a) one stationary mass, producing $U_{res\ station} = 20\ U_{mar}$ to $60\ U_{mar}$, and

b) one travelling mass, producing $U_{res\ travel} = 5\ U_{res\ station}$.

For couple test masses, use

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

d) two travelling masses, each producing $U_{c\ travel} = 5\ U_{c\ station}$.

9.4.4 Permissible test mass errors

9.4.4.1 General

The permissible test mass error is directly related to the task to be performed and shall not influence the test result by more than ±10 %.

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

For the R_{UR} test, the permissible mass error percentage is directly related to the claimed R_{UR} and is given by ±0,1·(100 % – R_{UR}).

EXAMPLE For a test with a claimed R_{UR} of 95 %, the permissible mass error is ±0,1·(100 % – 95 %) = ±0,5 %.

9.4.4.2 Position

The test mass mounting positions shall be at 30° intervals in each plane.

Proving rotors with only 8 holes per plane may be modified to comply with the requirements of this document (see Annex E).

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

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

a) in the axial direction within the same percentage as determined for the mass tolerance in 9.4.4.1 for the R_{UR} test (e.g. ±0,5 %), but applied to the correction plane distances;

b) in the radial position within the same percentage as shown in 9.4.4.2 a) (e.g. ±0,5 %), but applied to the radius;

c) in the angular position within the same percentage as shown in 9.4.4.2 a), 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 of Type B and Type C, it is advisable to align the thread pattern for the end drive to the 0° position of the proving rotor.

9.4.5 Material

For some proving rotors, test masses can be 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 plastic) in order to ensure their physical size makes them easier to handle.

10 Balance machine verification tests

10.1 General

This clause describes the tests that shall be carried out to evaluate the performance of a machine, depending on the machine type:

a) as pre-delivery tests at the manufacturers facility prior to delivery to the user;

b) after installation at the users facility;

c) where parts of the machine (e.g. those related to the performance of the machine or out of balance measurement) have been replaced in an already installed machine.

The tests to be performed are shown in Table 8. However, performing

d) the repeatability test, and

e) speed range test.

The test procedures to be used for the repeatability and speed range tests are described in Annex F.

The specific tests to be carried out on an already installed, unchanged machine, are subject to agreement between the machine manufacturer and user. However, to meet the requirements of this document, and as a minimum, U_{mar} and R_{UR} tests shall be carried out as shown in Table 9.

Table 8 — Balancing machine verification test matrix

Machine type	Test to be performed					
	U_{mar}	R_{UR}	I_{sc}	**Compensator**	**Repeatability** (see F.1)	**Speed range** (see G.1)
End drive horizontal two-plane	X	X		A	O	O
Belt drive horizontal two-plane	X	X		A	O	O
Dual drive horizontal two-plane	X	X		X	O	O
Self or other drive horizontal single-plane	X	X	X	A	O	O
Self or other drive horizontal multi-plane	X	X		A	O	O
Vertical single-plane	X	X	X	A	O	O
Vertical two-plane	X	X		X	O	O
Self or other drive vertical	X	X	A	X	O	O
Non-rotating machine	X	X	X	X	O	
Overhang horizontal machine single-plane	X	X	X	X	O	O
Overhang horizontal machine two-plane	X	X		X	O	O
Drive shaft machine	X	X		X	O	O

Key

X This test shall be carried out.

A This test shall be carried out if the machine has that capability and the function is to be used.

O This test shall be carried out with the agreement of all stakeholders.

Table 8 *(continued)*

Machine type	Test to be performed					
	U_{mar}	R_{UR}	I_{sc}	Compensator	Repeatability (see F.1)	Speed range (see G.1)
Axle machine	X	X		X	O	O
Special purpose single-plane	X	X	X	A	O	O
Special purpose multi-plane	X	X		A	O	O

Key

X This test shall be carried out.

A This test shall be carried out if the machine has that capability and the function is to be used.

O This test shall be carried out with the agreement of all stakeholders.

Table 9 — Tests that can be omitted after initial test for all machine types

Test	Test to be performed					
	U_{mar}	R_{UR}	I_{sc}	Compensator	Repeatability (see Annex F)	Speed range (see Annex G)
Run off at manufacturer	No	No	A	Yes	No	O
Run off at user	No	No	O	O	No	O
Routine test with mutual agreement	No	No	O	O	O	O

Key

A This test shall be carried out if the machine has that capability and the function is to be used.

O This test shall be carried out with the agreement of all stakeholders.

10.2 Requirements for evaluating balance machine performance

To evaluate the claimed performance of the machine, the tests described in 10.4 to 10.5 shall be performed by the manufacturer at their plant and after installation at the user's site:

a) the U_{mar} test;

b) the R_{UR} test;

c) the I_{sc} test (test for interference from couple moment unbalance with resultant unbalance indication), required only for single-plane machines;

d) the test of the compensator used for index balancing.

The tests shall be performed during acceptance testing of the balancing machine and on a periodic basis to ensure that the machine is capable of handling the actual balancing tasks in production. If the balance machine has both end and belt drives, all tests shall be carried out with each drive, but this can be reduced to the drive type that is most commonly used or, in agreement between the test conductor and the user, for machine installations that have not been altered.

Type A and Type B proving rotors are chosen according to the type of balancing machine under test (see 9.2). Type C proving rotors shall be used only if outboard rotors are to be balanced on a horizontal machine and upon prior agreement between the manufacturer and user, subsequently a user defined proving rotor can be used if a Type A, Type B or Type C proving rotor does not represent the rotors commonly balanced with regard to their mass and geometry.

NOTE Table 5 and Table 6 give an overview of the U_{mar} and R_{UR} tests for Type A, Type B and Type C proving rotors.

The tests described in 10.2 a) to 10.2 d) represent the minimum requirements designed to establish conformity with the requirements of this clause. However, those tests do not prove conformity with all requirements over the full range of variables, nor do they define the exact reason when the machine fails to comply.

When a balancing machine fails a test, the complete test shall be repeated once the machine has been rectified.

The machine shall then meet the requirements of all necessary tests to be considered acceptable.

However, performing

a) the repeatability test, and

b) the speed range test on a new or an already installed, unchanged machine, is subject to agreement between the machine manufacturer and user.

The test procedures to be used for the repeatability and speed range tests are described in Annex G and Annex F.

10.3 Test speed

The test speed to be used when running the proving rotor shall be agreed between manufacturer and user and shall be either (see Table 1):

a) a typical speed of the balancing machine in accordance with the machine specification, or

b) lay between 10 % to 20 % of the highest permissible test speed of the proving rotor (see Table 5 to Table 7) if that speed lies within the range of the balancing machine, or

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

d) when a user defined rotor is used as a proving rotor, the intended balancing speed for that rotor.

10.4 Test for establishing the minimum achievable residual unbalance, U_{mar}

10.4.1 General

The U_{mar} is the smallest amount of residual unbalance (g mm) that a balancing machine is capable of achieving under a given set of conditions.

This test is intended to check the ability of the machine to balance a rotor to the claimed U_{mar}.

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

An overview of U_{mar} and R_{UR} tests with the proving rotors described in Table 5 is shown in Table 11.

10.4.2 Initial balancing machine setting

10.4.2.1 Plane setting for balancing

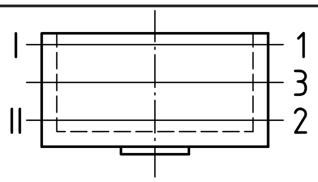
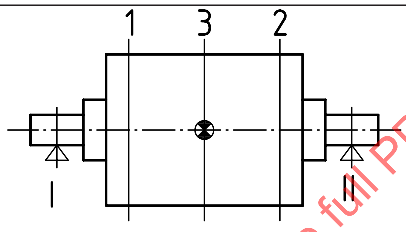
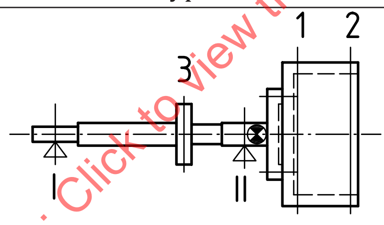
For the particular rotor under consideration, perform the mechanical set up of the balancing machine. Calibration or setting is done for balancing in plane(s) which are not the test planes (see Table 5 and Table 6).

The test planes for Type A, Type B and Type C proving rotors are described in Table 10 which should be read in conjunction with Table 6.

10.4.2.2 Initial unbalance

Ensure that the unbalance in each plane of the proving rotor is smaller than five times the claimed U_{mar} (10 times for a single-plane test). If necessary, correct for these unbalances. Use locations which do not interfere with the tests to be performed (e.g. correction planes on a Type B proving rotor or rotor body end-faces (see Key 2 in Figure 5)).

Table 10 — Proving rotors and their planes for the tests described in Table 6

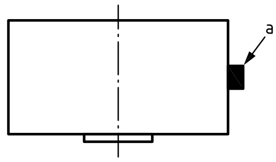
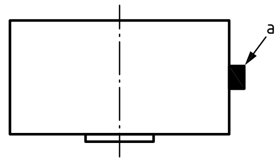
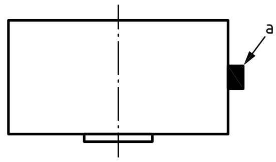
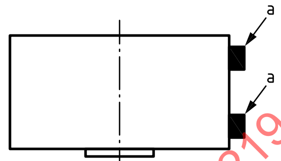
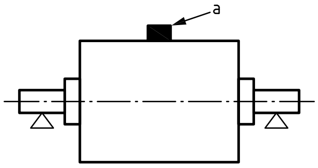
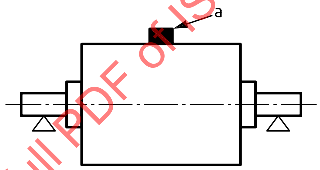
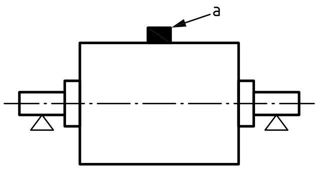
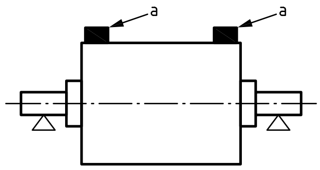
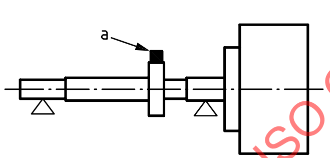
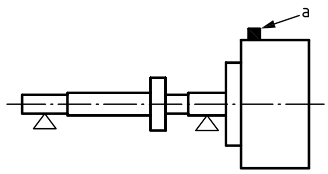
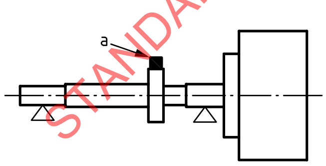
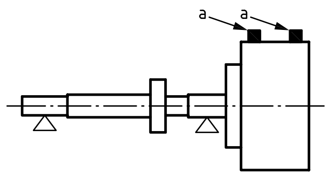
Balancing machine axis	Centre of mass location	Proving rotor (see 9.2)	Type of test
vertical	—	 Type A	single-plane → two-plane →
horizontal	inboard	 Type B	single-plane → two-plane →
	outboard	 Type C	single-plane → two-plane →

Key

1, 2, 3 test planes

I, II measuring planes for U_{mar}

Table 11 — Overview of U_{mar} and R_{UR} tests with proving rotors described in Table 5

U_{mar} **test** (see 10.4)	R_{UR} **test** (see 10.5)
Balancing with plane setting: resultant unbalance  Test mass producing 10 U_{mar} in Plane 3. Measuring: resultant unbalance	Test mass in Plane 3  $U_{station}$ = 20 U_{mar} to 60 U_{mar} U_{travel} = 5 $U_{station}$ Measuring: resultant unbalance
Balancing with plane setting: to correction planes near to Plane 1 and Plane 2  Test mass producing 10 U_{mar} in Plane 3. Measuring: in Plane I and Plane II	Test masses in each Plane 1 and Plane 2  $U_{station}$ = 20 U_{mar} to 60 U_{mar} U_{travel} = 5 $U_{station}$ Measuring: Plane 1 and Plane 2
Balancing with plane setting: resultant unbalance  Test mass producing 10 U_{mar} in Plane 3. Measuring: resultant unbalance	Test mass in Plane 3  $U_{station}$ = 20 U_{mar} to 60 U_{mar} U_{travel} = 5 $U_{station}$ Measuring: resultant unbalance
Balancing with plane setting: to correction planes near to Plane 1 and Plane 2  Test mass producing 10 U_{mar} in Plane 3. Measuring: in Plane I and Plane II	Test masses in each Plane 1 and Plane 2  $U_{station}$ = 20 U_{mar} to 60 U_{mar} U_{travel} = 5 $U_{station}$ Measuring: Plane 1 and Plane 2
Balancing with plane setting: resultant unbalance  Test mass producing 10 U_{mar} in Plane 3. Measuring: resultant unbalance	Test mass in Plane 1  $U_{station}$ = 60 U_{mar} to 100 U_{mar} U_{travel} = 5 $U_{station}$ Measuring: resultant unbalance
Balancing with plane setting: to correction planes near to Plane 1 and Plane 2  Test mass producing 10 U_{mar} in Plane 3. Measuring: in Plane I and Plane II	Test masses in each Plane 1 and Plane 2  $U_{station}$ = 60 U_{mar} to 100 U_{mar} U_{travel} = 5 $U_{station}$ Measuring: Plane 1 and Plane 2
For numbering of planes see Table 10.	
[a] Test mass(es).	

10.4.3 Unbalance added

Add two unbalance masses (e.g. 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, or

e) displaced by 180°.

EXAMPLE For planes on a Type B proving rotor, add the unbalance masses to the rotor body as near to the test planes as possible.

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

10.4.4 Readings

Readings of the initial unbalances (and after each correction step (see 10.4.5)) shall be recorded in the format of Table 1.

10.4.5 Correction

Balance the rotor as close to zero unbalance as possible in a maximum of four runs.

Apply corrections in the correction plane(s) after each run (e.g. correction planes on Type B proving rotor body end-faces (see Key 2 in Figure 5)).

On the fourth run, record the out of balance values in the format of Table 12.

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

10.4.6 Reference change

In the case of horizontal belt driven machines and after performing the actions specified in 10.4.2 to 10.4.5, change the angle of the one pulse per revolution mark by 60°.

If, after the reference system has been changed, the next reading (run 6) is unsatisfactory (see Note to 10.4.5), the problem shall be remedied before continuing the test.

10.4.7 Plane setting for U_{mar} test

Set the instrument to read in measuring plane(s) in accordance with the requirements of Table 5 and Table 6.

10.4.8 Test runs

Attach in test Plane 3 a test mass producing $10U_{mar}$ (see 9.4.1). Run the rotor, measure and record unbalance readings (values only) as shown in Table 13.

Attach the test mass in all the available holes in Plane 3 using a sequence that is arbitrary and then, for each position of the mass, run the rotor, measure and record readings in both planes as shown in Table 13.

10.4.9 U_{mar} evaluation

10.4.9.1 Calculation

Calculate the arithmetic mean value per plane by adding the values of all readings per plane and dividing the result by twelve. Enter the arithmetic mean value in Table 13 under mean value.

Divide each reading by the mean value of the respective plane and enter the results in Table 13 under multiples of mean value.

10.4.9.2 Plot

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

10.4.9.3 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 the claimed value of U_{mar} + 20 % to take account of the effects of variation in the position of the masses and test data scatter.

10.4.9.4 Assessment

The machine is considered to have passed the U_{mar} test (e.g. the claimed U_{mar} has been reached) if all points plotted on Figure 7 lie within the range given by the two dashed lines (0,88 and 1,12), with one exception allowed.

10.5 Test for unbalance reduction ratio, R_{UR}

10.5.1 R_{UR} 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.

An overview of U_{mar} and R_{UR} tests with the proving rotors described in Table 5 is shown in Table 11.

10.5.2 R_{UR} 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 the amount of unbalance indication, angle indication and plane separation.

NOTE On outboard Type C proving rotors and as an alternative, the R_{UR} test can be performed with resultant or couple unbalance test masses. Deviations from the two-plane test are described in this clause.

10.5.3 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 11 measuring runs. The test is performed with a stationary test mass and a travelling test mass (see 9.4.3) in each test plane.

Unbalance readings are recorded using the test sheet format shown in Table 12 and subsequently plotted and evaluated.

There are different R_{UR} test data sheets for two-plane (Table 14) and single-plane (Table 15) tests. Prepare the test data sheet prior to making the actual test runs so that test data are entered in the proper order.

Table 12 — Test data sheet for proving rotor balancing

Test date:
Test location:
Balancing machine operated by:
Readings taken and recorded by:

Table 12 *(continued)*

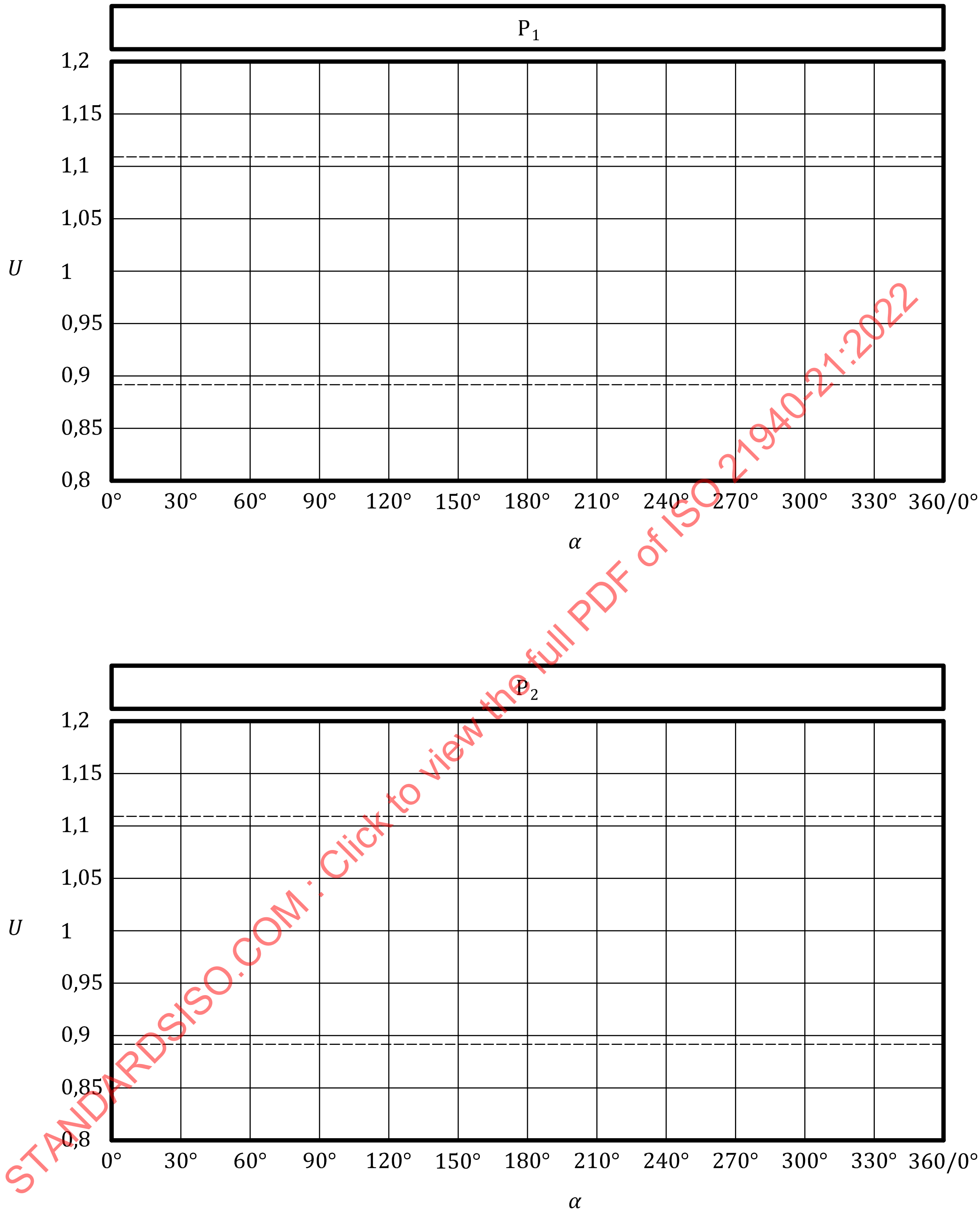
Balancing machine make:
Balancing machine model:
Proving rotor type:
Proving rotor number:
Serial number:
Proving rotor mass (kg):
U_{mar} (g mm):
10 U_{mar} (g mm):
Effective measurement radius (mm):
Test mass (g):
Test speed (r/min):

Run number	Plane 1 reading		Plane 2 reading		Correction
	U_{mar} g mm	**Angle** °	U_{mar} g mm	**Angle** °	g mm
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 13 — Test data sheet for U_{mar} test

Test mass angular position α °	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 reading

α position of test masses

P_1 plane 1

P_2 plane 2

NOTE Unbalance reading is in multiples of arithmetic mean values.

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

10.5.4 Test data sheet completion

10.5.4.1 Two-plane test

Preparation of a test data sheet (see Table 14) entails these steps:

a) at the top of the data sheet, enter the required information;

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 1 row on the Plane 1, stationary column;

c) in Plane 2 choose a position for the stationary test mass. The position shall be neither the same position as nor opposite to the stationary test mass in Plane 1. Enter the degree value in the Run 1 row on the Plane 2, stationary column;

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 1 row on the Plane 1, travelling column;

e) arbitrarily choose in Plane 2 a starting position for the travelling test mass. Enter the degree value in the Run 1 row on the Plane 2, travelling column;

f) for both travelling test masses, enter their positions for successive runs, letting them travel:

   1) in Plane 1 in ascending 30° intervals;

   2) in Plane 2 in descending 30° intervals.

   Do not use the stationary test mass positions, since two test masses cannot occupy the same position.

   For a resultant or couple test, use Table 14 with these modifications:

   3) mark Plane 1 as the left-hand couple to include the positions and readings for couple test masses in Plane 1 (couple test masses in Plane 2 are always 180° apart);

   4) mark Plane 2 as the middle plane (between Plane 1 and Plane 2) to include the positions and readings for the resultant test masses.

10.5.4.2 Multiple plane test

For testing when there are three or more test planes, it is recommended to modify the two-plane test sheets (see Table 12 and Table 13) by adding extra planes and using the same principle as for a two-plane test.

10.5.4.3 Single-plane test

Table 15 is for only one plane. The rules to choose positions for the stationary and travelling test masses are identical to Plane 1 of the two-plane test (see 10.5.3).

10.5.5 Plane setting

The machine shall be set to read in the test planes (see Table 5 and Table 6).

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

10.5.6 R_{UR} test runs

10.5.6.1 Initial point

Unless a U_{mar} test has immediately preceded the R_{UR} test, perform the steps specified in 10.4.2 to 10.4.6.

10.5.6.2 Test planes

Test planes shall be in accordance with the requirements of Table 5.

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

10.5.6.3 Procedure

Add the stationary and travelling test masses in their starting positions (see Table 14, Run 1 row) to the test planes of the proving rotor as shown in the data sheet.

Perform a run, measure and record the unbalance amount and angle readings for the planes shown 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 unbalance amount and angle readings for the planes shown on the data sheet, until 11 successive runs have been performed.

Divide the unbalance 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.

10.5.7 Plotting R_{UR} test data

10.5.7.1 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 R_{UR} limit circles. From the inside outwards, the concentric circles designate the limits for R_{UR} values of 95 %, 90 %, 85 % and 80 % respectively.

More detailed instructions for drawing these diagrams are given in Annex B.

10.5.7.2 Two-plane test

The two-plane test (see Figure 8) is carried out by completing these steps:

a) enter the angular position of Plane 1 stationary test mass on the short line above the arrow in the appropriate R_{UR} evaluation diagram. Mark radial lines at 20° intervals by entering degree markings in 20° increments (moving 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 value (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 R_{UR} diagram, utilizing the value scale as shown next to the vertical arrow;

d) plot the Plane 2 readings. 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 is the couple moment and Plane 2 the resultant moment (see 10.6.2).

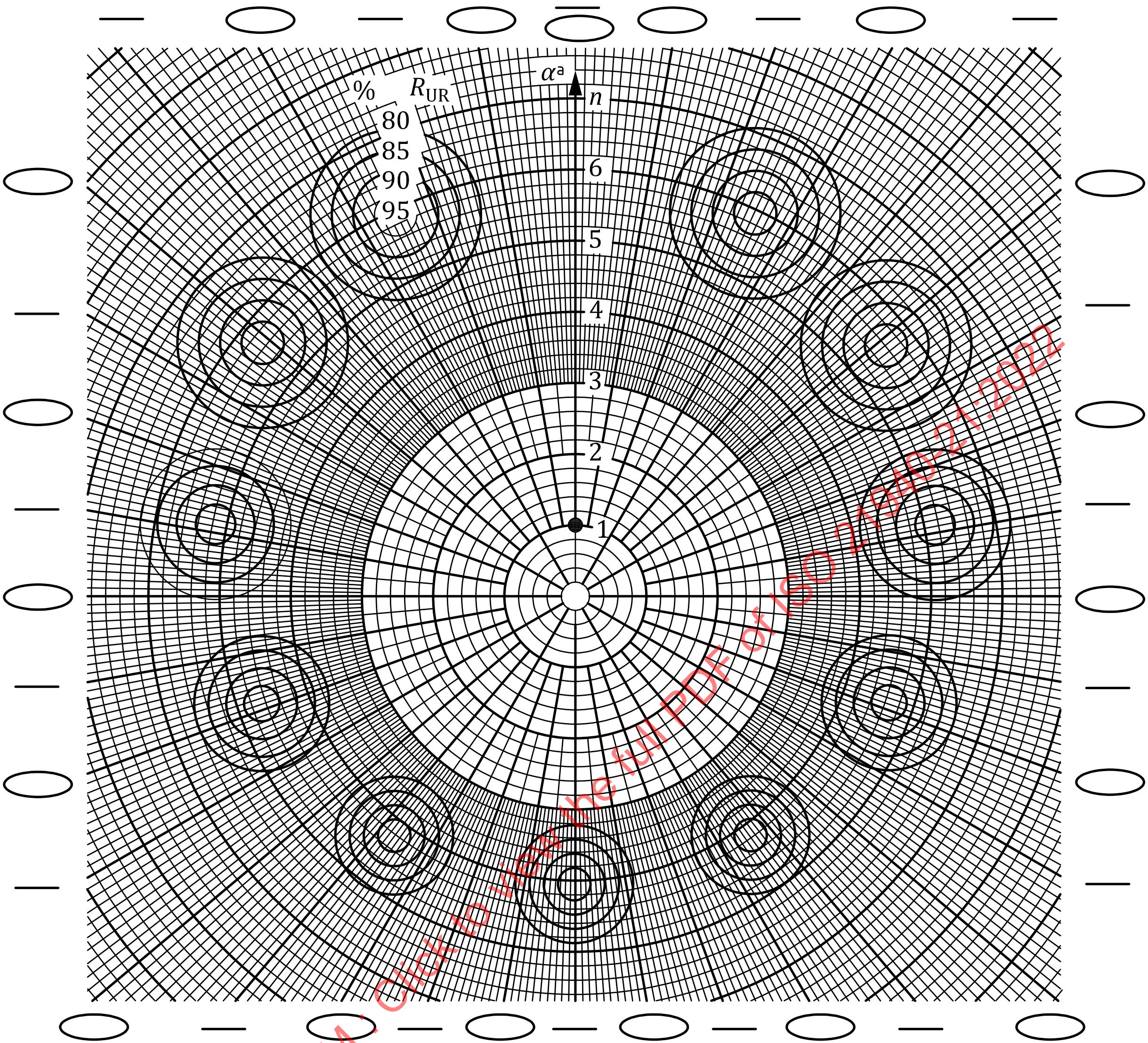
10.5.7.3 Single-plane test

Enter only one angular reference system into the diagram (see Table 14).

Table 14 — R_{UR} test data sheet for a two-plane test

Company:
Test location:
Test date:
Balancing machine make:
Balancing machine model:
Balancing machine operated by:
Readings taken and recorded by:
Proving rotor type:
Proving rotor serial number:
Proving rotor mass (kg):
Claimed e_{mar} (g mm/kg):
Claimed U_{mar} (g mm):
$U_{station}$ (g mm):
U_{mar} (g mm):
Effective measurement radius (mm):
Stationary mass $m_{station}$ (g):
U_{travel} = 5 $U_{station}$ (g mm):
Travelling mass m_{travel} (g):
Test speed (r/min):

Run	**Test mass positions (angles)**				**Unbalance reading**		**Amount**	**Unbalance reading**		**Amount**
	Plane 1		Plane 2		Plane 1		Reading Plane 1	Plane 2		Reading Plane 2
	Station-ary °	Travel-ling °	Station-ary °	Travel-ling °	Amount g mm	Angle °	Divided by $U_{station}$ Multiple of $U_{station}$	Amount g mm	Angle °	Divided by $U_{station}$ Multiple of $U_{station}$
1										
2	—		—							
3	—		—							
4	—		—							
5	—		—							
6	—		—							
7	—		—							
8	—		—							
9	—		—							
10	—		—							
11	—		—							



Achieved R_{UR}:

Test points plotted by:

Key

n	amount scale in multiples, n, of stationary test mass unbalance, $U_{station}$
α	position of stationary test mass (indicated by the vertical arrow)
% R_{UR}	unbalance reduction ratio, R_{UR}, as percentage
a	Insert angular reference system according to position of stationary mass.
___	plane 1, use ●
⬭	plane 2, use ⊙

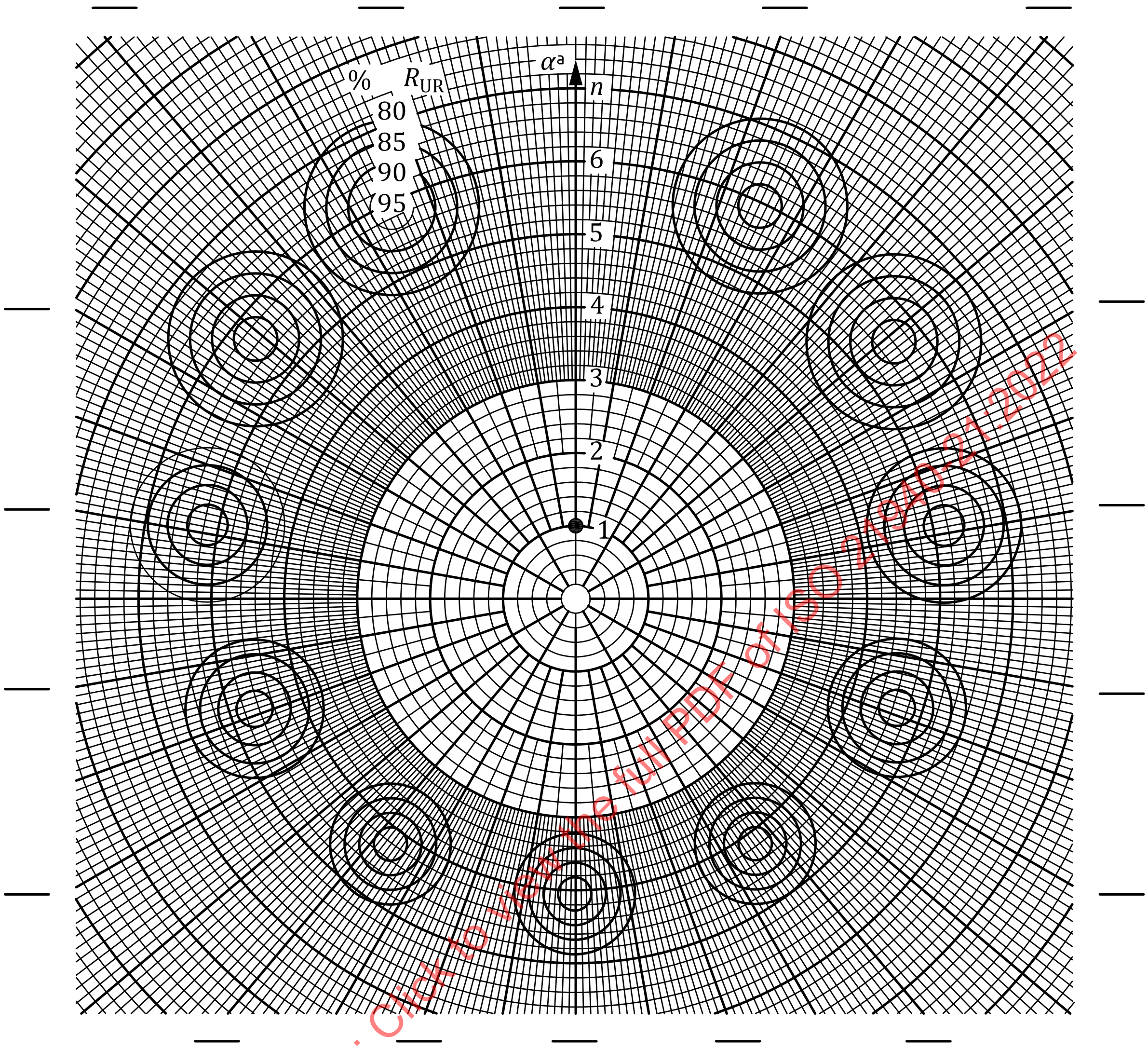
Figure 8 — R_{UR} evaluation diagram for two-plane test

Table 15 — R_{UR} test data sheet for a single-plane test

Company:
Test location:
Test date:

Table 15 *(continued)*

Balancing machine make:					
Balancing machine model:					
Balancing machine operated by:					
Readings taken and recorded by:					
Proving rotor type:					
Proving rotor serial number:					
Proving rotor mass (kg):					
Claimed e_{mar} (g mm/kg):					
Claimed U_{mar} (g mm):					
$U_{station}$ (g mm):					
U_{mar} (g mm):					
Effective measurement radius (mm):					
Stationary mass $m_{station}$ (g):					
U_{travel} = 5 $U_{station}$ (g mm):					
Travelling mass m_{travel} (g):					
Test speed (r/min):					
Run	**Test mass positions (angles)** Plane 3		**Unbalance reading** Plane 3		**Amount** Reading plane 3
	Stationary °	Travelling °	Amount g mm	Angle °	Divided by $U_{station}$ Multiple of $U_{station}$
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					



R_{UR} achieved:

Test points plotted by:

Key

n	amount scale in multiples, n, of stationary test mass unbalance, $U_{station}$
α	position of stationary test mass (indicated by the vertical arrow)
% R_{UR}	unbalance reduction ratio, R_{UR}, as percentage
a	Insert angular reference system according to position of stationary mass.
___	resultant plane

Figure 9 — R_{UR} evaluation diagram for single-plane test

10.5.8 Evaluation

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

If a R_{UR} 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 R_{UR} evaluation diagram shall fall within the R_{UR} limit circles that correspond to the claimed value for the R_{UR}, with one exception per correction plane allowed. If not, the machine fails the test.

10.6 Test for couple moment interference on single-plane machines

10.6.1 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 10.4.5.

10.6.2 Procedure

Add one test mass each (e.g. the travelling mass of the R_{UR} test) in Plane 1 and Plane 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.

10.6.3 Evaluation

None of the four readings may exceed the value of the attached couple moment unbalance multiplied by the claimed couple moment interference ratio, I_{sc}, plus the claimed U_{mar}.

In ISO 21940-2, the couple moment unbalance interference ratio I_{sc} is the ratio of the change in static unbalance indication and the change in couple moment inducing the change in indication.

The I_{sc} is calculated by using Formula 4:

$$I_{sc} = \frac{U_s}{U_c} \tag{4}$$

where:

U_s is the change in static unbalance indication induced by a change in couple unbalance;

U_c is the change in couple moment unbalance indication induced by a change in couple moment unbalance.

10.7 Compensator test

10.7.1 Initial point

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

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 10.4.5) or ensure that the unbalance is smaller than 5 U_{mar} in each plane (see 10.4.2.2).

10.7.2 Procedure

Add in Plane 1:

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

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

Add in Plane 2:

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

d) 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 indexing, move

e) the travelling test mass in Plane 1 from the 150° position to the 330° position (a 180° shift), and

f) the travelling test mass in Plane 2 from the 30° position to 210° position (a 180° shift).

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

Remove

g) in Plane 1 the travelling test mass located at 330°, and

h) 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.

10.7.3 Evaluation

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

For dedicated or special machines, when there are two independent compensators available, the compensator test shall be completed for each compensator.

10.8 Simplified tests

10.8.1 General

If a balancing machine has been previously type tested, or a machine in operation is periodically undergoing tests, a simplified U_{mar} test as described in 10.4 shall be carried out.

Both the U_{mar} and the R_{UR} tests may be simplified by reducing the number of test runs performed.

10.8.2 Simplified U_{mar} test

The simplified U_{mar} test shall be performed by carrying out these steps:

a) follow the procedures described in 10.4.2 to 10.4.7;

b) in 10.4.8, miss every second angular position, thus reducing the number of runs required to 6.

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

c) follow the procedures described in 10.4.9.1 to 10.4.9.3 but calculate the arithmetic mean value per plane by dividing the sum of the results taken by 6;

d) the balancing machine shall be considered to have passed the simplified U_{mar} test, if all plotted points are within the range given by the two dashed lines shown in Figure 7 (e.g. 0,88 and 1,12). No exceptions are allowed.

10.8.3 Simplified R_{UR} test

The simplified R_{UR} test shall be performed by carrying out these steps:

a) follow the procedures described in 10.5.4.1 but miss all positions being 60° or multiples thereof apart from the stationary test mass in each plane. This reduces the number of runs required to 6;

b) for the travelling test masses, enter the 60° ascending or descending intervals in the log as descried in 10.5.6;

c) make 6 successive runs in accordance with the procedures described in 10.5.6.3;

d) all test points recorded on the test sheet shall fall within the R_{UR} limit circles (or on their perimeter lines) that correspond to the claimed value for the R_{UR}. No exceptions are allowed.

Annex A
(informative)

Information provided by the user to the balancing machine manufacturer

A.1 General

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

A.2 Rotor to be balanced

A.2.1 Essential rotor data

The essential rotor data to be provided by the user to the balance machine manufacturer should include, but is not limited to

a) any applicable limiting factors (e.g. mass, dimensions and tolerances),

b) if the balancing machine is to be used for many classes of rotors. Table A.1 should be completed for each class. The maximum and minimum size of rotor that the machine is required to balance should be indicated, and

c) 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.

Table A.1 — Typical data for rotors (with rigid behaviour) to be balanced

Parameter	Rotor type[a]					Units
	1	2	3	4	...	
Mass						kg
Quantity[b]						
Production rate required[c]						per hour/per day[d]
Dimensions (see Figure A.2 and Figure A.3)						mm
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
Correction plane location, B						mm
Correction plane location, C						mm
End clearance on driven end, P[f]						mm
Service speed						r/min
Resonance speed[g]						r/min
Moment of inertia[h]						kg m^2
Air resistance[i]						N
Motor power and speed						kW and 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] Class(es) of rotor(s) and use (e.g. 4-cylinder crankshaft, flywheel, ventilator, electric rotor, fan).

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

[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 $\int R^2 \, \mathrm{d}m$ over the entire rotor body, where dm is an increment of mass and r is its distance from the shaft axis.

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

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

[k] Unbalance tolerance (g mm) in each tolerance 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 (e.g. belt drive, end drive, either belt or end drive, air drive, roller drive, self-powered drive, band drive).

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

A.2.2 Other rotor data

Other rotor data to be provided by the user to the balance machine manufacturer should include, but is not limited to:

a) If possible, detailed drawings of typical rotors to be balanced should be made available. This is particularly important for rotors with unusual geometry (see Figure A.2 and Figure A.3).

b) If correction planes are located other than between the journals, their locations should be described.

c) If the balancing machine is to be used with outboard rotors. If so, state which are Load B and negative Load A (see Figure A.1).

d) Presence of a thrust load. If so, give value and direction expected during balancing operation (applicable to horizontal machines only).

e) Requirement of the use for the balancing machine manufacturer to supply the necessary fixtures and attachments (e.g. driving adaptors, pulleys, mounting adaptors and mandrels).

f) Surface finish, roundness and hardness of the journal.

g) If the rotors are to be balanced in their own bearings. If so, give details (e.g. type of bearing and maximum bearing outside diameter).

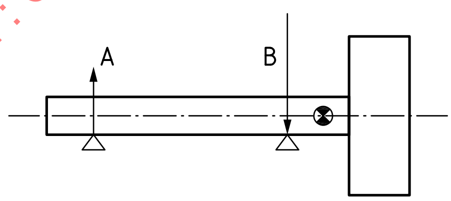
h) If a specific balancing speed is desired. If so, explain why.

i) Expectation of the user for the balancing machine manufacturer to supply the means of balance correction to be used (e.g. drills, milling cutters).

j) Any other special rotor properties (e.g. rotating magnetic fields and any aerodynamic effects) that need to be taken into account.

k) Any other special test requirements by the user.

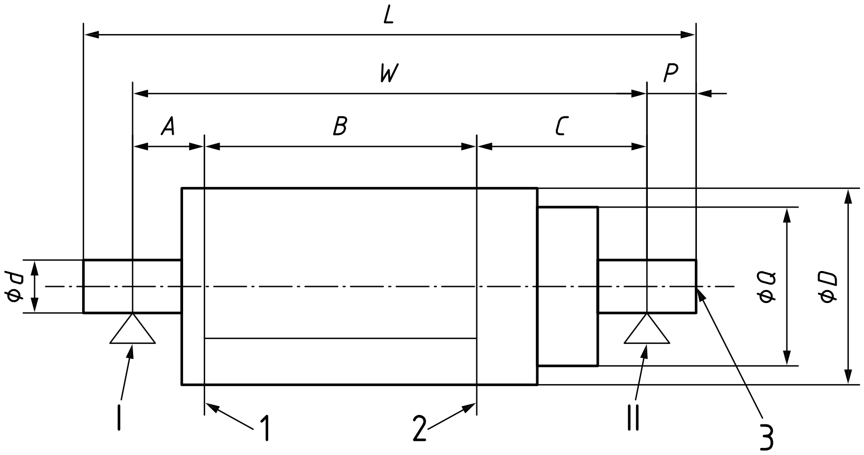
l) Any cycle time requirements by the user.



Key

A, B loads

Figure A.1 — Loads



Key

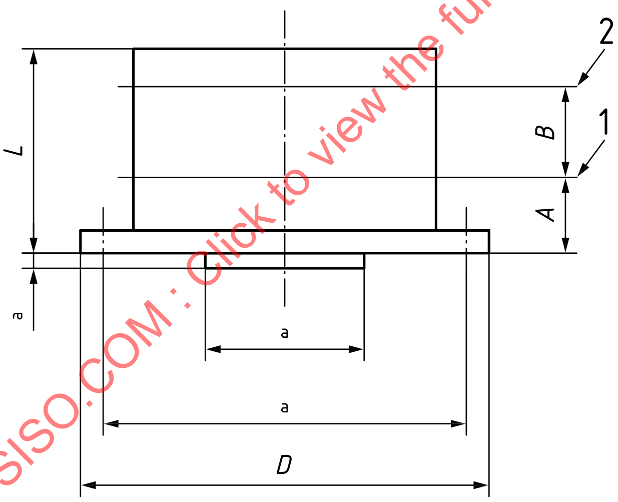
1, 2 correction planes

3 driven end

I, II bearing planes

NOTE For dimensions, see Table A.1.

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



Key

1, 2 correction planes

[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 (see Figure 4).

NOTE For dimensions, see Table A.1.

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

A.3 Other technical information

The technical information to be provided by the user to the balance machine manufacturer should include, but is not limited to:

a) If the main electrical supply is three or single phase voltage. Give the supply frequency and maximum allowed deviation percentage. With a three-phase system grounded, state whether there is a neutral lead available.

b) If the electrical equipment should meet any particular standard or specification.

c) If tropical insulation is required.

d) If compressed air is available and at what supply pressure and with what maximum variation.

e) If the floor where the machine is to be located is rigid (e.g. equivalent to a concrete slab laid on compacted earth) and thickness of concrete floor.

f) State any possible sources of vibration in the vicinity of the balance machine installation (e.g. hammers and heavy vehicles) and state their average rate of occurrence.

g) Units to be marked on any indicating devices used.

h) In which language should the operating instructions and leaflets accompanying the balancing machine preferably be written and what other languages are acceptable.

A.4 Administrative information

The administrative information to be supplied by the user to the balance machine manufacturer should include, but is not limited to

a) need of the user for the services of a balancing machine service engineer to install and calibrate the machine,

b) need of the user for the services of a balancing machine service engineer to instruct personnel,

c) intention of the user to send an operator to be trained by the manufacturer,

d) names and addresses of people in the user's organization in charge of balancing,

e) who inspects and accepts the machine and where and where are the applicable specifications held,

f) interest of the user in having a maintenance contract and if so, whom the quotation shall be addressed to,

g) shipping address for the machine,

h) box markings needed,

i) relevant insurance instructions, and

j) state, as applicable:

    1) shipping arrangements to the requirements of Incoterms 2020[7];

    2) user requested delivery date;

    3) user requested factory acceptance date;

    4) manufacturer requested date for part and project information;

    5) manufacturer requested date for sample parts;