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Geometrical product specifications (GPS) — Rotary axis form-measuring instruments — Design and metrological characteristics

Spécification géométrique des produits (GPS) — Instruments de mesure de forme à axe rotatif — Caractéristiques de conception et caractéristiques métrologiques

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Foreword

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This document was prepared by Technical Committee ISO/TC 213, *Dimensional and geometrical product specifications and verification*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 290, *Dimensional and geometrical product specification and verification*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

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

This document is a geometrical product specification standard and is to be regarded as a general GPS standard (see ISO 14638). It influences chain link F of the chains of standards on form, orientation, location and run-out.

The ISO GPS matrix model given in ISO 14638 gives an overview of the ISO GPS system, of which this document is a part. The fundamental rules of ISO GPS given in ISO 8015 apply to this document and the default decision rules given in ISO 14253-1 apply to specifications made in accordance with this document, unless otherwise indicated. For more detailed information of the relation of this document to other standards and the GPS matrix model, see Annex F.

See ISO/TR 14253-6 for additional information on the selection of alternative decision rules.

There are different types and variants of rotary axis form-measuring instrument. The metrological characteristics described in this document apply to all types and variants.

Geometrical product specifications (GPS) — Rotary axis form-measuring instruments — Design and metrological characteristics

1 Scope

This document specifies the most important design and metrological characteristics of rotary axis form-measuring instruments.

It is not applicable to coordinate measurement systems as defined by the ISO 10360 series, whether the systems are fitted with a rotary axis or not, except by special agreement.

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 1101, *Geometrical product specifications (GPS) — Geometrical tolerancing — Tolerances of form, orientation, location and run-out*

ISO 14253-5, *Geometrical product specifications (GPS) — Inspection by measurement of workpieces and measuring equipment — Part 5: Uncertainty in verification testing of indicating measuring instruments*

ISO/TR 14253-6, *Geometrical product specifications (GPS) — Inspection by measurement of workpieces and measuring equipment — Part 6: Generalized decision rules for the acceptance and rejection of instruments and workpieces*

ISO 14978:2018, *Geometrical product specifications (GPS) — General concepts and requirements for GPS measuring equipment*

ISO/IEC Guide 98-3, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

ISO/IEC Guide 99:2007, *International vocabulary of metrology — Basic and general concepts and associated terms (VIM)*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 1101, ISO 14978 and ISO/IEC Guide 99 and the following apply.

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

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

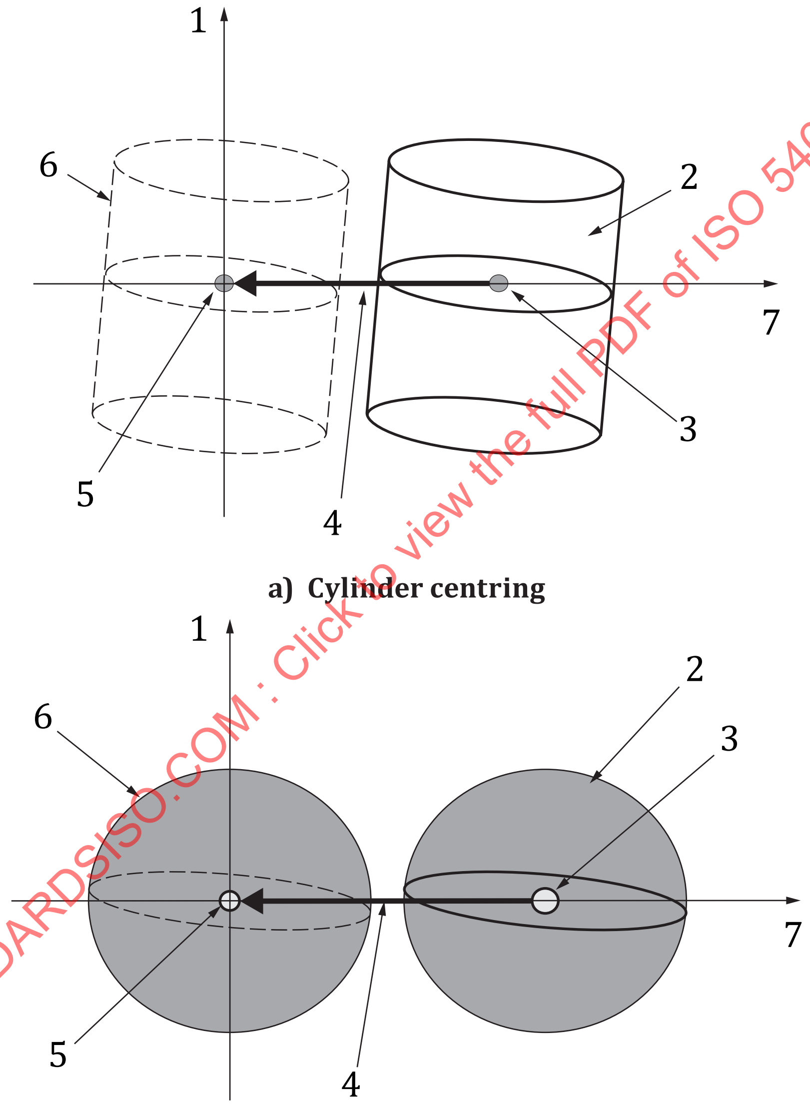
— IEC Electropedia: available at https://www.electropedia.org/

3.1 General terms

3.1.1
rotary axis form-measuring instrument
measuring instrument having a rotary axis and quantifying local form deviations from extracted integral surfaces in a cylindrical coordinate system

3.1.2
centring
adjusting, in a plane perpendicular to the axis of rotation, the position of the centre point of the workpiece to be coincident to the axis of rotation of the instrument

Note 1 to entry: See Figure 1.



a) Cylinder centring

b) Sphere centring

Key

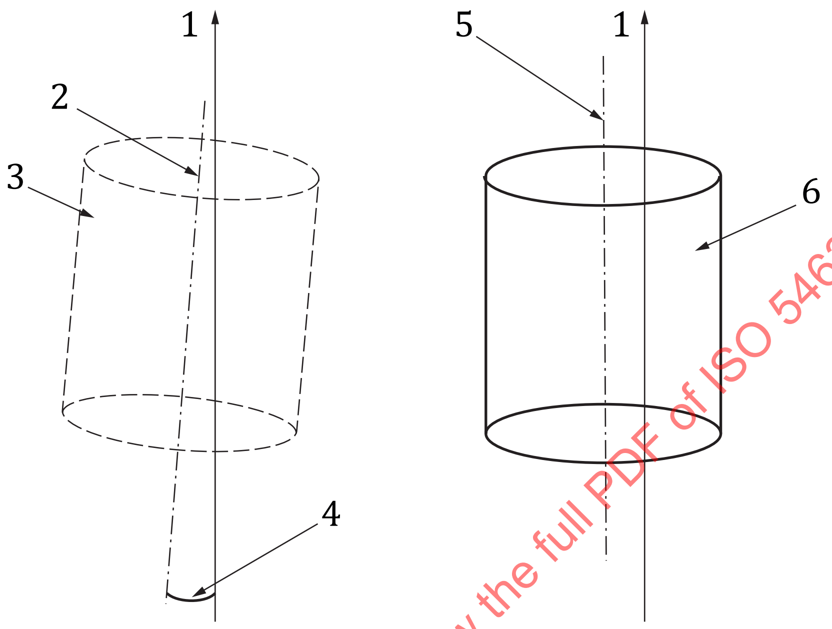
1 axis of rotation
2 revolute workpiece before centring
3 centre point before centring
4 centring displacement
5 centre point after centring
6 revolute workpiece after centring
7 orthogonal axis to the axis of rotation

Figure 1 — Centring

3.1.3
levelling
adjusting the centre line of the workpiece to be parallel to the axis of rotation or adjusting the normal vector to a plane feature of the workpiece to be parallel to the axis of rotation

Note 1 to entry: See Figure 2.

Note 2 to entry: Levelling is often combined with, or followed by, centring in order to bring the axis of the workpiece to be coaxial with the rotary axis of the instrument.



Key

1 axis of rotation
2 centre line of revolute workpiece before levelling
3 revolute workpiece before levelling
4 angular displacement
5 centre line of revolute workpiece after levelling
6 revolute workpiece after levelling

Figure 2 — Levelling

3.2 Terms relating to probe system

3.2.1
stylus
mechanical device consisting of a tip and an arm

4 Design characteristics

4.1 General

This measuring instrument is primarily constructed to acquire form deviations in cylindrical coordinates through the direct measurement of radial (and axial) deviations. The design characteristics of a rotary axis form-measuring instrument are described generically in Annex A, and depend on its type.

The cylindrical coordinate system is configured with the longitudinal axis nominally coincident with the rotary axis and with a nominally perpendicular transverse axis.

NOTE 1 See Figure 3.

NOTE 2 Displacements measured along the longitudinal axis are designated as *H* and are measured from a point specified by the manufacturer.

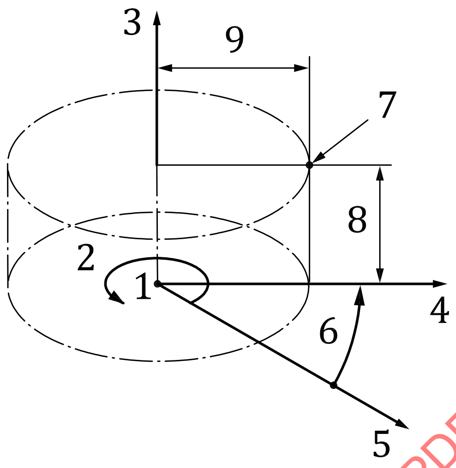
NOTE 3 Radius, designated as *R*, is measured from the rotary axis and its basic direction is the transverse axis.

NOTE 4 Rotation angle, designated as *θ*, is measured from a line with orientation specified by the manufacturer in the transverse plane.

NOTE 5 Direction along the rotary axis is called "axial direction" for rotary characteristics.

NOTE 6 Outward direction around the rotary axis is called "radial direction" for rotary characteristics.

NOTE 7 Rotating direction around the rotary axis is called "angular direction" for rotary characteristics.



Key

1 origin (centre position of rotary bearing)
2 angular motion
3 axis line of rotation (longitudinal axis)
4 transverse axis or radial direction
5 angular reference axis in the transverse plane (θ=0)
6 rotation angle (angular distance of transverse axis from reference axis)
7 probing point
8 longitudinal distance (distance of the probing point from the transverse plane)
9 radial distance (of the probing point from the rotary axis)

Figure 3 — Measuring coordinate system

4.2 Types of rotary axis form-measuring instruments

4.2.1 General

There are a number of different types of rotary axis form-measuring instruments, with variants of each of these types.

4.2.2 Rotating workpiece instrument

Design characteristics of this type of instrument shall be in accordance with Annex A.

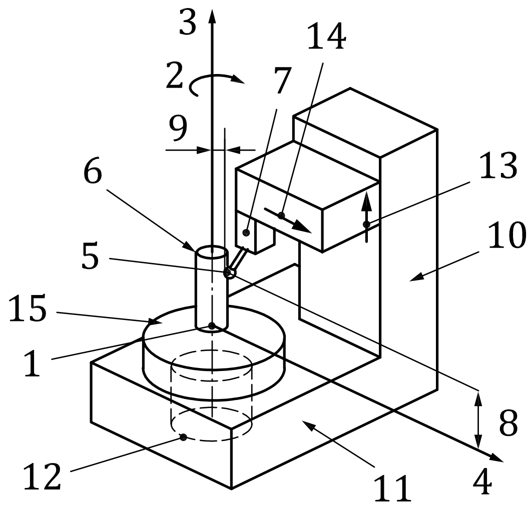
Rotating workpiece instruments include the following variants:

a) Vertical axis rotating workpiece instrument on which the workpiece is fixed on a worktable, see Figure 4.

b) Horizontal axis rotating workpiece instrument, which is a variant of type a), where the longitudinal axis lies in a horizontal plane, see Figure 5.

c) Vertical axis rotating workpiece between centres, which is a variant of type a), where the workpiece is rotated between centres instead of on a worktable.

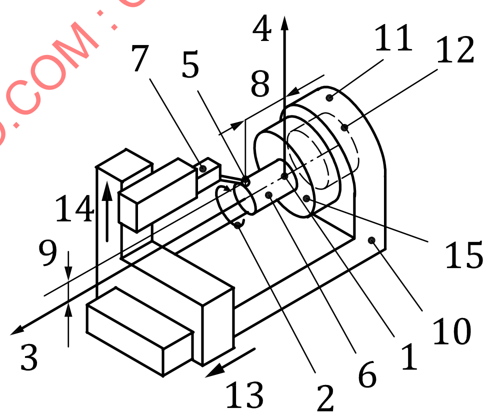
d) Horizontal axis rotating workpiece between centres, which is a variant of type b), where the workpiece is rotated between centres instead of on a worktable.



Key

1	origin of measuring coordinate system	9	probing point radius *R* from rotary axis
2	angular motion	10	column
3	axis line of rotation	11	base
4	transverse axis	12	rotary spindle
5	probing point	13	longitudinal axis motion
6	workpiece	14	transverse axis motion
7	probe	15	worktable
8	probing point height *H* from the top plane of the worktable		

Figure 4 — Vertical axis rotating workpiece instrument



Key

1	origin of measuring coordinate system	9	probing point radius *R* from rotary axis
2	angular motion	10	column
3	axis line of rotation or longitudinal axis	11	base
4	transverse axis direction	12	rotary spindle
5	probing point	13	longitudinal motion

6 workpiece
7 probe
8 probing point height H from worktable top plane
14 transverse motion
15 fixture for workpiece on worktable

Figure 5 — Horizontal axis rotating workpiece instrument

4.2.3 Stationary workpiece instrument

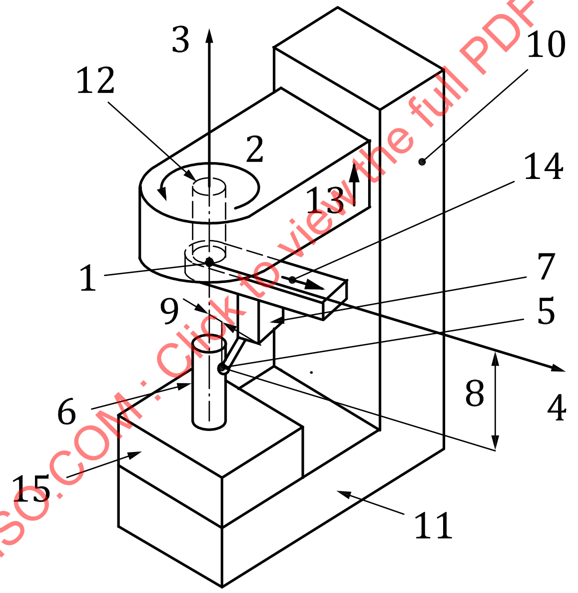
The stationary workpiece type instruments include the following variants:

a) Vertical axis stationary workpiece instrument on which the stylus turns around the workpiece, which is fixed on a worktable, see Figure 6.

b) Horizontal axis stationary workpiece instrument, which is a variant of type a) in which the longitudinal axis lies in a horizontal plane, see Figure 7.

c) Horizontal axis stationary workpiece between both centres instrument, which is a variant of b), where the workpiece is held between centres instead of in a workpiece fixture.

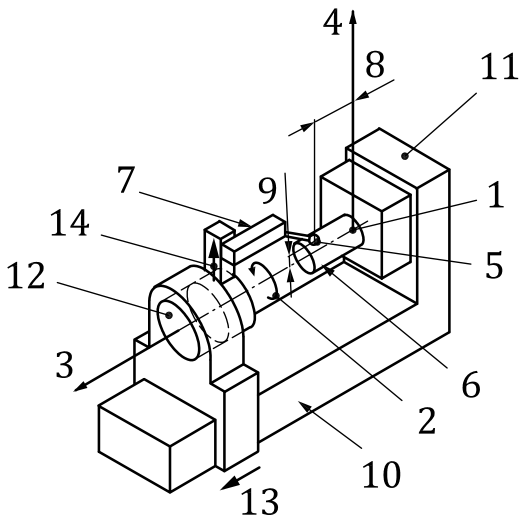
d) Hole insertion with stationary workpiece instrument, a variant of a type where the instrument works inside a fixed cylindrical hole on a workpiece, see Figure 8.



Key

1 origin of measuring coordinate system
2 angular motion
3 axis line of rotation
4 transverse axis
5 probing point
6 workpiece
7 probe
8 probing point height H from the origin at the transverse axis
9 probing point distance R from rotary axis
10 column
11 base
12 rotary spindle
13 longitudinal axis motion
14 transverse axis motion
15 worktable

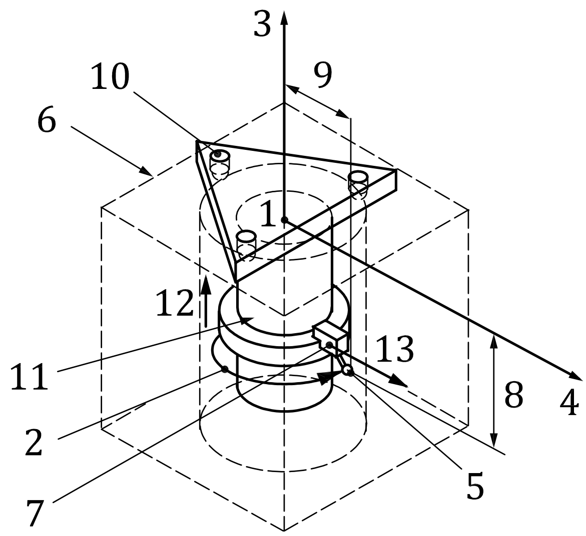
Figure 6 — Vertical axis stationary workpiece instrument



Key

1	origin of measuring coordinate system	8	probing point height *H* from the origin at the transverse axis
2	angular motion	9	probing point distance from rotary axis
3	axis line of rotation or transverse axis	10	base
4	longitudinal axis	11	column
5	probing point	12	rotary spindle
6	workpiece	13	transverse axis motion
7	probe	14	adjusting radius

Figure 7 — Horizontal axis stationary workpiece instrument



Key

1 origin of measurement coordinate
2 angular motion
3 axis line of rotation axis
4 transverse axis
5 probing point
6 workpiece
7 probe
8 probing point height *H* from the origin at the transverse axis
9 radius *R* of workpiece at the position of the probe contacting point
10 base
11 rotary spindle
12 longitudinal motion
13 axis of the lever type probe

Figure 8 — Hole insertion with stationary workpiece instrument

4.3 Design characteristics of probe

4.3.1 Contact probe

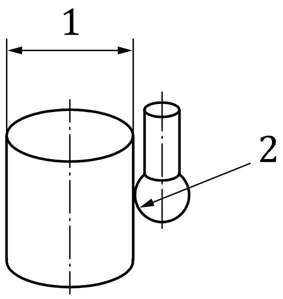
A contact probe consists of a fixed part ("main body including transducer") (see ISO/IEC Guide 99:2007, 3.7) and a movable part ("stylus") which is also called the "measuring element".

A contact probe needs a measuring force to maintain contact with the surface throughout the measurement. Excessive force could cause bending in the measurement loop and also damage the contacting point or the surface being measured. The measuring force should therefore be kept as small as possible.

The stylus tip should be manufactured from hard, wear-resistant material. It shall be well finished and free of flats or other irregularities which could affect the accuracy of the instrument.

The geometrical properties of the contact element shall be sufficient for the use of the measuring instrument.

The default geometry of a stylus tip is a sphere (see Figure 9).



Key

1 diameter of cylindrical workpiece

2 tip radius of sphere stylus in any direction

Figure 9 — Sphere stylus tip geometry

4.3.2 Other types of probe

There are many different types of probe, which may have limitations on the types of materials that can be measured. For rotary axis form-measuring instruments equipped with other probes, the manufacturer can state each of the specifications (see Annex E).

5 Metrological characteristics

5.1 General

The metrological characteristics, other concepts and principles that are common across types and variants are described below. Because the verification of the metrological characteristics may vary dependent on instrument type and variant, testing and verification are described in Annex A relating to the instrument type and variant. The testing and verification shall be carried out as specified in Annex A. The material measures for these tests are described in Annex B.

A rotary axis form-measuring instrument can be used to measure many types of geometrical features. The instrument may, therefore, have many different metrological characteristics. The supplier of a rotary axis form-measuring instrument shall specify the maximum permissible error (MPE) of each metrological characteristic. These MPEs apply when the instrument is used in accordance with the rated operating conditions stated by manufacturer or supplier and the manufacturer's recommendations.

NOTE The manufacturer or supplier does not need to specify MPE values for metrological characteristics that are not included in the instrument functions or in the required measurements on the target workpiece.

The probe error is presented in 5.4, separately from Annex A, due to its potential contributor to all other metrological characteristics of a rotary axis form-measuring instrument.

The length unit of metrological characteristics is micrometres, by default.

5.2 Rating operating condition

5.2.1 Environmental conditions

Limits for permissible environmental conditions that influence the measurements (e.g. temperature conditions, humidity, vibration and ambient lighting at the site of installation) shall be specified by:

— the manufacturer, in the case of acceptance tests;

— the user, in the case of reverification tests.

In both cases, the user is free to choose the environmental conditions within the specified limits given in the instrument data sheet under which testing to this document will be performed.

The user is responsible for providing the environmental conditions as stated by the manufacturer in the data sheet. If the environment is not within the rated operating conditions, then conformity or nonconformity decision cannot be made unless the rated operating condition are met.

5.2.2 Operating conditions

The instrument shall be operated using the procedures given in the manufacturer's operating manual when conducting the tests given in Annex A.

5.3 Correction of form deviations on material measure

As discussed in Annex B, many of the measurement standards needed for verifying conformity to specification should have small form deviations. The form deviations contribute to the measurement uncertainty of the test values. To reduce the contribution of the form deviations on the material measure to the test uncertainty, this document allows correction of the form deviations.

NOTE The following methods are typically used for correction of the form deviation of the measurement standards:

a) compensation of the calibrated profile method;

b) reversal error separation method (see ISO 230-7 and references [21],[22],[25] and [27]);

c) multi-step error separation method; (see references [23],[24],[25],[27],[28] and [32]).

5.4 Probe characteristics

5.4.1 Reference point

Where applicable, the probe used for form measurements shall be provided with user-accessible means for setting the probe to zero or to the reference point. The metrological characteristics described in this document apply when the probe is properly set in accordance with the manufacturer's recommendations, and the reference point is considered fixed when verifying the metrological characteristics.

5.4.2 Probe error

5.4.2.1 General

The probe error (E_p) is the error of indication when the probe is in contact with a material measure, for any angular motion of the material measure or of the stylus depending on the type of the rotary axis form-measuring instrument. The probe error is calculated as the signed deviation of the probe indication from the calibrated reference value of a material measure.

The MPE of probe error shall be specified in at least one measuring range stated by the manufacturer or supplier.

NOTE 1 The probe error can include the sensitivity error, the linearity error, the instrumental drift, the resolution or digital step, the repeatability, the measurement noise, the hysteresis error and the dynamic response (see Annex C).

NOTE 2 The probe error is a contributor to all metrological characteristics of the instrument.

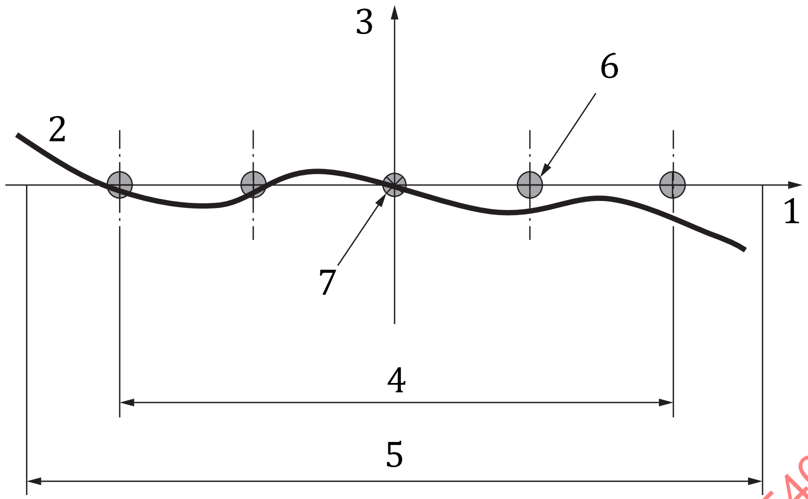
The sensitivity shall be adjusted following the manufacturer's recommendations prior to the probe error test.

5.4.2.2 Test method

5.4.2.2.1 Test points and range

The verification test of probe errors shall be carried out with five or more test points. The test points shall be well distributed, as evenly as practicable, throughout the measuring range of the probe (see Figure 10). The test points shall cover at least the central 75 % of the measuring range of the probe.

The reference point of the probe shall be at the centre (zero point) of its measuring range. This reference point shall be located on the reference plane of the standard and be one of the test points.



Key

1 actual displacement
2 probe error curve
3 probe error
4 test range
5 measuring range of probe
6 test point
7 reference point

Figure 10 — Analysis of probe error

5.4.2.2.2 Test direction and location

The user is free to choose the probing direction (horizontal or vertical) for the probe error verification test, if not stated otherwise by the manufacturer.

5.4.2.3 Measurement standard and testing procedure

When testing conformity to specifications, sufficient testing shall be used to establish confidence in the results and the tester may choose suitable instruments or measurement standards from those described in Annex B. The instrument or measurement standard used shall cover the range to be tested.

If each target step of displacement has a different probing position, the probing positions should be set along an accurate (rotary, longitudinal or transverse) traversing motion. Probe error shall be calculated from the measured length difference of each displacement. Typical procedures of each instrument and material measures are also shown in Annex B.

5.4.2.4 MPE function

5.4.2.4.1 General

Maximum permissible probe error, $E_{P,MPE}$, is a two-sided MPE function as shown in ISO 14978:2018, 7.2.

5.4.2.4.2 Proportional value MPE functions

Upper limit MPE:

$$E_{P,MPE} = + (a + |L \times b|)$$

Lower limit MPE:

$$E_{P,MPE} = - (a + |L \times b|)$$

5.4.2.4.3 Constant value MPE functions

Upper limit MPE:

$$E_{P,MPE} = + a$$

Lower limit MPE:

$$E_{P,MPE} = - a$$

5.4.2.4.4 Proportional value MPE functions with probe range

Upper limit MPE:

$$E_{P,MPE} = + (a + |L \times b|) / (\text{probe range})$$

Lower limit MPE:

$$E_{P,MPE} = - (a + |L \times b|) / (\text{probe range})$$

where

- a are positive constants stated by the manufacturer;
- b is a dimensionless positive constant stated by the manufacturer;
- L is the actual displacement in micrometres (L = 0 at the reference point)

The MPE of the probe error can also be indicated as a percentage of the measuring span stated by the manufacturer when the MPE is intended to indicate using constant value. The MPE of the probe error can also be indicated as a percentage with proportional measuring span.

6 Determination of conformity to specification

6.1 General

All errors of indication associated with the metrological characteristics shall conform to the specified MPE values.

6.2 Measurement uncertainty

Evaluation of measurement uncertainty shall be performed in accordance with ISO/IEC Guide 98-3. When determining conformity with specification, the measurement uncertainty associated with a test value (the test value uncertainty) shall be evaluated in accordance with ISO 14253-5. Additional guidance is available in ISO 14978:2018, Annex D.

6.3 Decision rule

When demonstrating conformity or non-conformity to specifications, the decision rule accompanying the specifications shall be followed. If no decision rule is stated in the specifications, and no special agreement is made between supplier and customer, then the default decision rule shall be simple acceptance and rejection, with the measurement capability index, C_m, being one or larger, in accordance with ISO/TR 14253-6.

NOTE Information on the selection of an alternative decision rule can be found in ISO/TR 14253-6.

Annex A
(normative)

Design and metrological characteristics for rotating workpiece instruments

A.1 Design characteristics

The design of this type of rotary axis form-measuring instrument shall follow the general guidelines in ISO 14978. The design shall be such that the metrological characteristics conform to the requirements of this document.

Table A.1 gives a list of design characteristics for this type of rotary axis form-measuring instrument. Relevant design characteristics should be specified when communicating requirements.

Table A.1 — List of design characteristics

Design characteristics		
Component	**Description**	**Unit**
Overall dimensions	Height	mm
	Width	mm
	Depth	mm
	Mass (weight)	kg
Mains connection	AC line voltage	V
	AC line frequency	Hz
	Apparent power input	VA
Measuring range	Maximum test diameter	mm
	Maximum measuring length on longitudinal axis	mm
	Maximum measuring length on transverse axis	mm
Traversing speed	Rotational speed (ω_{cyc})	Hz or r/min
	Traversing speed on longitudinal axis	mm/s
	Traversing speed on transverse axis	mm/s
Loading table	Size or diameter	mm
	Load capacity	N (or kg)
	Centring range	mm
	Levelling range	degree
Probe	Probe type (contact or non-contact)	-
	Maximum measuring range of probe	mm or µm
	Stylus tip radius on a contact probe, or a half of effective spot size on a non-contact probe	mm or µm

NOTE 1 Table A.1 shows the most important design characteristics for a rotating workpiece form-measuring instrument. It is possible that some of these characteristics are not applicable to some variants.

NOTE 2 In addition to the characteristics shown in Table A.1, other design characteristics can be specified by the manufacturer, depending on the application.

A.2 Metrological characteristics

A.2.1 General

The following metrological characteristics are complementary to the probe error :

— radial error (see A.2.2);

— axial error (see A.2.3);

— longitudinal straightness error (see A.2.4);

— parallelism error (see A.2.5);

— transverse straightness error (see A.2.6);

— squareness error (see A.2.7).

Many of the metrological characteristics described in this Annex can be measured with a smaller measurement uncertainty if error separation techniques are used to minimize uncertainty contributions from the measurement standard.

Once the metrological characteristics have been determined, computer aided accuracy techniques may also be used to software correct the instrument to meet the manufacturer's specification.

In a few cases, such error separation techniques are part of the instrument's normal operation, for instance when radial error separation techniques are used to measure high precision components.

A.2.2 Radial error

A.2.2.1 General

The radial error (E_R) is the peak-to-valley roundness deviation, RONt (see ISO 12181-1) that would be obtained from a longwave-pass filtered roundness profile of a perfectly round and perfectly centred section of a measurement standard in a direction perpendicular to the axis of rotation.

The radial error shall not exceed the maximum permissible radial error.

NOTE 1 Radial error can consist of "pure radial error", which is typically described as "radial motion error", and proportionally dependent error, called "tilt error" (see Figure A.1). Radial motion error cannot be separately evaluated from tilt error.

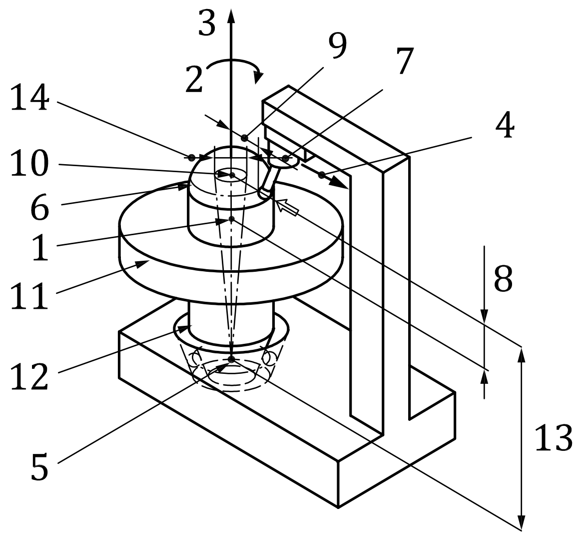
NOTE 2 Radial error can include the effect of "closure error" (see reference [31]).

NOTE 3 Radial error can also be influenced by probe error and the remaining errors in centring as uncertainty effect.

NOTE 4 Radial error is a contributor to the measurement uncertainty of roundness or cylindricity observed on a workpiece.

NOTE 5 Tilt error also affects axial error and can be assessed by verification of either radial or axial errors.

NOTE 6 "Closure error" can also be caused by instrument drift (see ISO/IEC Guide 99:2007, 4.21) or influences from the environment or measurement process.



Key

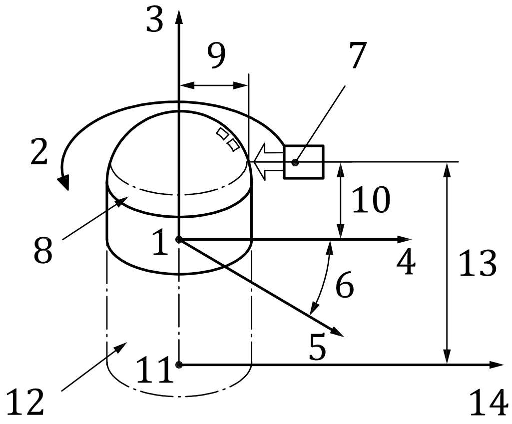
1 origin of measuring coordinates
2 angular motion
3 axis line of rotation
4 transverse axis
5 centre position of tilt error
6 hemisphere or sphere measurement standard
7 probe
8 nominal height of probing point from origin
9 distance of the probing point from rotary axis
10 centre of probing roundness profile
11 worktable or transverse reference plane
12 rotary spindle
13 actual probing height from tilt error centre
14 tilt error at height

Figure A.1 — Principle of reference point of tilt error

A.2.2.2 Test method

A.2.2.2.1 General

Radial error shall be tested by measuring the roundness profile around a roundness standard, for example a precision sphere or hemisphere (see Figure A.2).



Key

1 origin of measuring coordinates
2 angular motion
3 axis line of rotation
4 reference axis on the transverse plane when testing at H_1 (paralleled to transverse axis)
5 measured position of rotary axis on transverse plane
6 angular distance from reference axis
7 Probe
8 measurement standard (sphere or hemisphere)
9 distance of the probing point from rotary axis
10 height H_1 of probing point from origin
11 origin of measuring coordinates and the centre of roundness standard when testing at H_2
12 spacer when testing at H_2
13 height H_2 of probing point from origin
14 reference axis on the transverse plane when testing at H_2

Figure A.2 — Test method for radial error

A.2.2.2.2 Test points and conditions

The verification test of radial error shall be carried out with a measuring process that has a sufficiently small measurement uncertainty.

Probe configuration, orientation, direction, rotation speed and testing set-up conditions of the instrument should be specified by the manufacturer or supplier.

A.2.2.2.3 Test position

The radial error may include tilt error, which is a proportional error. Tilt error also affects the axial error and may be assessed by the evaluation of either radial or axial errors. To assess the tilt error component of the radial error, measurements should be taken at two different positions in the longitudinal axis direction:

a) H_1, as close to zero of the longitudinal axis as practicable (the height of the standard is acceptable);

b) H_2 = larger or equal to one half of the maximum travel of the longitudinal axis.

Some instruments may have a longitudinal axis with a very long maximum travel. When the maximum travel of the longitudinal axis of the instrument is greater than 400 mm, the set-up of the measurement standard for this test may be unstable. In this case, it is acceptable to locate H_2 at least 200 mm from H_1 in the longitudinal direction.

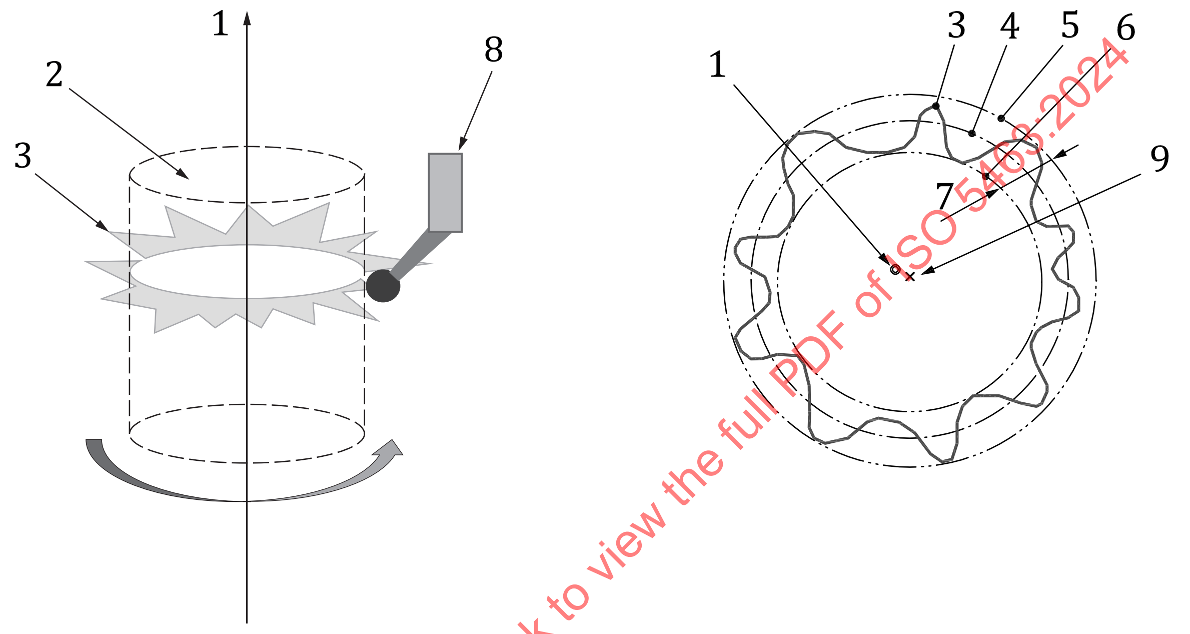
A.2.2.3 Measurement standard and testing procedure

The radial error shall be tested with a suitable measurement standard with an appropriate uncertainty. Typical measurement standards are shown in Annex B. When testing conformity to specifications, sufficient testing shall be used to establish confidence in the results.

The reference fit for calculating the radial error shall be the least-squares reference circle (LSCI) (see ISO 12181-1).

This error is calculated as the RONt of the measured roundness profile of the roundness standard (artefact) after error separation of artefact form if required (see Figure A.3). Unless otherwise specified, the default filter condition is 1-50 UPR, Gaussian. The number of sample points and the ratio between the diameter, d, of the reference circle and the radius, r, of the stylus tip shall be chosen to avoid the distortion of the roundness profile from the influence of the stylus tip.

The test measurement shall be repeated three times without changing measurement set-up (e.g. realignment, removing reference standard) and none of the three results of the measurement shall exceed the maximum permissible radial error.



a) Evaluation method **b) Radial error on polar chart**

Key

1 axis of rotation
2 roundness standard
3 roundness profile as it has been modified by a filter
4 least-squares reference circle
5 circumscribed circle with the reference centre
6 inscribed circle with the reference centre
7 RONt with the reference circle centre
8 probe
9 associated derived centre (see ISO 12181-1:2011)

Figure A.3 — Evaluation analysis method of radial error on polar chart

A.2.2.4 MPE functions

Maximum permissible radial error may be indicated in one of two different forms as follows (see ISO 14978):

a) $E_{R,MPE} = a + H \times b$

b) $E_{R,MPE} = c$

where

a, c are positive constant stated by the manufacturer or supplier;

b is a dimensionless positive constant of proportionality for tilt error and is supplied by the manufacturer or supplier, which is stated proportionally based on the characteristics at the test position "H_1" and "H_2";

H is an absolute displacement of the probing point from the reference point in millimetres.

NOTE The performance of the rotational axis can depend on the load of the workpiece. The manufacturer or supplier can specify more than one radial error MPE value for different spindle loading conditions as another rated operating condition (see ISO 14978:2018, 6.1.5.3).

A.2.3 Axial error

A.2.3.1 General

The axial error (E_A) is the axial circular run-out that would be obtained from a longwave-pass filtered profile measured on a perfectly flat measurement standard whose surface is perfectly square to the rotary axis. The axial error shall not exceed the maximum permissible axial error.

NOTE 1 Axial error can consist of "pure axial error", which is typically described as "axial motion error", and a proportionally dependent error, called "tilt error". Tilt error cannot be evaluated separately from axial error.

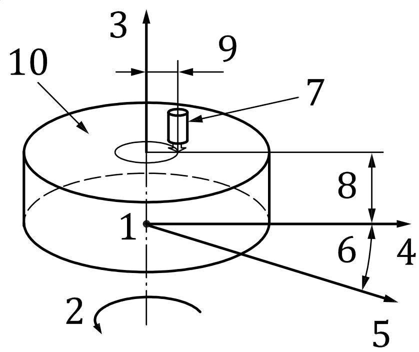
NOTE 2 Axial error can include the effect of "closure error", which is the axial difference between the axial offset at the starting and end points of the flatness profile. "Closure error" is usually caused by instrument drift (see ISO/IEC Guide 99:2007, 4.21).

NOTE 3 Test value of axial error can be influenced by probe error, resolution or digital step, repeatability, measurement noise, flatness of the standard and levelling error.

A.2.3.2 Test method

A.2.3.2.1 General

The axial error shall be tested by measuring axial circular run-out on a flatness standard (see Figure A.4) or a centred spherical standard (see A.2.3.2.3).



Key

1 origin of measuring coordinates
2 angular motion
3 axis line of rotation or longitudinal axis
4 transverse axis or radial direction
5 reference axis on the transverse plane
6 angular distance of transverse axis from reference axis
7 probe
8 height of probing point from transverse plane
9 distance of probing point from rotary axis
10 measurement standard

Figure A.4 — Test method of axial error

A.2.3.2.2 Test points and condition

The verification test for axial error shall be carried out with a measuring process that has a sufficiently small measurement uncertainty.

Probe configuration, orientation, direction, rotation speed and the test set-up conditions of the instrument should be specified by the manufacturer or supplier.

A.2.3.2.3 Test position

The axial error may include tilt error, which is a proportional error. Tilt error also affects the radial error and may be assessed by the evaluation of either radial or axial errors. It is recommended that the tilt error component is assessed as part of the radial error (see A.2.2.2.2). Where tilt error has been assessed as part of the radial error, a single axial run-out measurement is required at R_1 = as close to zero (on rotary axis) as practicable (for “pure axial motion error” evaluation).

For this test, either a centred spherical roundness standard or a levelled flatness standard may be used. Where tilt error is to be assessed by two axial measurements on a levelled flatness standard, the second measurement position should be chosen as R_2:

R_2 = larger or equal to a half of maximum travel in transverse axis direction

Some instruments may have a transverse axis with a very long maximum travel. When maximum travel of transverse axis of the instrument is greater than 100 mm, the set-up of the measurement standard at this position may be unstable. In this case, R_2 is located at 50 mm from R_1 in the transverse direction.

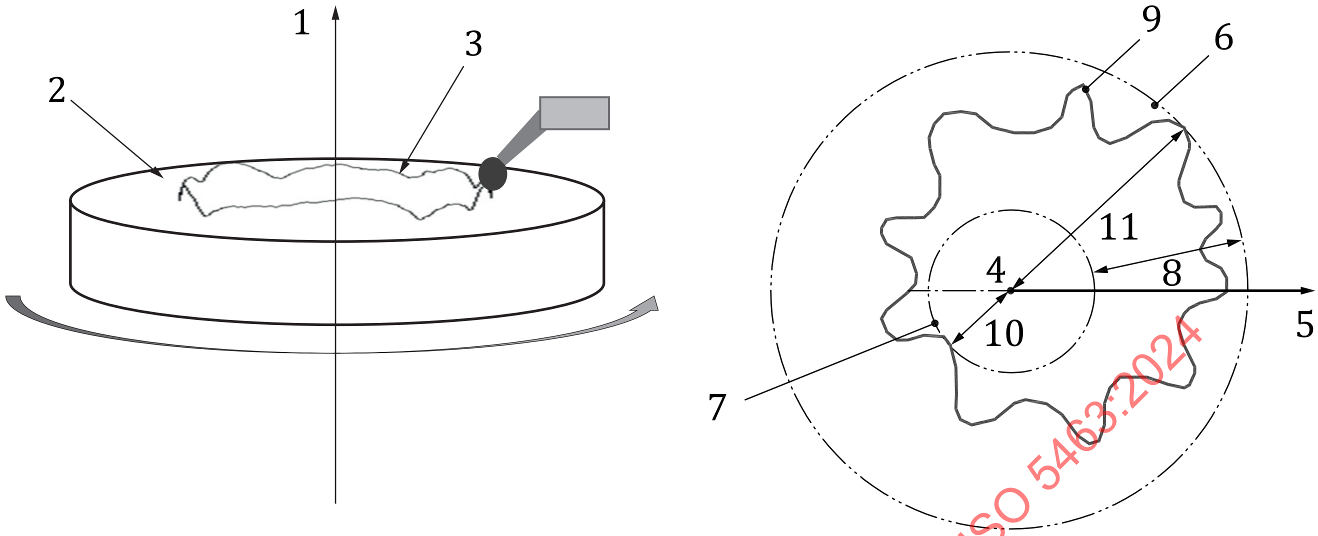
A.2.3.3 Measurement standard and testing procedure

The axial error shall be tested with a suitable measurement standard with an appropriate measurement uncertainty. Typical measurement standards are shown in Annex B. When testing conformity to specifications, sufficient testing shall be used to establish confidence in the results.

When testing at the test position R_1, a centred spherical roundness standard is acceptable to use as measurement standard.

Axial error is calculated as the circular run-out of the measured circular profile of the measurement standard (see Figure A.5). Unless otherwise specified, the default filter condition is the same as the radial error.

The test measurement shall be repeated three times without changing measurement set-up (e.g. realignment, removing reference standard) and none of the three results of the measurement shall exceed the maximum permissible axial error.



a) Evaluation method **b) Axial error polar chart**

Key

1 axis of rotation
2 measurement standard
3 measured profile of axial displacement
4 reference centre on axial displacement equal zero
5 axial displacement
6 circumscribed circle with the reference centre
7 inscribed circle with the reference centre
8 run-out of the polar axial profile on the centre of measurement standard
9 polar profile of axial displacement on the rotary centre of measurement standard
10 minimum value of the axial displacement
11 maximum value of the axial displacement

Figure A.5 — Evaluation analysis method of axial error and polar chart

A.2.3.4 MPE functions

Maximum permissible axial error may be indicated as follows (see ISO 14978):

$$E_{\mathrm{A,MPE}} = a + R \times b$$

where

a is a positive constant stated by the manufacturer or supplier;

b is a dimensionless positive constant of proportionality for tilt error and is supplied by the manufacturer or supplier;

R is the measured positional radius expressed in millimetres.

NOTE The performance of the rotational axis can depend on the load of the workpiece. The manufacturer or supplier can specify more than one axial error MPE value for different spindle loading conditions as another rated operating condition (see ISO 14978:2018, 6.1.5.3).

A.2.4 Longitudinal straightness error

A.2.4.1 General

The longitudinal straightness error (E_{SL}), is the peak-to-valley straightness deviation, STRt (see ISO 12780-1) on a longwave-pass filtered straightness profile in the longitudinal axis of a perfectly straight measuring standard aligned parallel to the rotary axis. This longitudinal straightness error can only be specified if the instrument is equipped with a motorized longitudinal axis.

The longitudinal straightness error shall not exceed the maximum permissible longitudinal straightness error.

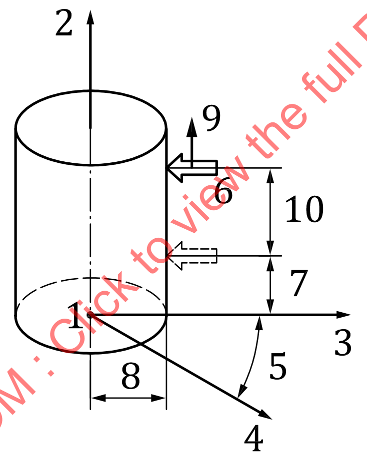
NOTE 1 Longitudinal straightness error can include probe error, resolution or digital step, repeatability, instrumental drift and straightness of straightness standard.

NOTE 2 Longitudinal straightness error is a contributor of measurement error of straightness, cylindricity or parallelism of generatrix observed on a workpiece.

A.2.4.2 Test method

A.2.4.2.1 General

The longitudinal straightness error shall be tested by measuring a straightness profile on a suitable straightness standard (see Figure A.6).



Key

1 origin of measuring coordinates
2 axis line of rotation or longitudinal axis
3 transverse axis or radial direction
4 reference axis on the transverse plane
5 angular distance of transverse axis from reference axis
6 probe
7 lowest height of probing point from the transverse plane
8 minimum radius of probing point from rotary axis
9 traversing direction of longitudinal axis
10 longitudinal traversing length

Figure A.6 — Test method of longitudinal straightness error

A.2.4.2.2 Test points and condition

The verification test of the longitudinal straightness error shall be carried out with a sufficient number of test points and with a measuring process that has a sufficiently small measurement uncertainty.

Probe configuration, orientation, direction, rotation speed and set-up conditions of the instrument should be specified by the manufacturer or supplier.

A.2.4.2.3 Test length and position

The evaluation length *L* of this error shall be stated by the manufacturer or supplier.

Unless otherwise specified, the evaluation length *L* shall be as long as practicable relative to the maximum traverse of length of the longitudinal axis.

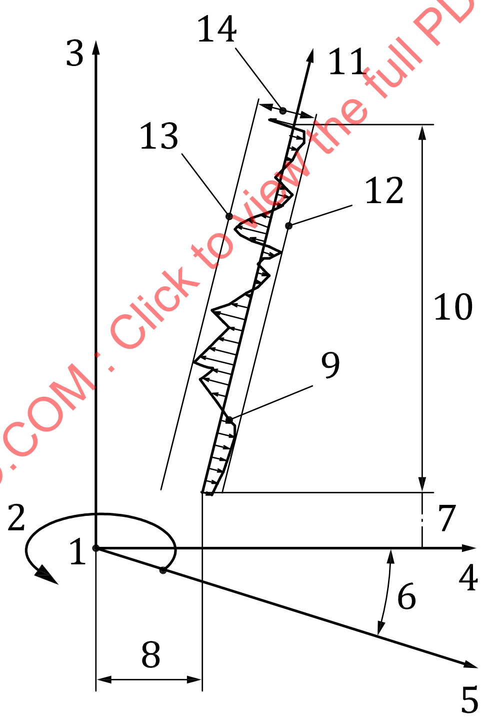
The evaluation length used in testing shall be greater than 90 % of the evaluation length stated by the manufacturer.

The measurement line on the straightness standard should be aligned as close as practical to the rotary axis.

A.2.4.3 Measurement standard and testing procedure

The longitudinal straightness error shall be tested with a suitable measurement standard with an appropriate measurement uncertainty. Typical measurement standards are shown in Annex B. When testing conformity to specifications, sufficient testing shall be used to establish confidence in the results. The measurement standard used shall cover the evaluation length.

This error is calculated as STRT (see ISO 12780-1:2011, 3.5.1) of the measured straightness profile of the straightness standard (see Figure A.7). The reference fit should be least-squares straight line (LSLI) (see ISO 12780-1). Unless otherwise specified, the default filter condition is longwave-pass, L_s = 2,5 mm, Gaussian. ISO 12780-2 gives the maximum sample point spacing that shall be used for the extracted line and the stylus tip radius needed to avoid distortion of the straightness profile from the influence of the stylus tip.



Key

1 origin of measuring coordinates
2 angular motion
3 axis line of rotation
4 transverse axis or radial direction
8 minimum radius of the probing point from rotary axis
9 longitudinal straightness profile
10 evaluation length for longitudinal straightness error
11 direction of longitudinal straightness profile

5	reference axis on the transverse plane	12	maximum minus deviation of longitudinal straightness profile
6	angular distance of transverse axis from reference axis	13	maximum plus deviation of longitudinal straightness profile
7	lowest height of probing point from transverse plane	14	longitudinal straightness error

Figure A.7 — Evaluation analysis method for longitudinal straightness error

A.2.4.4 MPE functions

Maximum permissible straightness error; $E_{SL.MPE}$ may be indicated in the following form.

$$E_{SL,MPE} = a/L$$

where

a are positive constant stated by the manufacturer or supplier;

L is the evaluation length in millimetres stated by the manufacturer or supplier.

A.2.5 Parallelism error

A.2.5.1 General

The parallelism error (E_{PAR}) is the parallelism between the axis of rotation and the associated LSLI of longitudinal axis within the measurement range.

NOTE 1 The measurement of parallelism error includes probe error, instrumental drift and the cylindricity and cylinder taper of the cylindrical standard.

NOTE 2 Parallelism error is an uncertainty contributor to the measurement of cylindricity, cylinder taper or parallelism of the generatrix observed on a workpiece.

The parallelism error should not exceed the MPE with the specified testing condition.

A.2.5.2 Test method

A.2.5.2.1 General

This error shall be tested using one of the following two methods.

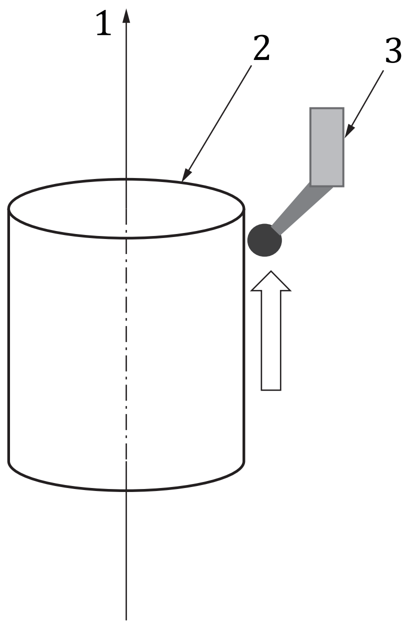
a) Straightness measurement profile: this error is described as the measured travel difference in radial direction on longitudinal straight lines with respect to the axis of rotation. This error can only be specified if the instrument equips motorized longitudinal axis.

b) CYLtt: this error is calculated as the measured cylinder taper, CYLtt, when using the rotary axis form-measuring instrument to measure a perfectly cylindrical standard which is perfectly aligned to the axis of rotation.

A.2.5.2.2 Test of straightness case

A.2.5.2.2.1 General

The parallelism error of this case shall be tested by measuring a straightness profile on a suitable straightness standard that has been accurately centred and levelled to the rotary axis (see Figure A.8).



Key

1 axis of rotation

2 measurement standard

3 probe

Figure A.8 — Test method of parallelism error by straight line

A.2.5.2.2.2 Test points and condition of straight lines

The verification test for parallelism error shall be carried out with a sufficient number of test points on straight line by a straightness standard to evaluate parallelism. The measuring process of this test should have sufficiently small measurement uncertainty.

Probe configuration, orientation, direction, measurement speed and the test set-up conditions of the instrument should be specified by the manufacturer or supplier.

When the longitudinal axis drives to collect measurement data, it shall be motorized.

A.2.5.2.2.3 Test length and position of straight line

The evaluation length L of this error shall be stated by the manufacturer or supplier.

Unless otherwise specified, the evaluation length L of this error shall be larger or equal to half of the maximum traversing length of the longitudinal axis. It might not be practicable to measure the parallelism error over a length greater than 200 mm when the specification of the instrument is greater than 400 mm. In such cases, L is acceptable to be 200 mm anywhere within the longitudinal axis as selected by the user.

The evaluation length used in testing shall be within 90 % to 110 % of the evaluation length stated by the manufacturer.

A.2.5.2.2.4 Measurement standard and testing procedure of straight line

The parallelism error shall be tested with a suitable measurement standard with an appropriate measurement uncertainty. Typical measurement standards are shown in Annex B. When testing conformity to specifications, sufficient testing shall be used to establish confidence in the results. The measurement standard used shall cover the evaluation length.

This error is calculated using reference lines fitted to measured straightness profile of the straightness standard. The reference fit should be LSLI (see ISO 12780-1). Unless otherwise specified in case of selecting two straight lines, the default filter condition is longwave-pass, L_S = 2,5 mm, Gaussian. ISO 12780-2 gives the maximum sample point spacing that shall be used for the extracted line and the stylus tip radius needed to avoid distortion of the straightness profile from the influence of the stylus tip (see Figure A.9).

Key

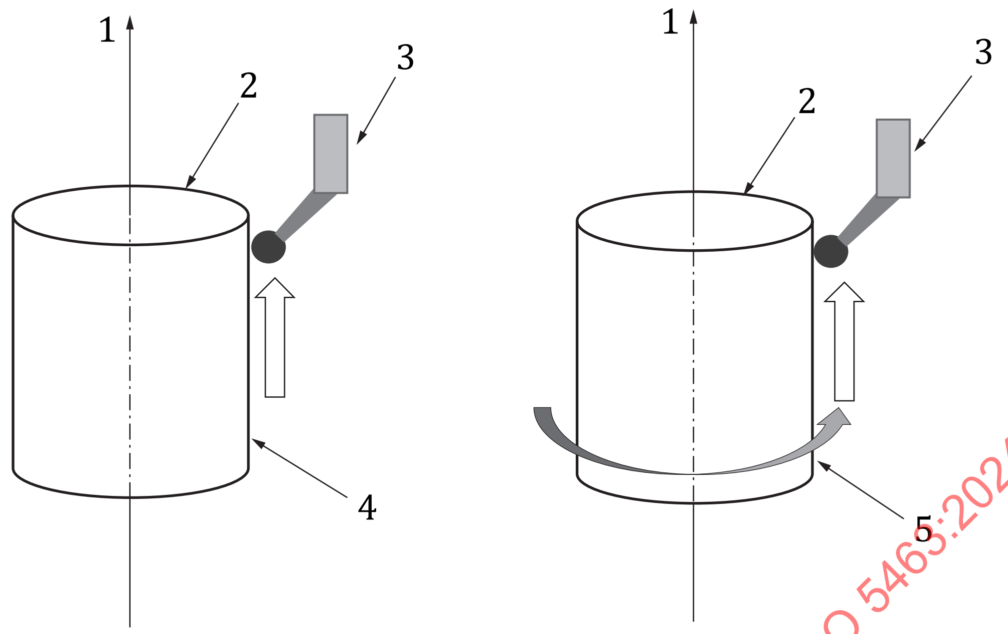
1 axis of rotation
2 measured displacement
3 evaluation length
4 measurement line located on 0 degree
5 least squares straight line
6 measured travel difference in radial direction

Figure A.9 — Evaluation method of parallelism error by straight line

A.2.5.2.2.5 Correction of alignment error of material measure of straight line

The material measure of straight line needs to be aligned with the axis of rotation for this test in order to minimize test uncertainty. However, this perfect alignment is typically not so easy. The manufacturer and/or user can take the correction of this alignment error using correction method. For example, two straight line test is recommended.

This parallelism error is described as half the sum of measured travel difference in radial direction on two longitudinal straight lines, one is on zero degree rotary position, and the other is on 180° rotary position, when measuring longitudinal straightness profiles without levelling each of the lines (see Figure A.10).



Key

1 axis of rotation

2 measurement standard

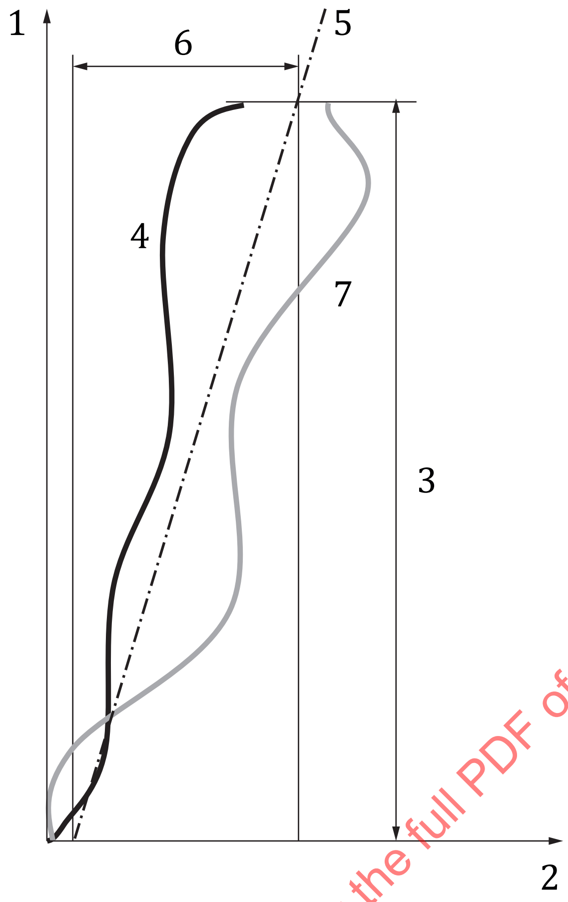
3 probe

4 measurement line located on 0 degree

5 measurement line located on 180 degree

Figure A.10 — Test method of parallelism error by two straight lines

This error is calculated using averaged reference lines fitted to two measured straightness profiles of the straightness standard (see Figure A.11).



Key

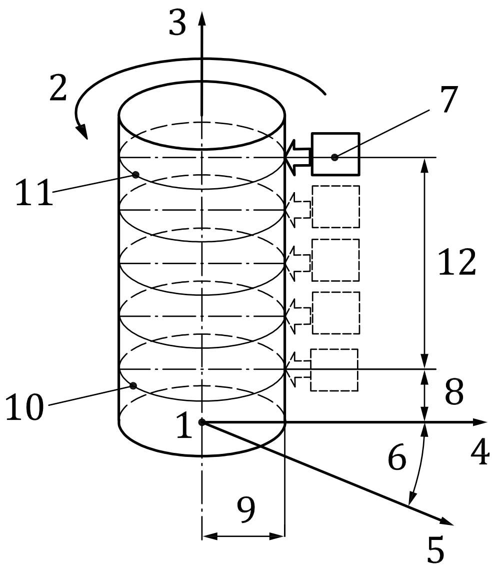
1 axis of rotation
2 measured displacement
3 test length
4 measured profile at 0 degree
5 averaged least-squares straight line
6 measured travel difference in radial direction
7 measured profile at 180 degree

Figure A.11 — Evaluation method for analysing parallelism error by two straight lines

A.2.5.2.3 Test of CYLtt case

A.2.5.2.3.1 General

The parallelism error shall be tested by measuring roundness profiles on a cylindrical standard that has been accurately centred and levelled to the rotary axis (see Figure A.12).



Key

1 origin of measuring coordinate
2 angular motion
3 axis line of rotation or longitudinal axis
4 transverse axis or radial direction
5 reference axis on the transverse plane
6 angular distance of transverse axis from reference axis
7 probe
8 height of the lowest traced roundness profile
9 distance of the probing point from rotary axis
10 roundness profile without radius correction on the lowest height
11 roundness profile without radius correction on the highest height
12 evaluation length on the cylinder

Figure A.12 — Test method of parallelism error by CYLtt

A.2.5.2.3.2 Test points and condition of CYLtt

The verification test for parallelism error shall be carried out with a sufficient number of test points with measuring three or more cross-sections on a cylindrical standard to evaluate taper. The measuring process of this test should have sufficiently small measurement uncertainty.

Probe configuration, orientation, direction, rotation speed and the test set-up conditions of the instrument should be specified by the manufacturer or supplier.

A.2.5.2.3.3 Test length and section of CYLtt

The test sections should be evenly distributed, as far as is practicable, over the evaluation length L.

The evaluation length L of this error shall be stated by the manufacturer or supplier.

Unless otherwise specified, the evaluation length L of this error shall be larger or equal to half of the maximum traversing length of the longitudinal axis. It might not be practicable to measure the parallelism error over a length greater than 200 mm when the specification of the instrument is greater than 400 mm. In such cases, L is acceptable to be 200 mm anywhere within the longitudinal axis as selected by the user.

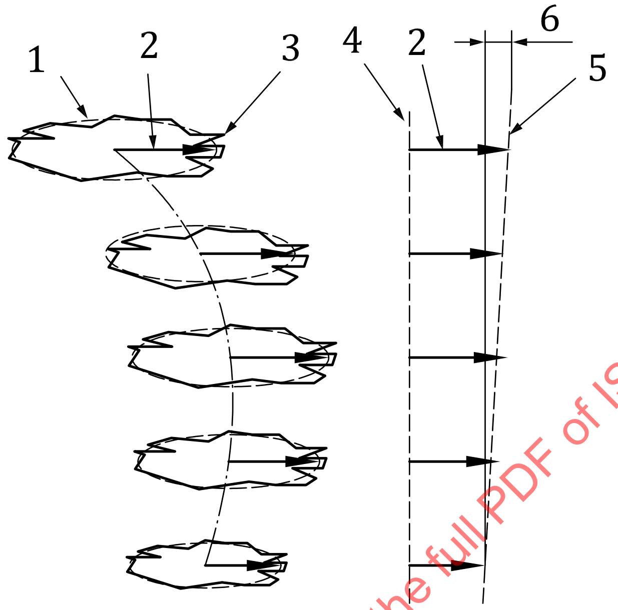
The evaluation length used in testing shall be within 90 % to 110 % of the evaluation length stated by the manufacturer.

A.2.5.2.3.4 Measurement standard and testing procedure of CYLtt

The parallelism error shall be tested with a suitable measurement standard with a measurement uncertainty appropriate for the specification of the instrument. Typical measurement standards are shown in Annex B.

When testing conformity to specifications, sufficient testing shall be used to establish confidence in the results. The measurement standard used shall cover the evaluation length.

This parallelism error is calculated as the largest local cylinder taper, CYLtt (see ISO 12180-1:2011, 3.5.2.5 and Figure A.13). The reference fit shall be the least-squares reference cylinder (LSCY). Unless otherwise specified, the default filter condition is 1-50 UPR, Gaussian. The number of the sample points and the ratio between the diameter, *d*, of the reference circle and the radius, r, of the stylus tip shall be chosen to avoid the distortion of the roundness profile from the influence of the stylus tip.



Key

1 least-squares reference circle on the local cross-section

2 radius of the least-squares reference circle on the local cross-section

3 measured profile on the local cross-section

4 reference axis of least-squares reference cylinder on the cylindrical measurement standard

5 associated straight line through the local radii

6 largest local cylinder taper

Figure A.13 — Evaluation method for analysing parallelism error by CYLtt

A.2.5.3 MPE function

Maximum permissible parallelism error, $E_{PAR,MPE}$, may be indicated in the following form.

$$E_{PAR,MPE} = a/L$$

where

a are positive constants, stated by the manufacturer or supplier;

L is the evaluation length in millimetres, stated by the manufacturer or supplier;

NOTE The performance of the rotational axis can depend on the load of the workpiece. The manufacturer or supplier can specify more than one parallelism error MPE value for different spindle loading conditions as another rated operating condition (see ISO 14978:2018, 6.1.5.3).

A.2.6 Transverse straightness error

A.2.6.1 General

The transverse straightness error (E_{SR}) is the peak-to-valley straightness deviation, STRt, (see ISO 12780-1) of a longwave-pass filtered straightness profile of a nominally perfectly flat measurement standard aligned perfectly perpendicular to the rotary axis when measured in the transverse axis. The transverse straightness error shall not exceed the MPE with the specified testing measuring condition. This transverse straightness error is only specified if the instrument is equipped with a motorized transverse axis.

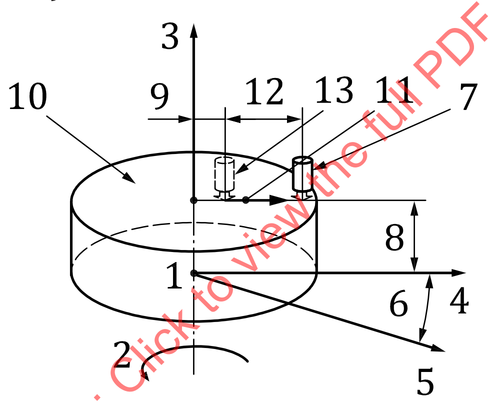
NOTE 1 Transverse straightness error includes probe error, resolution or digital step, hysteresis error, repeatability and instrumental drift.

NOTE 2 Transverse straightness error is an uncertainty contributor to the measurement of straightness, flatness or perpendicularity to the centre axis observed on a workpiece.

A.2.6.2 Test method

A.2.6.2.1 General

The transverse straightness error shall be tested by measuring a straightness profile on a suitable straightness standard (see Figure A.14).



Key

1 original point of measurement coordinates
2 angular motion
3 axis line of rotation or longitudinal axis
4 transverse axis or radial direction
5 reference axis on the transverse plane
6 angular distance of transverse axis from reference axis
7 probe at ending position of traverse
8 height of probing point from transverse plane
9 radius of starting position from rotary axis
10 traversing direction of longitudinal axis
11 probe at starting position of traverse
12 traversing length on flat end of cylinder
13 probe at first position of traverse

Figure A.14 — Test method for transverse straightness error

A.2.6.2.2 Test points and condition

The verification test of the transverse straightness error shall be carried out with a sufficient number of test points and with a measuring process that has a sufficiently small measurement uncertainty.

Probe configuration, orientation, direction and set-up conditions of the instrument should be specified by the manufacturer or supplier.

A.2.6.2.3 Test length and position

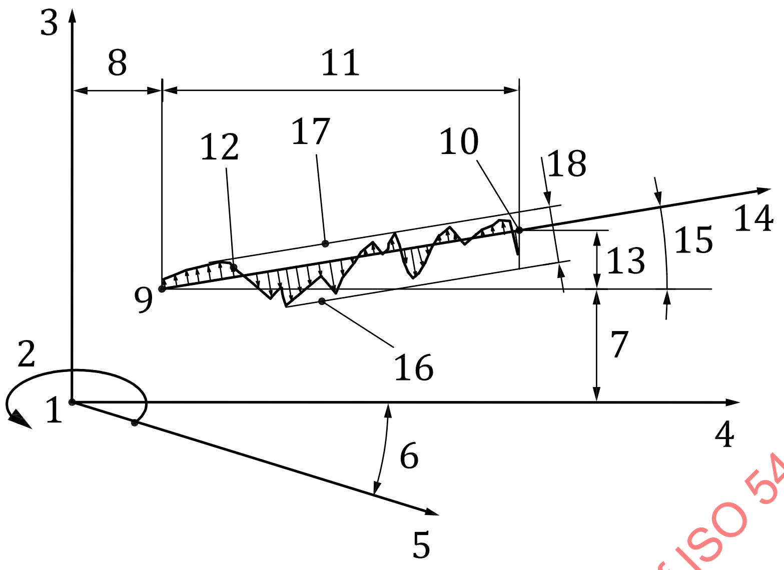
The evaluation length *L* of this error should be stated by the manufacturer or supplier. Unless otherwise specified, the length should be as close as practicable to the maximum travel of the transverse axis.

A.2.6.3 Measurement standard and test procedure

The transverse straightness error shall be tested with a suitable measurement standard having an appropriate measurement uncertainty. Typical measurement standards are shown in Annex B. When testing conformity to specifications, sufficient testing shall be used to establish confidence in the results. The measurement standard used shall cover the evaluation length.

The measurement standard should be levelled to be perpendicular to the axis of rotation.

This error is calculated as the STRt (see ISO 12780-1:2011, 3.5.1) of the measured straightness profile of the straightness standard (see Figure A.15). Unless otherwise specified, the default filter condition is longwave-pass, L_s = 2,5 mm, Gaussian. ISO 12780-2 gives the maximum sample point spacing that shall be used for the extracted line and the stylus tip radius needed to avoid distortion of the straightness profile from the influence of the stylus tip.



Key

1 origin
2 angular motion
3 axis line of rotation or longitudinal axis
4 transverse axis or radial direction
5 reference axis on transverse plane
6 angular distance of transverse axis from reference axis
7 lowest height of starting point of mean line of transverse straightness profile without correction of profile direction
8 minimum radius of probing point from rotary axis
9 starting point of mean line of transverse straightness profile without correction of profile direction
10 end point of mean line of transverse straightness profile without correction of profile direction
11 evaluation length for straightness
12 transverse straightness profile without correction of profile direction
13 height difference between starting point and end point of mean line of transverse straightness profile without correction of profile direction
14 direction of transverse straightness profile
15 inclination angle squareness error φ between mean line of transverse straightness profile and rotary axis
16 the maximum minus deviation of longitudinal straightness profile
17 the maximum plus deviation of longitudinal straightness profile
18 transverse straightness error

Figure A.15 — Evaluation analysis method of transverse straightness error

A.2.6.4 MPE function

The maximum permissible straightness error, $E_{SR,MPE}$, may be indicated in the following form.

$$E_{SR,MPE} = a/L$$

where

a is a positive constant stated by the manufacturer or supplier;

L is the evaluation length in millimetres.

If the MPE functions are specified at one or more fixed evaluation lengths that are much shorter than the total traversing length, then the straightness error shall be evaluated in three positions: one shorter zone, one middle zone and one longer zone in the total traversing length.

A.2.7 Squareness error

A.2.7.1 General

The squareness error (E_{SQ}) that is calculated between the reference line (a radial line formed by the intersection of the traversing plane of the probe tip and the transverse plane) and the least-squares line of a measured, longwave-pass filtered straightness profile of a measuring standard in the transverse axis.

NOTE 1 The squareness error includes probe error and instrumental drift.

NOTE 2 Squareness error is a contributor of measurement of flatness or perpendicularity to the centre axis observed on a cylinder type workpiece.

A.2.7.2 Test method

A.2.7.2.1 General

The squareness error shall be tested by measuring on a suitable straightness standard, which should be adjusted to be perpendicular to the rotary axis (see Figure A.14).

A common method of assessing this error uses a straightness measurement. While not precluding the use of other methods, this document describes the straightness measurement method.

A.2.7.2.2 Test points and condition

The verification test of the squareness error shall be carried out with a sufficient number of test points and with a measuring process that has a sufficiently small measurement uncertainty.

Probe configuration, orientation, direction and instrument set-up conditions should be specified by the manufacturer or supplier.

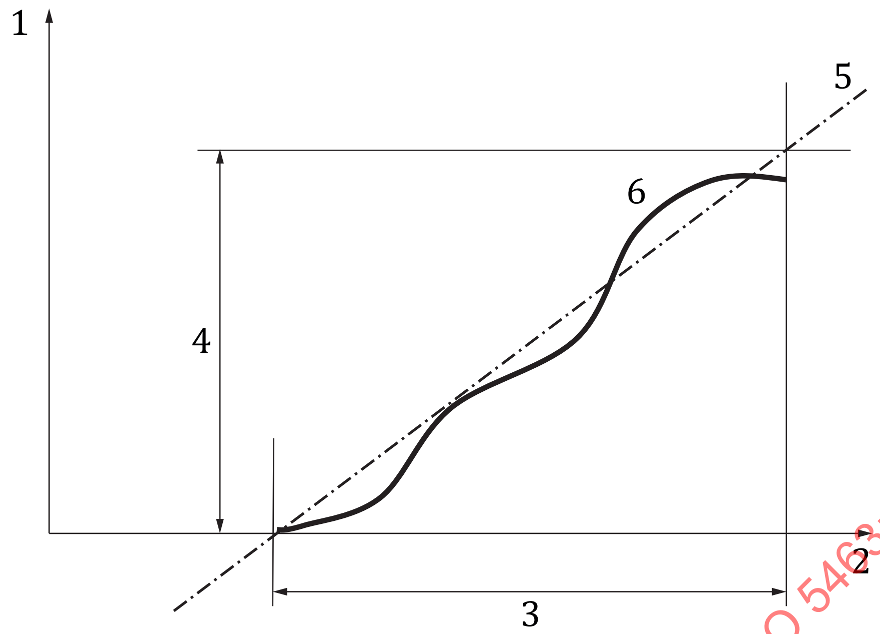
A.2.7.2.3 Test length and location

The evaluation length L of this error should be stated by the manufacturer or supplier. Unless otherwise specified, the length should be as close as practicable to the maximum traverse length of the transverse axis.

A.2.7.3 Measurement standard and testing procedure

The squareness error shall be tested with a suitable measurement standard with an appropriate uncertainty. Typical measurement standards are shown in Annex B. When testing conformity to specifications, sufficient testing shall be used to establish confidence in the results. The measurement standard used shall cover the evaluation length.

The squareness error is calculated as the height difference between the starting position and the end position of the least-squares mean line of the vertical deviation measured on the level-adjusted straightness standard (see Figure A.16).



Key

1 axis of rotation of longitudinal axis
2 reference axis on transverse plane
3 evaluation length
4 squareness error
5 least-squares mean line of the straightness profile
6 measured profile

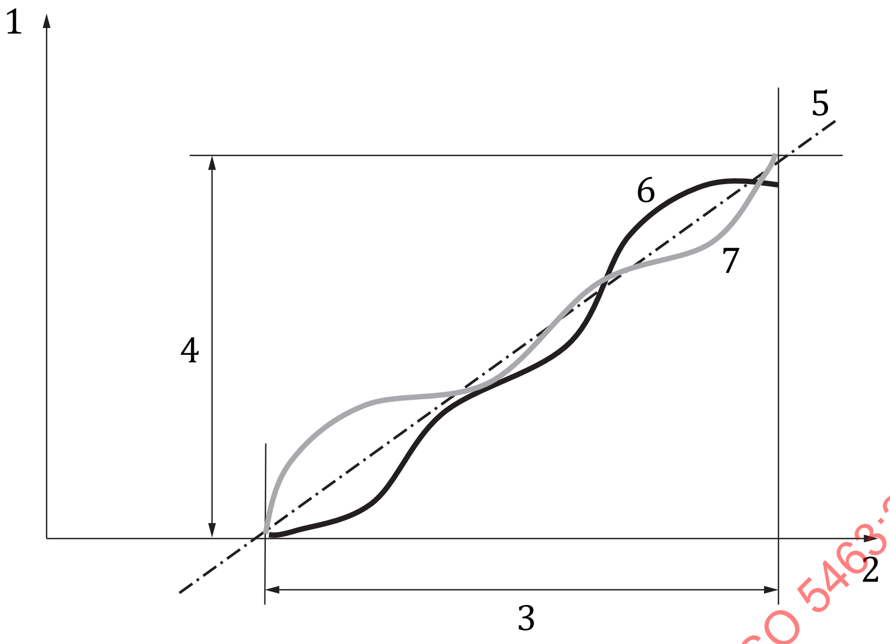
Figure A.16 — analysis of squareness error

A.2.7.3.1 Correction of alignment error of material measure of straight line

The material measure of straight line needs to be aligned with the axis of rotation for this test in order to minimize test uncertainty. However, this perfect alignment is typically not so easy. The manufacturer and/or user can take the correction of this alignment error using a correction method. For example, two straight line test is recommended.

This squareness error is described as half of the sum of the difference in height between the starting position and the end position of the two least-squares mean lines of the vertical deviation measured on the straightness standard, one is on zero degree rotary position, and the other is on 180° rotary position, when measuring longitudinal straightness profiles without levelling each of the lines.

This error is calculated using averaged reference lines fitted to two measured straightness profiles of the straightness standard (see Figure A.17).



Key

1 axis of rotation of longitudinal axis
2 reference axis on transverse plane
3 evaluation length
4 squareness error
5 least-squares mean line of the straightness profile
6 measured profile at 0 degree
7 measured profile at 180 degree

Figure A.17 — analysis of squareness error

A.2.7.4 MPE functions

Maximum permissible squareness error, $E_{SQ,MPE}$, may be indicated in the following form.

$$E_{SQ,MPE} = a/L$$

where

a is a positive constant, stated by the manufacturer or supplier;

L is the evaluation length in millimetres.

A.2.8 Metrological characteristics (supplier's specification)

Table A.2 gives the list of metrological characteristics for a rotary axis form-measuring instrument.

NOTE Depending on instrument configuration, some elements of Table A.2 will possibly not apply or additional metrological characteristics can be specified.

Table A.2 — Metrological characteristics

Characteristics			MPE	Default unit
Probe	Probe error	E_{P}	$E_{P,MPE}$	µm
Rotary axis	Radial error	E_{R}	$E_{R,MPE}$	µm
	Axial error	E_{A}	$E_{A,MPE}$	µm
Longitudinal axis	Longitudinal straightness error	E_{SL}	$E_{SL,MPE}$	µm
	Parallelism error	E_{PAR}	$E_{PAR,MPE}$	µm
Transverse axis	Transverse straightness error	E_{SR}	$E_{SR,MPE}$	µm
	Squareness error	E_{SQ}	$E_{SQ,MPE}$	µm

Annex B
(informative)

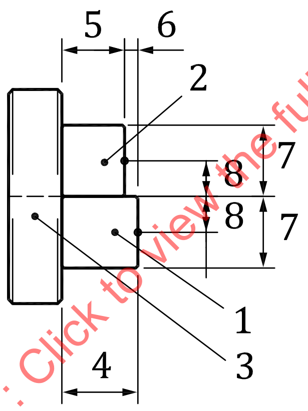
Artefacts for metrological characteristics

B.1 Material measure for gain setting or probe error verification

B.1.1 Gauge blocks (on a reference plane)

A calibrated reference value for magnification setting or this probe error test may be produced using calibrated gauge blocks. See ISO 3650 for the structure, the specification and marking of gauge blocks.

Two or more gauge blocks are wrung onto a flatness standard as shown in Figure B.1. The standard thus created is aligned to one of the principal measurement axes of the instrument. The displacement corresponding to the height difference between a pair of centre positions of the gauge blocks is measured by changing the position of the probe stylus tip with θ-axis, Z-axis or R-axis traverse of the instrument as appropriate.



Key

1 longer gauge block
2 shorter gauge block
3 optical flat or flatness standard
4 longer gauge block length
5 shorter gauge block length
6 step height difference
7 width of gauge blocks
8 probing positions at the centre of width

Figure B.1 — A pair of gauge blocks on a flatness standard

B.1.2 Flick standard (or magnification standard)

A calibrated reference value for magnification setting or probe error test may be produced using a calibrated flick standard (see reference [26] and[29]).

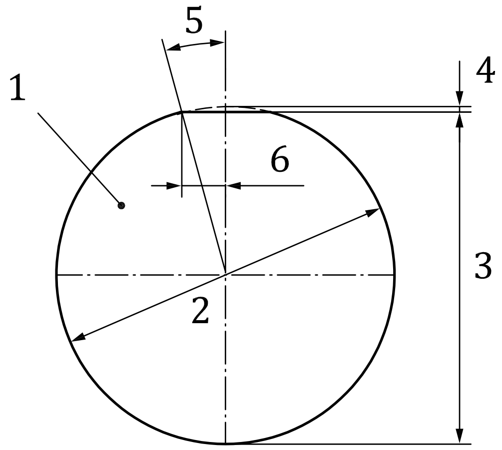
A flick standard comprises a precision cylindrical component with one or more small flats round the periphery (see Figure B.2), the radial depths of which have been calibrated.

The axis of the flick standard is supposed to be accurately aligned to the rotary axis.

In polar coordinates, after removal of the component eccentricity and suppression of the radius, the flat will appear as a parabolic departure as shown in Figure B.3.

From the measurement, the flattened depth is calculated as the radial departure of the valley of a parabola fitted to the data in the flick area from the LSCI fitted to the data excluding the flick area.

Alternatively, the valley which is calculated as RONv on the roundness profile from the minimum circumscribed reference circle MCCI of the calibrated flick standard may be used as a simplified operator. Note that results from this method may show greater variability depending on the number of data points within the profile.



Key

1 magnification standard or flick standard

2 diameter of reference cylinder

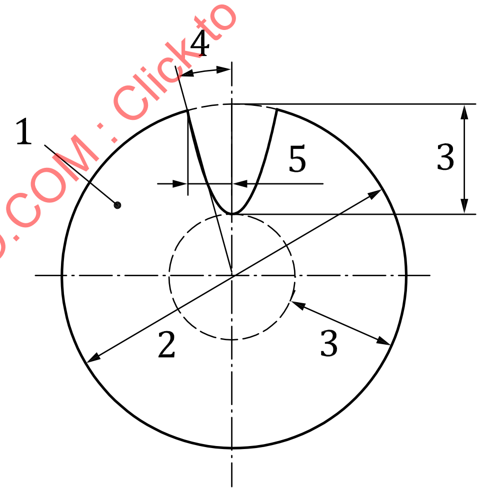
3 length between the centre position of flattened area and the opposite cylinder surface

4 flattened depth

5 half angle of flattened area on the polar chart

6 flattened half width

Figure B.2 — Flick standard



Key

1 magnification standard or flick standard

2 diameter of reference circle on the chart

3 flattened depth on the polar chart

4 half angle of concave area on the polar chart

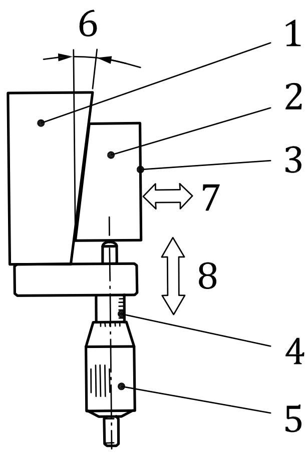
5 distance of concave area on the polar chart

Figure B.3 — A flick standard with residual eccentricity removed and suppression of the radius

B.1.3 Magnification calibrator (screw-driven reducing lever or dial gauge calibrator)

A calibrated reference value for magnification setting or probe error test may be produced using a calibrated magnification calibrator (see Figure B.4). This measurement standard produces an adjustable size using a screw, a lever and/or a pair of wedges with a calibrated scale.

Any size within the range of the calibrated scale can be realized statically with only one measurement standard.



Key

1 base with certain angle inclination
2 slider with the same inclination as the base
3 top surface with compressed height displacement
4 scale of adjuster displacement
5 manual adjusting wheel
6 the slope angle
7 direction of height adjustment
8 direction of slider movement

Figure B.4 — Magnification calibrator

B.1.4 Combination of displacement actuator and length calibration equipment

A calibrated reference value for magnification setting or probe error test may be produced using a combination of a calibrated actuator that gives changeable size (e.g. a piezo-electric actuator) and equipment that measures length precisely (e.g. a laser interferometer).

Any size within the range of the calibrated scale can be realized statically with only one measurement standard.

B.1.5 Depth measurement standard

A calibrated reference value for magnification setting or probe error test may be produced using a calibrated depth measurement standard. See ISO 5436-1:2000, 5.2 and 5.2.1.

The form of the standard and the testing procedure are essentially the same as B.1.1.

B.2 Material measure used for testing metrological characteristics by rotary motion

A spherical or hemispherical material measure can be used for testing metrological characteristics by rotary motion, which has circumference lines with very small form deviation.

The polar deviation of the radial error motion of the instrument is measured by executing a roundness measurement on this material measure which is set up just on the axis average line on the worktable of the instrument.