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ISO 13041-3

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Test conditions for numerically controlled turning machines and turning centres —

Part 3:
Geometric tests for machines with inverted vertical workholding spindles

Conditions d'essai des tours à commande numérique et des centres de tournage —

Partie 3: Essais géométriques pour les machines à broches verticales inversées

Reference number
ISO 13041-3:2009(E)

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 13041-3 was prepared by Technical Committee ISO/TC 39, *Machine tools*, Subcommittee SC 2, *Test conditions for metal cutting machine tools.*

ISO 13041 consists of the following parts, under the general title *Test conditions for numerically controlled turning machines and turning centres*:

Part 1: Geometric tests for machines with a horizontal workholding spindle

— *Part 2: Geometric tests for machines with a vertical workholding spindle*

Part 3: Geometric tests for machines with inverted vertical workholding spindles

— *Part 4: Accuracy and repeatability of positioning of linear and rotary axes*

Part 5: Accuracy of feeds, speeds and interpolations

— *Part 6: Accuracy of a finished test piece*

— *Part 7: Evaluation of contouring performance in the coordinate planes*

— *Part 8: Evaluation of thermal distortions*

Test conditions for numerically controlled turning machines and turning centres —

Part 3: Geometric tests for machines with inverted vertical workholding spindles

1 Scope

ISO 13041-3:2008 specifies, with reference to ISO 230-1 and ISO 230-7, the geometric tests on general-purpose, numerically controlled (NC) turning machines and turning centres with inverted vertical workholding spindles, as well as the corresponding applicable tolerances.

This part of ISO 13041 presents the different concepts or configurations and common features of NC turning machines and turning centres with inverted vertical spindles. It also provides a terminology and designation of controlled axes. (See Figures 1, 2, 3 and 4.)

This part of ISO 13041 deals only with the verification of the accuracy of the machine. It does not apply to the operational testing of the machine (e.g. vibration, abnormal noise, stick-slip motion of components), nor to machine characteristics (e.g. speeds, feeds), as such checks are generally carried out before testing accuracy.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 230-1:1996, *Test code for machine tools — Part 1: Geometric accuracy of machines operating under no-load or finishing conditions*

ISO 230-7:2006, *Test code for machine tools — Part 7: Geometric accuracy of axes of rotation*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
turning machine
machine tool in which the principle movement is on the rotation of the workpiece against the stationary cutting tool(s)

3.2
manual control
mode of operation where each movement of the machine is individually initiated and controlled by the operator

3.3
numerical control
NC
computerized numerical control
CNC
automatic control of a process performed by a device that makes use of numerical data introduced while the operation is in progress

[ISO 2806:1994]

3.4
manually controlled turning machine
turning machine whose process steps for the machining are controlled or started by an operator without support by an NC-machining program

3.5
numerically controlled turning machine
NC turning machine
turning machine that operates under numerical control (NC) or computerized numerical control (CNC)

3.6
turning centre
NC turning machine equipped with power-driven tool(s) and the capacity to orientate the work-holding spindle around its axis.

NOTE It can include additional features such as automatic tool changing from a turret and/or magazine.

3.7
numerically controlled turning machine with inverted vertical workholding spindle
NC turning machine with inverted vertical workholding spindle
NC turning machine where the workpiece is mounted on an inverted vertical workholding spindle equipped with a workholding device at the lower end of the workholding spindle.

NOTE For other types of vertical workholding spindle machine, see ISO 13041-2.

3.8
turning centre with inverted vertical workholding spindle
turning centre having an inverted vertical workholding spindle equipped with a workholding device at the lower end of the vertical workholding spindle.

NOTE 1 It can include additional features such as automatic tool changing from a magazine or Y-axis motion.

NOTE 2 For other types of vertical workholding spindle turning centre, see ISO 13041-2.

4 Preliminary remarks

4.1 Measuring units

In this part of ISO 13041, all linear dimensions, deviations and corresponding tolerances are expressed in millimetres, angular dimensions are expressed in degrees, and angular deviations and the corresponding tolerances are expressed in ratios, but in some cases microradians or arcseconds may be used for clarification purposes. The equivalence of the following expressions should always be kept in mind:

$$0{,}010/1\,000 = 10 \times 10^{-6} = 10\ \mu\text{rad} \approx 2\ \text{arcsec}$$

4.2 Reference to ISO 230-1 and ISO 230-7

For application of this part of ISO 13041, reference shall be made to ISO 230-1 or ISO 230-7, especially for the installation of the machine before testing, warming-up of spindles and other moving parts, the description of measuring methods, and recommended accuracy of testing equipment.

In the “Observations” block of tests described in Clauses 5 and 6, the instructions are preceded by a reference to the corresponding clause/subclause in ISO 230-1 and/or ISO 230-7 in cases where the test concerned is in compliance with their specifications. Tolerances are given for each geometric test (see G1 to G20).

4.3 Machine levelling

Prior to conducting tests on a machine, the machine should be levelled according to the recommendations of the supplier/manufacturer (see ISO 230-1:1996, 3.11).

4.4 Testing sequence

The sequence in which the geometric tests are given in no way defines the practical order of testing. In order to make the mounting of instruments or gauging easier, tests may be performed in any order.

4.5 Tests to be performed

When testing a machine, it is not always necessary or possible to carry out all the tests given in this part of ISO 13041. When the tests are required for acceptance purposes, the choice of tests relating to the components and/or the properties of the machine of interest is at the discretion of the user, in agreement with the supplier/manufacturer. The tests to be used are to be clearly stated when ordering a machine. A mere reference to this part of ISO 13041 for the acceptance tests, without specifying the tests to be carried out, and without agreement on the relevant expenses, cannot be considered as binding for any contracting party.

4.6 Measuring instruments

The measuring instruments indicated in relation to the tests given in Clauses 5 and 6 are examples only. Other instruments measuring the same quantities and having at least the same measurement uncertainty and the same resolution may be used. Linear displacement sensors shall have a resolution of 0,001 mm or better.

4.7 Diagrams

For reasons of simplification, the figures in Clauses 5 and 6 of this part of ISO 13041 illustrate only one type of machine.

4.8 Software compensation

When built-in software facilities are available for compensating geometric, positioning, contouring and thermal deviations, their use during these tests should be based on agreement between the user and the supplier/manufacturer. When the software compensation is used, this shall be stated in the test reports.

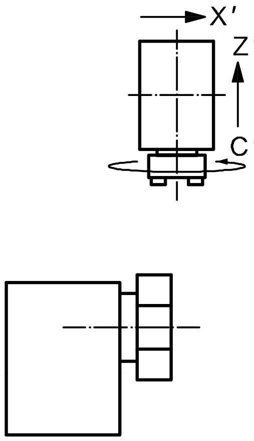
4.9 Minimum tolerance

When the tolerance for a geometric test is established for a measuring length different from that given in this part of ISO 13041 (see ISO 230-1:1996, 2.311), it shall be taken into consideration that the minimum value of tolerance is 0,005 mm.

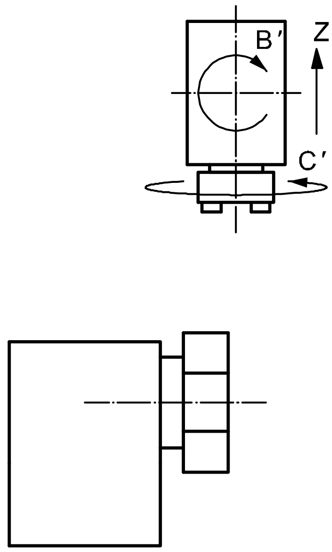
4.10 Machine classifications, descriptions, terminology and designation of axes

The machines considered in this part of ISO 13041 are divided into three basic configurations, as shown in Figure 1.

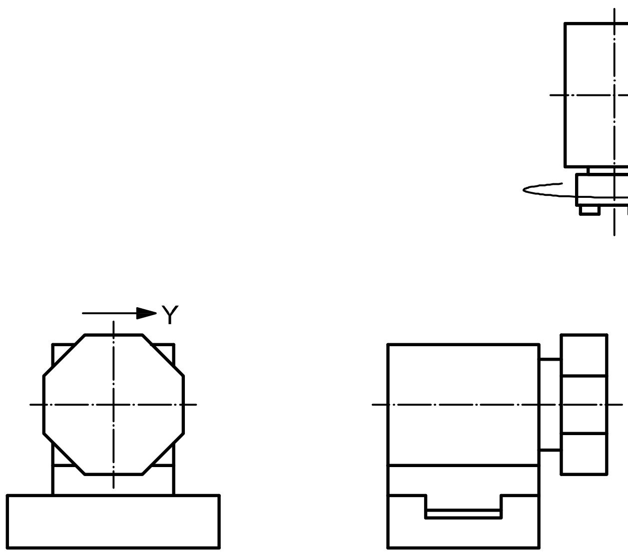
This type of machine tool may also be considered as a machining unit in an FMS (flexible manufacturing system).



a) Basic configuration

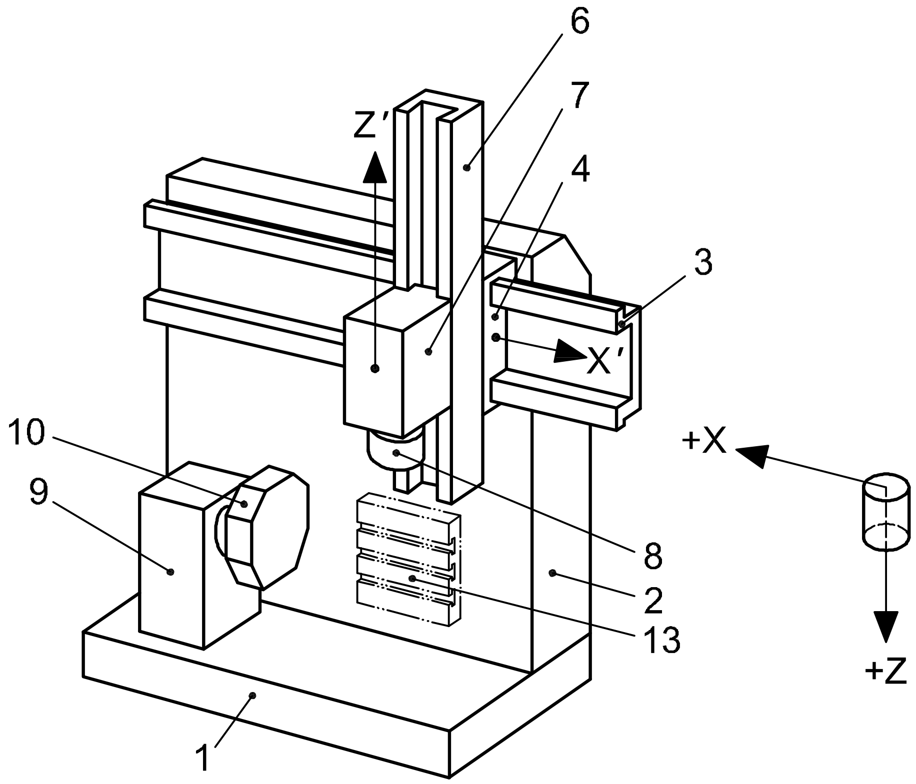


b) Workhead with B axis



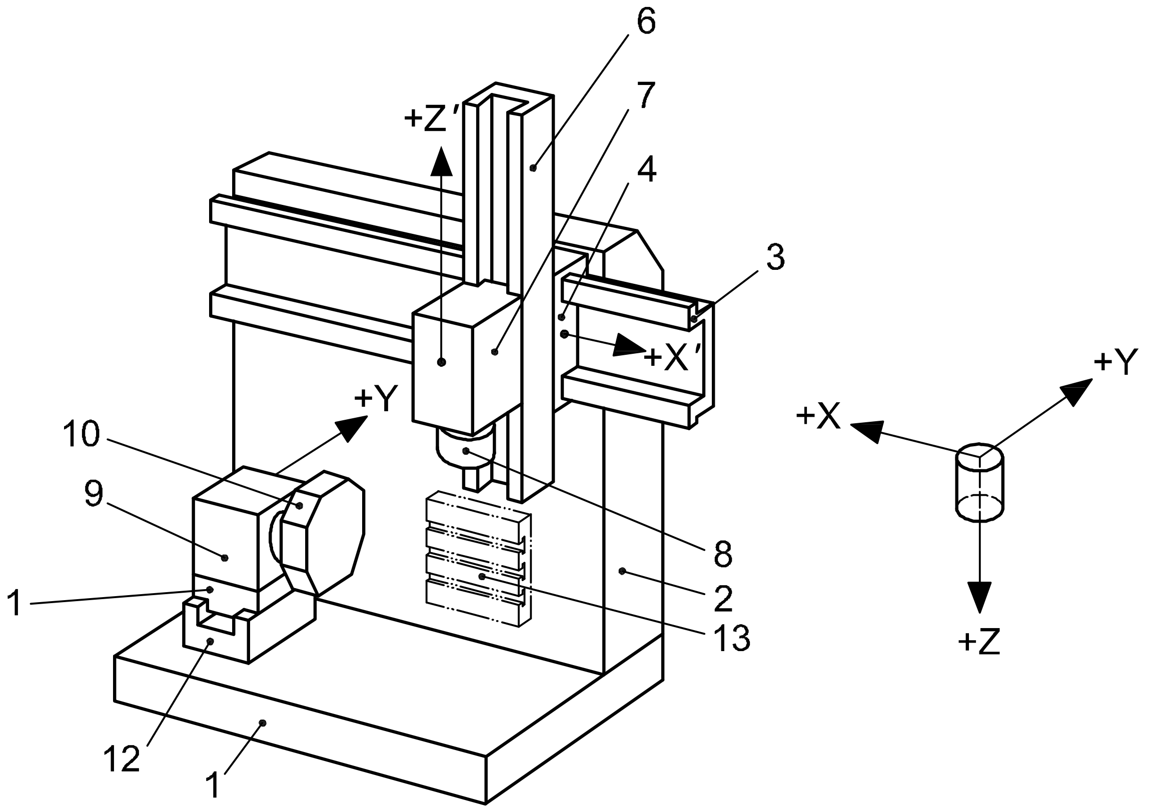
c) Turret with Y axis

Figure 1 — Three machine configurations with one workhead and one turret



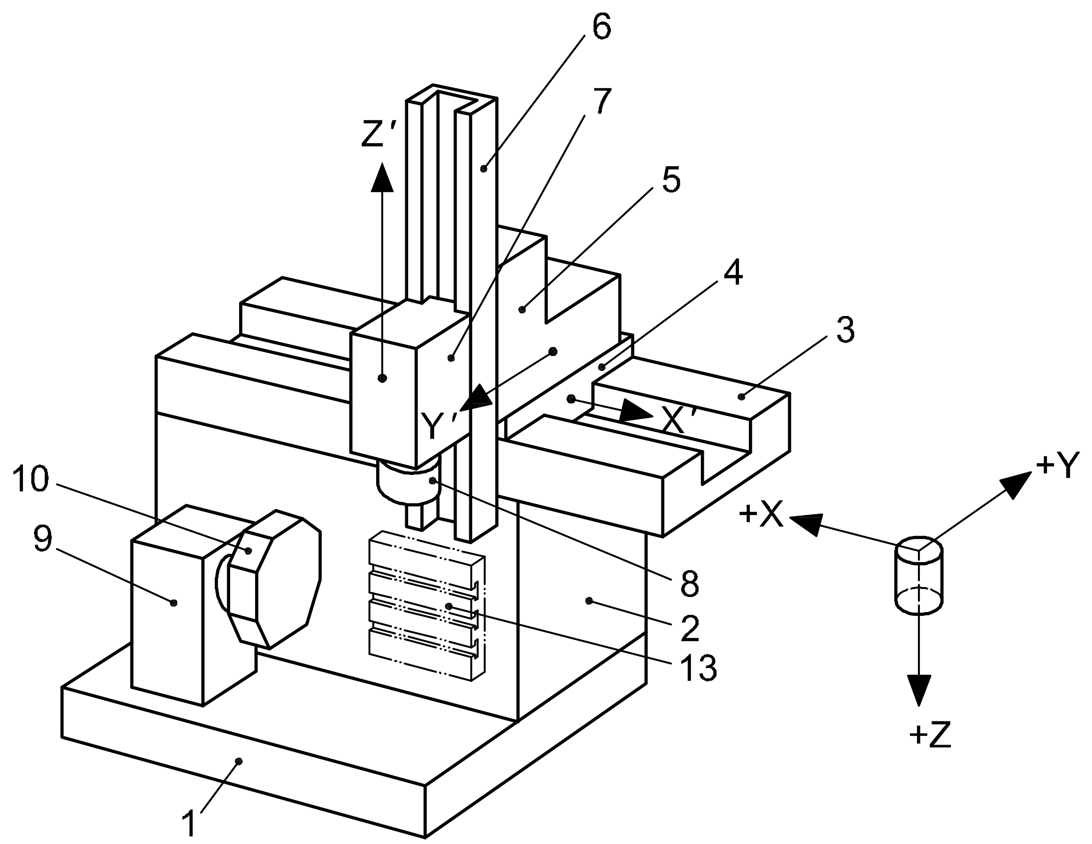
For the component nomenclature, refer to Table 1.

Figure 2 — Example of inverted vertical turning machine



For the component nomenclature, refer to Table 1.

Figure 3 — Example of inverted vertical turning centre (turret head with Y-axis motion)



For the component nomenclature, refer to Table 1.

Figure 4 — Example of inverted vertical turning centre (spindle with Y-axis motion)

Table 1 — Component nomenclature (see Figures 2, 3 and 4)

Item number	Designation		
	English	French	German
1	base	base	Maschinenbett
2	column	montant	Maschninenständer
3	cross rail	traverse porte-chariot	Querführung
4	carriage, X axis	chariot, axe X	Schlitten, X Achse
5	carriage, Y axis	chariot, axe Y	Schlitten, Y Achse
6	workholding spindle head stock slideway	glissière de la poupée fixe de la broche	Werkstückspindelkastenführung
7	workholding spindle head stock, Z axis	poupée fixe de la broche, axe Z	Werkstückspindelkasten, Z Achse
8	workholding spindle	broche porte-pièce	Werkstückspindel
9	turret head	porte-tourelle	Revolverkopf
10	turret	tourelle	Revolver
11	turret head carriage, Y axis	chariot du porte-tourelle, axe Y	Revolverkopfschlitten, Y Achse
12	turret head slideway	coulisseau du porte-tourelle	Revolverkopfführung
13	tool plate	plateau à outils	Werkzeugspannplatte

4.11 Turrets

Vertical turning centres have not only stationary tools but also power-driven rotary tools, which are fitted on the turret or tool plate (item 13 in Figures 2, 3 and 4). When the number of tools expected to be used exceeds the capacity of the turret, an automatic change of tools in the turret, or a change of turret, can be provided. An automatic tool change device can also be required in cases of power-driven spindles in which the tools can be automatically set. However, ISO 13041 does not provide any test methods for automatic tool change operations.

4.12 Machine size categories

Machines are classified into three size categories, on the basis of the criteria specified in Table 2.

Table 2 — Machine size range

Criteria	Category 1	Category 2	Category 3
Nominal chuck diameter, d	$d \leqslant 250$	$250 < d \leqslant 400$	$400 < d$
Maximum turning diameter, D	$D \leqslant 315$	$315 < D \leqslant 500$	$500 < D$
NOTE 1 The choice of criteria is at the manufacturer's discretion. NOTE 2 Nominal chuck diameter is defined in ISO 3442-1 and ISO 3442-2.			

5 Geometric tests

5.1 Workholding spindle(s)

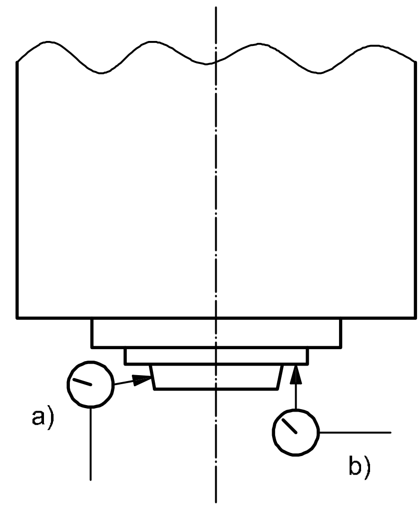
Object — **G1**

Checking of the workholding spindle nose:

a) run-out of centring diameter;

b) face run-out of the spindle face.

Diagram



Tolerance

Category 1	Category 2	Category 3
a) 0,005	0,008	0,012
b) 0,008	0,010	0,015

Measured deviation

Measuring instruments

Linear displacement sensor

Observations and references to ISO 230-1:1996, 5.612.2, 5.632

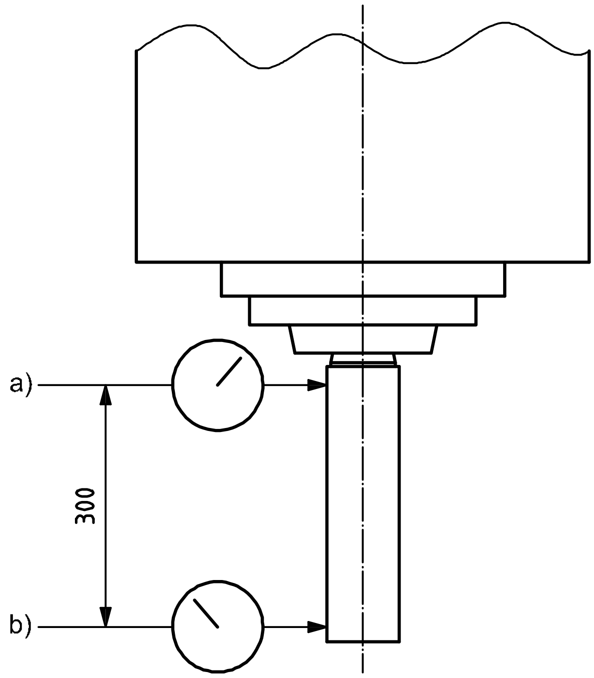
Measurements shall be taken on all workholding spindles.

a) 5.612.2

When the surface is conical, the stylus of the linear displacement sensor shall be normal to the contacting surface.

b) 5.632

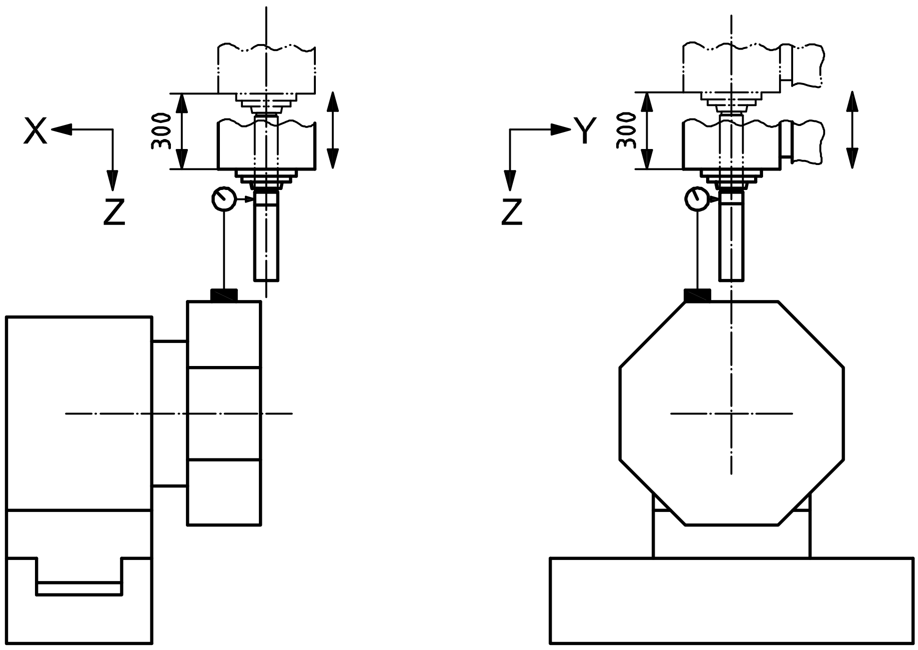
Measurements shall be taken on the maximum diameter.

Object	**G2**
Checking the run-out of the workholding spindle bore a) at the spindle nose, b) at a distance of 300 mm from the spindle nose. See also Test R1.	
Diagram	
	
Tolerance **Category 1** **Category 2** **Category 3** a) 0,010 0,015 0,020 b) 0,015 0,020 0,025	**Measured deviation**
Measuring instruments Linear displacement sensor and special test mandrel	
Observations and references to the ISO 230-1, 5.612.3 Rotate the spindle slowly at least two revolutions at each measuring location when measuring the spindle run-out. The measurements shall be repeated at least four times, the mandrel being rotated through 90° in relation to the spindle. The average of the readings shall be recorded. Steps should be taken to minimize the effects of tangential drag upon the stylus of the measuring instrument. Measurements shall be performed on all workholding spindles.	

5.2 Relation between workholding spindle(s) and linear axes of motion

Object Checking the parallelism between the Z-axis motion and the workholding spindle axis of rotation a) in the ZX plane, b) in the YZ plane.	**G3**

Diagram



a) b)

Tolerance	**Measured deviation**
For a measuring length of 300 or full stroke up to 300	
Category 1 **Category 2** **Category 3**	
a) 0,010 0,015 0,020	
b) 0,015 0,020 0,025	

Measuring instruments

Linear displacement sensor and special test mandrel

Observations and references to ISO 230-1:1996, 5.412.1, 5.422.3

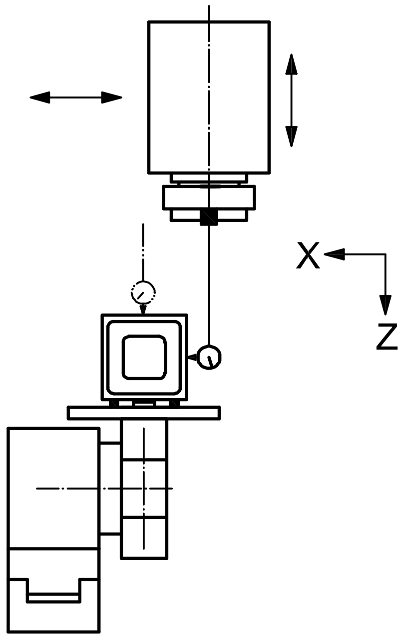
For each plane of measurement, turn the workholding spindle to find the mean position of run-out and then move the spindle head in the Z direction and take the maximum difference of the readings.

Alternatively, take readings along the test mandrel at a rotary position and then rotate the spindle by 180°, taking readings at the initial positions. The maximum difference between the two averaged measurements gives the parallelism deviation.

This test applies to all workholding spindles and Z-axis motions.

Object Checking the squareness between the Z-axis motion and the X-axis motion in the ZX plane.	**G4**

Diagram



Tolerance			**Measured deviation**
For a measuring length of 300 or full stroke up to 300			
Category 1	**Category 2**	**Category 3**	
0,010	0,015	0,020	

Measuring instruments

Linear displacement sensor, square and special plate

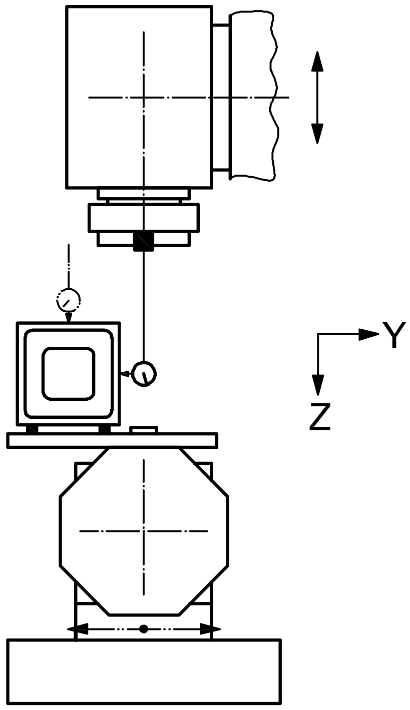
Observations and references to ISO 230-1:1996, 5.522.1, 5.522.4

Set the square on a special plate fixed to the tool plate or turret parallel to the X-axis motion. Mount the linear displacement sensor on the nose of the workholding spindle locked to contact the measuring Z-axis surface of the square, and traverse the workholding spindle head in the Z-axis direction. Preferably, mount the linear displacement sensor on the spindle housing to avoid locking the spindle.

The squareness deviation is the maximum difference of the linear displacement sensor readings.

Object Checking the squareness between the Z-axis motion and the Y-axis motion in the YZ plane.	**G5**

Diagram



Tolerance			**Measured deviation**
For a measuring length of 300 or full stroke up to 300:			
Category 1	**Category 2**	**Category 3**	
0,015	0,020	0,025	

Measuring instruments

Linear displacement sensor, square and special plate

Observations and references to ISO 230-1:1996, 5.522.1, 5.522.4

Set the square on a special plate fixed to the tool plate or turret parallel to the Y-axis motion. Mount the linear displacement sensor on the nose of the workholding spindle locked on and in contact with the measuring Z-axis surface of the square, with the workholding spindle head traversed in the Z-axis direction. Preferably, mount the linear displacement sensor on the spindle housing to avoid locking the spindle.

The squareness deviation is the maximum difference of the linear displacement sensor readings.

5.3 Angular deviations of linear axis motion

G6

Object

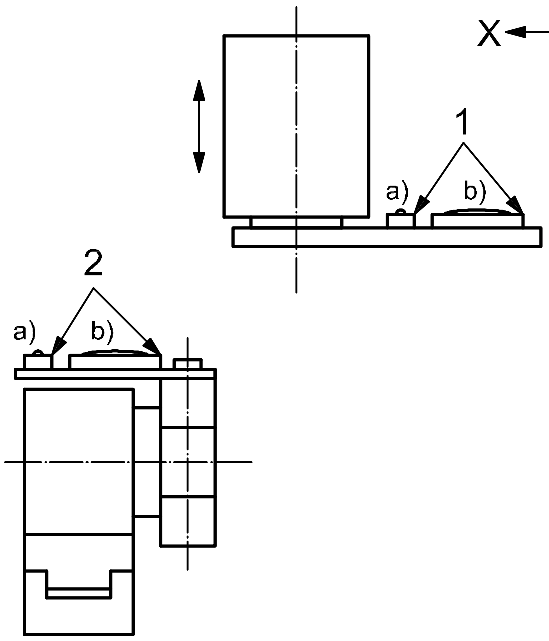
Checking the angular deviations of the Z-axis motion

a) in the YZ plane, EAZ,

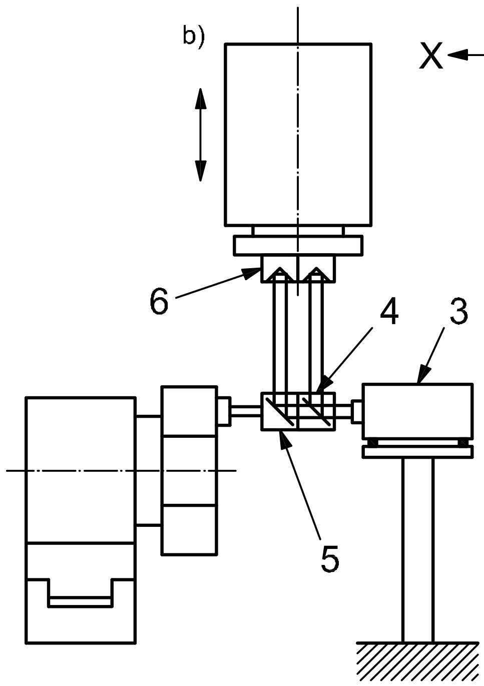
b) in the ZX plane, EBZ.

NOTE The test applies only within the machining area and does not include the auxiliary operation area.

Diagram



Precision level method



Laser interferometer method

Key

1 measuring level

2 reference level

3 laser head

4 interferometer

5 beam bender

6 reflectors

Tolerance

For a) and b), for Z-axis travel of up to 500:

0,040/1 000

Measured deviation

Measuring instruments

Precision level and special plate, laser measuring equipment or autocollimator

Observations and references to ISO 230-1:1996, 5.232.21, 5.232.22, 5.232.23

Set the precision level on the special plate fixed to the spindle nose horizontally.

Bidirectional measurements shall be carried out at a minimum of three positions equally spaced along the direction of travel in both directions of motion.

The difference between the maximum and minimum readings is the angular deviation.

Object	**G7**

Checking the angular deviations of the X-axis motion

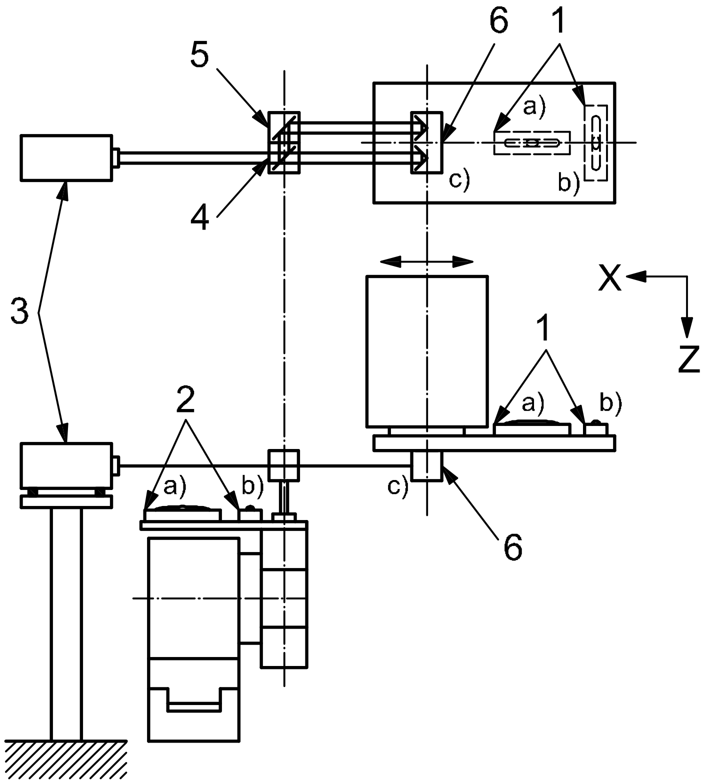
a) in the ZX plane, EBX (pitch),

b) in the YZ plane, EAX (roll),

c) in the XY plane, ECX (yaw).

NOTE The test applies only within the machining area.

Diagram



Key

1 measuring level
2 reference level
3 laser head
4 interferometer
5 beam bender
6 reflectors

Tolerance	**Measured deviation**
For a), b), and c), for X-axis travel of up to 500: 0,040/1 000	

Measuring instruments

a) Precision level or autocollimator and reflector or laser measuring equipment

b) Precision level

c) Autocollimator and reflector or laser measuring equipment

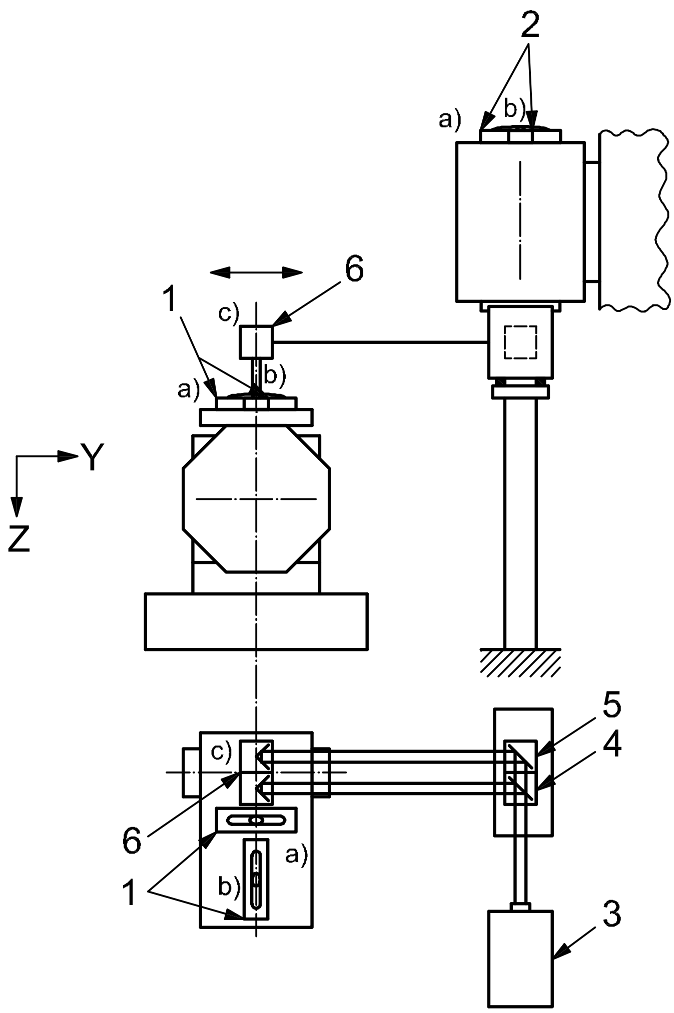
Observations and references to ISO 230-1:1996, 5.232.21, 5.232.22, 5.232.23

Measurements shall be carried out at the minimum of three positions equally spaced along the X-axis travel in both directions of motion.

The difference between the maximum and minimum readings is the angular deviation.

Object	G8
Checking the angular deviations of the Y-axis motion a) in the YZ plane, EAY (pitch), b) in the ZX plane, EBY (roll), c) in the XY plane, ECY (yaw).	

Diagram



Key

1 measuring level
2 reference level
3 laser head
4 interferometer
5 beam bender
6 reflectors

Tolerance	Measured deviation
For a), b), and c), for Y-axis travel of up to 500: 0,1/1 000	

Measuring instruments

a) Precision level, autocollimator or laser measuring equipment, special plate
b) Precision level, special plate
c) Autocollimator or laser measuring equipment, special plate

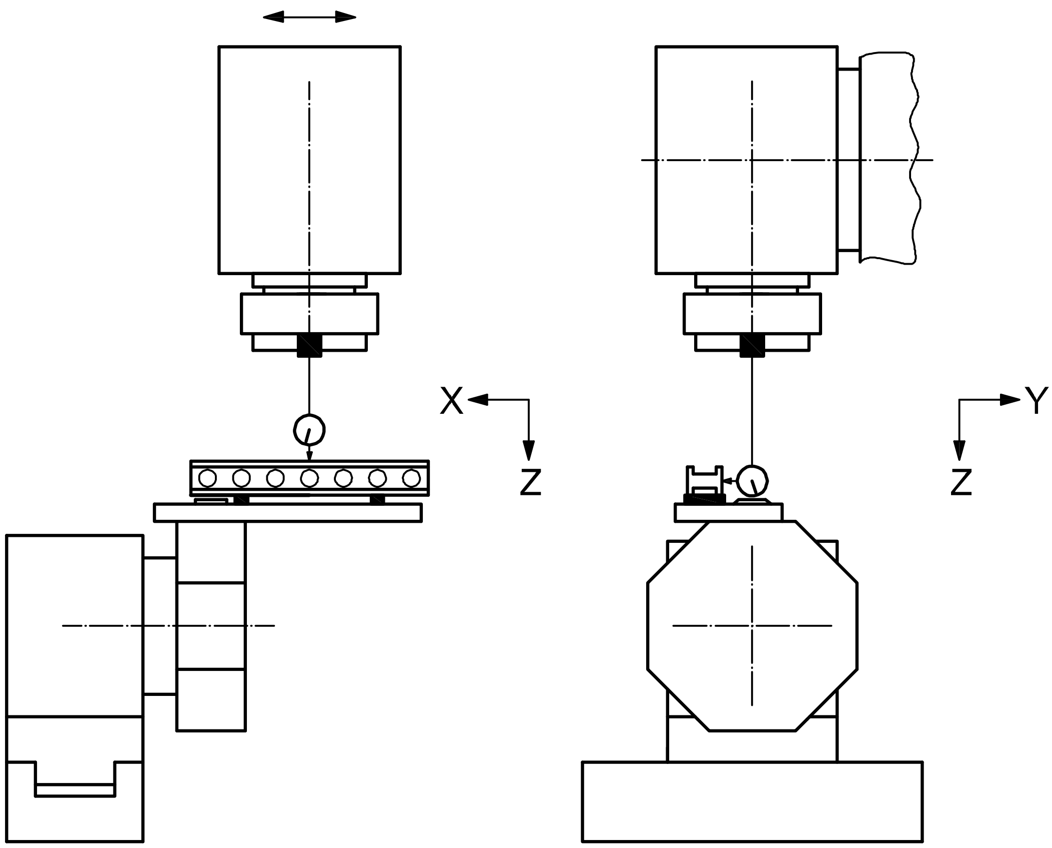
Observations and references to ISO 230-1:1996, 5.232.21, 5.232.22, 5.232.23

Set the measuring equipment (precision level, reflector) on the special plate fixed to the tool plate or turret, and fix a second plate to the spindle nose. Measurements shall be carried out at a minimum of three positions equally spaced along the direction of travel in both directions of motion.

The difference between the maximum and minimum readings is the angular deviation.

Object Checking the straightness of the X-axis motion a) in the vertical ZX plane, EZX, b) in the horizontal XY plane, EYX.	**G9**

Diagram



a) b)

Tolerance	**Measured deviation**
For a) and b): 0,02 over a measuring length of 300	

Measuring instruments

For a) and b), straightedge, adjustable block and linear displacement sensor or optical equipment

Observations and references to ISO 230-1:1996, 5.212.11 and 5.232.11

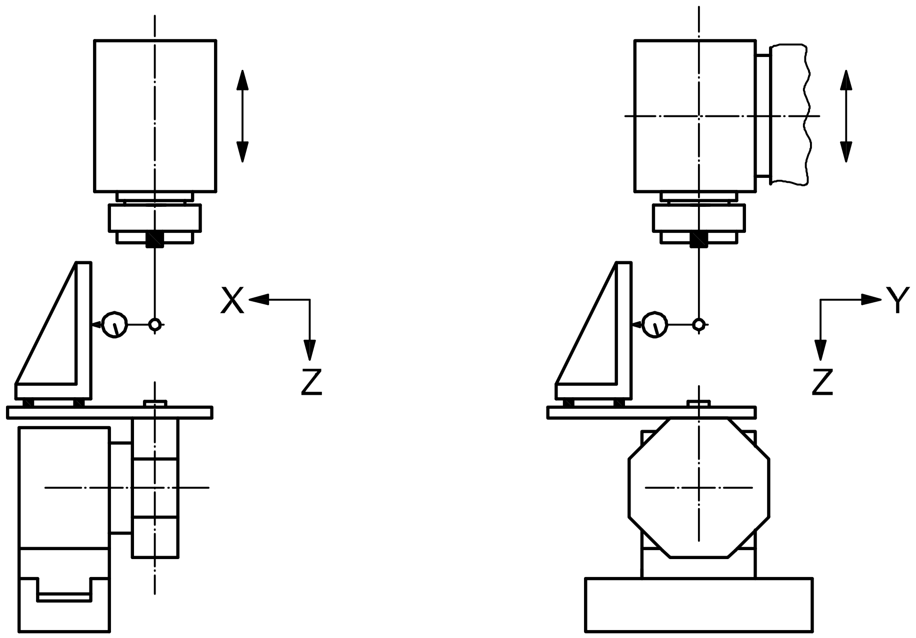
If the tool turret is movable in the Y-axis direction, position it such that the workholding spindle axis average line is in line with the tool turret pocket. Lock the spindle headstock in position near the tool turret. Place the straightness reference (straightedge, straightness reflector, alignment telescope) on the tool turret parallel to the X-axis motion.

NOTE "Parallel" in this context means that the readings at both ends of the movement give the same value and that in this case the maximum difference of the readings gives the straightness deviation.

Mount the linear displacement sensor, the interferometer or the target on the spindle near to the position of the workpiece. For machines utilizing tooling blocks mounted on the tool plate, requiring an extra-long X-axis stroke, a shorter straightedge may be mounted on the work spindle with the linear displacement sensor mounted on the tool turret and tool plate. In this setup, the re-staging of the linear displacement sensor is necessary when the end of the straightedge is reached. This method could be more practical for covering the entire travel range than the mounting of a very long straightedge cantilevered on the tool turret.

Object	**G10**
Checking the straightness of Z-axis motion a) in the XZ plane, EXZ, b) in the YZ plane, EYZ.	

Diagram



a) b)

Tolerance	**Measured deviation**
For a) and b): 0,02 over a measuring length of 300	

Measuring instruments

For a) and b), precision square, adjustable block and linear displacement sensor or optical equipment

Observations and references to ISO 230-1:1996, 5.212.11, 5.232.11

The straightness reference (straightness reflector, alignment telescope) shall be placed on the tool turret parallel to the Z-axis movement.

NOTE "Parallel" in this context means that the readings at both ends of the movement give the same value and that in this case the maximum difference of the readings gives the straightness deviation.

Mount the linear displacement sensor, the interferometer or the target on the workholding spindle headstock near to the position of the workpiece. The measuring line should be close to the workholding spindle axis of rotation.

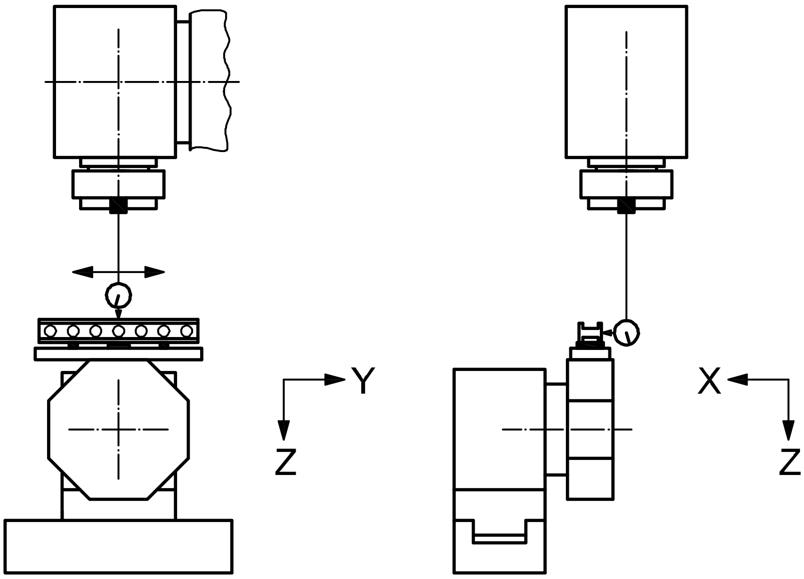
Alternatively, the test setup according to G3 (test mandrel mounted on workhead spindle and linear displacement sensor mounted on tool turret) may be used.

Object — **G11**

Checking the straightness of the Y-axis motion

a) in the vertical YZ plane, EZY,

b) in the horizontal XY plane, EXY.



a) b)

Tolerance	**Measured deviation**
For a) and b): 0,02 over a measuring length of 300	

Measuring instruments

For a) and b), straightedge, adjustable blocks and linear displacement sensor

Observations and references to ISO 230-1:1996, 5.212.11, 5.232.11

The straightness reference (straightness reflector, alignment telescope) shall be placed on the tool turret parallel to the Y-axis movement.

NOTE "Parallel" in this context means that the readings at both ends of the movement are the same value and that in this case the maximum difference of the readings gives the straightness deviation.

Mount the linear displacement sensor, the interferometer or the target on the workholding spindle headstock near to the position of the workpiece. The measuring line should be close to the workholding spindle axis of rotation.

5.4 Turret and power-driven tools

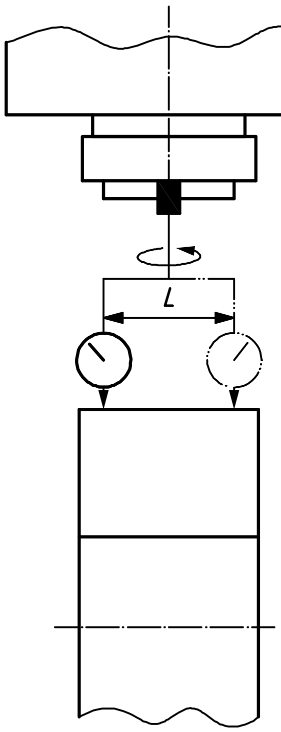
5.4.1 Tool-fixing face of turret

Object — **G12**

Checking the squareness of tool-fixing faces of the turret to the workholding spindle axis.

NOTE The test applies to tool-fixing faces of the turret square to the workholding spindle axis.

Diagram



Key

L measuring length

Tolerance	Measured deviation
0,02/100 L = 100	

Measuring instruments

Linear displacement sensor

Observations and reference to ISO 230-1:1996, 5.512.1, 5.512.4

Repeat the test for each tool-fixing face of the turret.

Object — **G13**

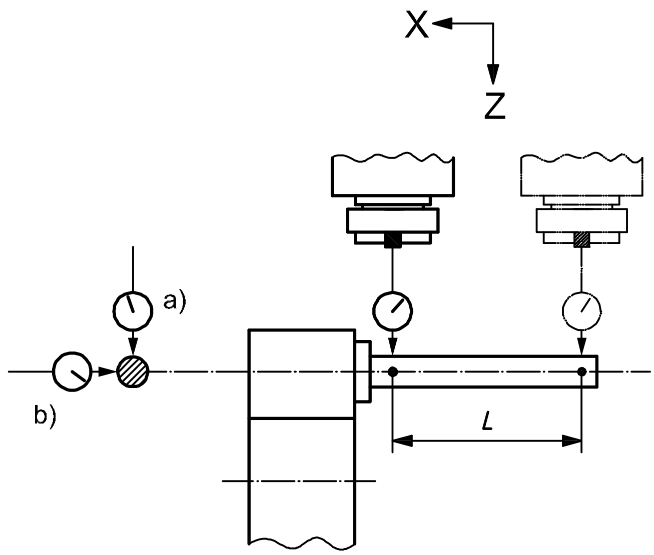
Checking the squareness of tool-fixing faces of the turret to the X-axis motion

a) in the ZX plane,

b) in the XY plane.

NOTE The test applies to tool-fixing faces of the turret parallel to the YZ plane.

Diagram



Key

L measuring length

Tolerance	**Measured deviation**
a) and b): 0,02 for L = 100	

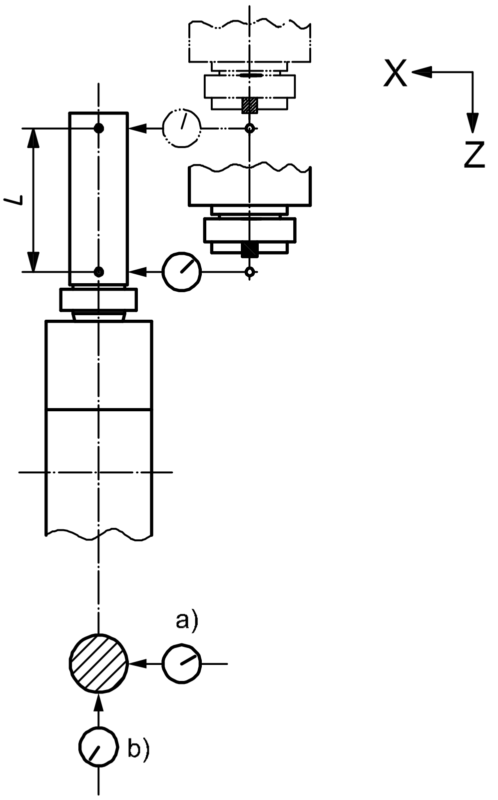
Measuring instruments

Test mandrel and linear displacement sensor

Observations and references to ISO 230-1:1996, 5.512.1, 5.512.4

Repeat the test for each tool-fixing face of the turret.

5.4.2 Tool-fixing bore of turret

<table>
<tr><td colspan="2">Object
Checking of parallelism between the tool-fixing bore axis of the turret and the Z-axis motion
a) in the ZX plane,
b) in the YZ plane.
NOTE The test applies to tool-fixing bores of the turret parallel to the Z-axis motion.</td><td>G14</td></tr>
<tr><td colspan="3">Diagram


Key
L measuring length</td></tr>
<tr><td>Tolerance
For a) and b):
0,02 for L = 100</td><td colspan="2">Measured deviation</td></tr>
<tr><td colspan="3">Measuring instruments
Test mandrel and linear displacement sensor</td></tr>
<tr><td colspan="3">Observations and references to ISO 230-1:1996, 5.422.3
Repeat the test for each tool-fixing bore of the turret.
Fix the mandrel to the tool-fixing bore of the turret and fix the linear displacement sensor to the workholding spindle so that the linear displacement sensor stylus touches the mandrel in the ZX/YZ plane. Preferably, mount the linear displacement sensor on the spindle housing to avoid locking the spindle.</td></tr>
</table>

Object	**G15**

Object

Checking of parallelism between tool-fixing bore axis of turret and the X-axis motion

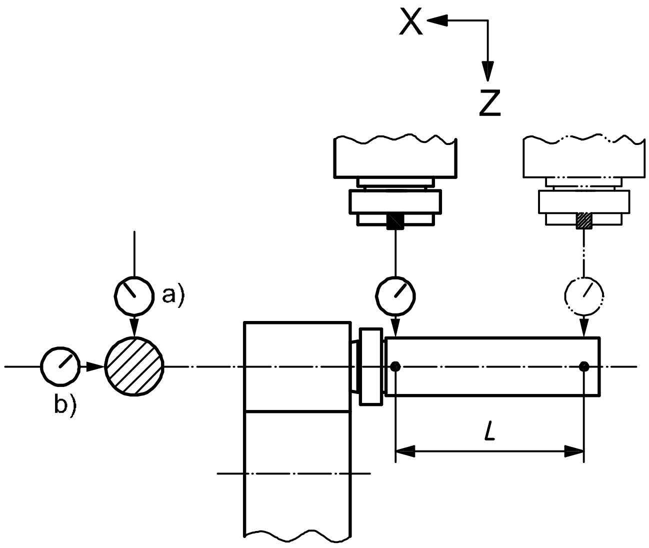
a) in the ZX plane,

b) in the XY plane.

NOTE The test applies to tool-fixing bores of turrets parallel to the X-axis motion.

G15

Diagram



Key

L measuring length

Tolerance	**Measured deviation**
For a) and b): 0,02 for L = 100	

Measuring instruments

Test mandrel and linear displacement sensor

Observations and references to ISO 230-1:1996, 5.422.3

Repeat the test for all tool-fixing bores.

Fix the mandrel to the tool-fixing bore and the linear displacement sensor to the workholding spindle so that the linear displacement sensor stylus touches the mandrel in the ZX/XY plane. Preferably, mount the linear displacement sensor on the spindle housing to avoid locking the spindle.

5.4.3 Turret for power-driven tools

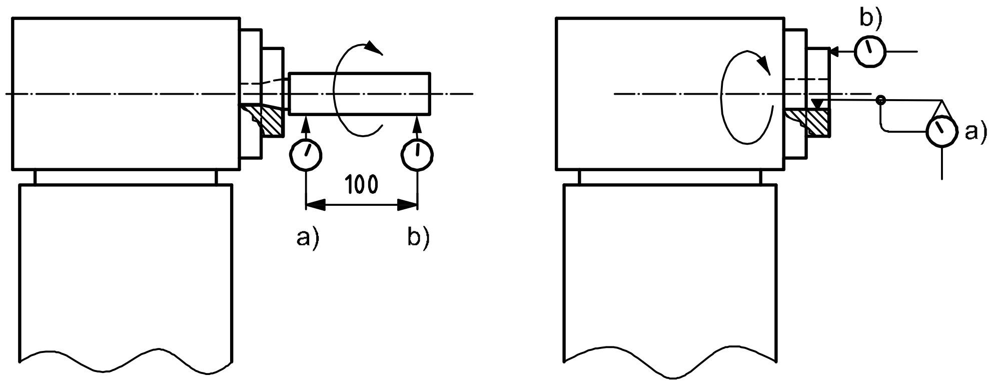
Object — **G16**

Testing of the run-out and radial (or face) run-out of the tool spindle(s), bore and face.

1) Run-out of internal taper bore
   a) at spindle nose,
   b) at a position of 100 mm from spindle nose.

2) Cylindrical bore:
   a) run-out of spindle nose;
   b) radial (or face) run-out of tool spindle surface.

Diagram



1) 2)

Tolerance				**Measured deviation**
1) a):	0,010	b)	0,015	
2) a) and b):	0,010			

Measuring instruments

1) Test mandrel and linear displacement sensor
2) Linear displacement sensor

Observations and references to ISO 230-1:1996, 5.612.3, 5.632

Measurements shall be performed on all tool spindles.

For 1), repeat the measurements at least four times, the mandrel being rotated through 90° in relation to the spindle. Record the average of the readings.

Steps should be taken to minimize the effect of the tangential drag upon the stylus of the measuring instrument.

Check 2) b) at the maximum possible radius.

Object | **G17**

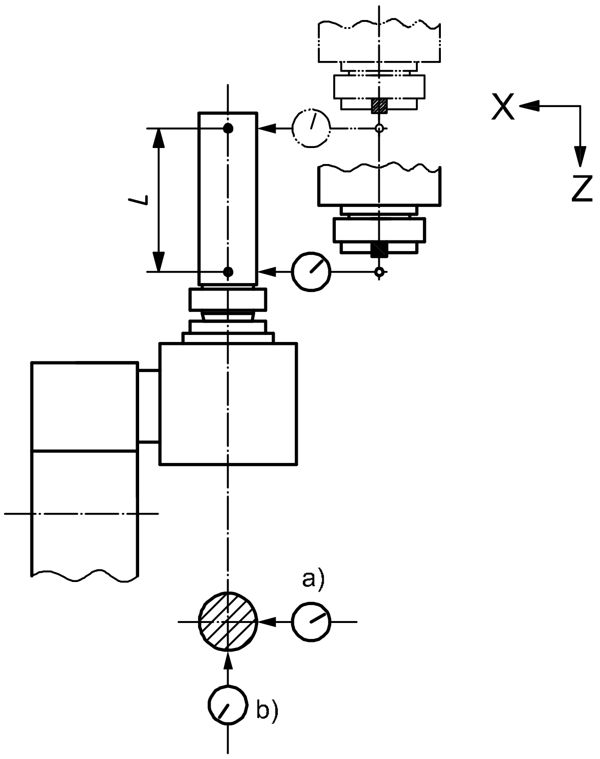
Checking of parallelism between the tool spindle axis and the Z-axis movement

a) in the ZX plane,

b) in the YZ plane.

NOTE The test applies to all rotating turret spindles parallel to the Z axis.

Diagram



Key

L measuring length

Tolerance	**Measured deviation**
For a) and b): 0,02 for *L* = 100	

Measuring instruments

Test mandrel and linear displacement sensor

Observations and references to ISO 230-1:1996, 5.412.1, 5.422.3

Turn the tool spindle to find the mean position of run-out and then move the workholding spindle in the Z direction. Take the maximum difference of the readings.

Alternatively, take readings along the test mandrel at a rotary position and then rotate the spindle by 180° and take readings at the initial positions. The maximum difference of the two averaged measurements gives the parallelism deviation. Preferably, mount the linear displacement sensor on the spindle housing to avoid locking the spindle.

Corresponding tests shall be applied for rotating turret spindles that are parallel to the Y or X axis.

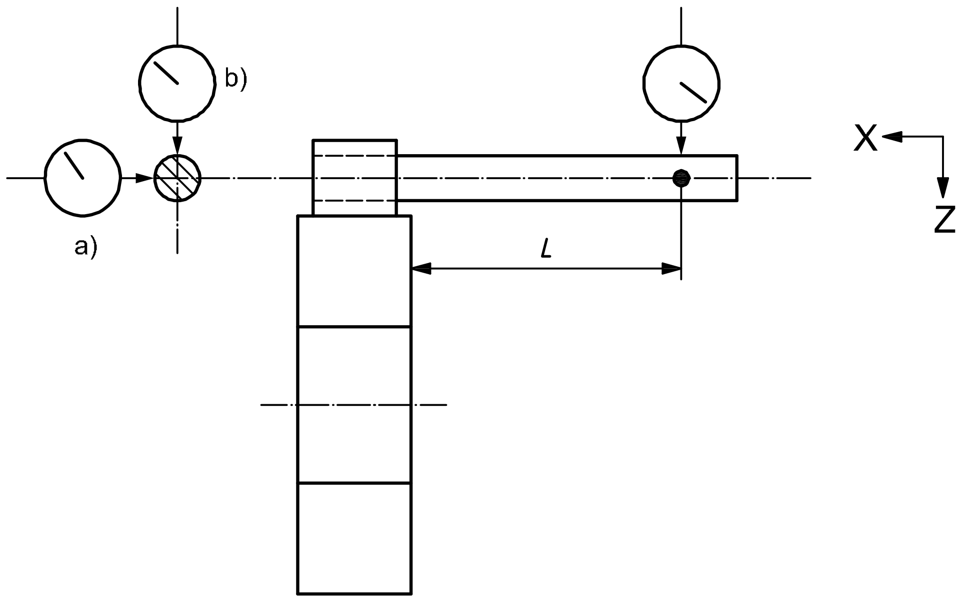
5.4.4 Accuracy and repeatability of turret indexing

Object — **G18**

a) Checking the repeatability of the turret indexing (XY plane).

b) Checking repeatability of motion of the turret in the radial direction (ZX plane).

Diagram



Key

L measuring length

Tolerance

	Category 1	Category 2	Category 3
	L = 50	L = 100	L = 100
a) and b):	0,005	0,010	0,015

Measured deviation

Measuring instruments

Test mandrel and linear displacement sensor

Observations and references to ISO 230-1:1996, 6.42

Measure at distance L from the turret face or tool-fixing face. With the turret in mid-stroke, position the linear displacement sensors so they contact the test mandrel at the 0° and 90° measurement positions. Record the turret's index position, axis position and the linear displacement sensor readings.

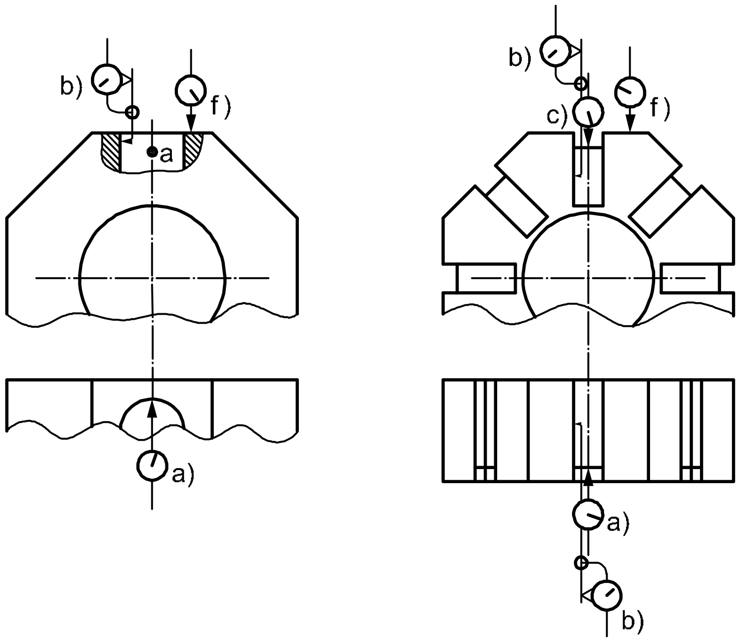
Separate the measuring instruments from the test mandrel along with the axis parallel to the mandrel axis, then index the turret 360° and reposition the measuring instruments to the measuring position under automatic cycle. Record the linear displacement sensor readings.

Repeat the cycle three times, with the linear displacement sensor reset to zero at the start of the test. The deviation is the maximum difference between the three sets of readings. Preferably, mount the linear displacement sensor on the spindle housing to avoid locking the spindle. Repeat the test at a minimum of three different turret orientations, setting the linear displacement sensor to zero for each location.

NOTE The repeatability of positioning of the linear axes (used for clearing the linear displacement sensors) can influence the measuring result.

Object Checking the accuracy of the turret indexing.	G19

Diagram



Tolerance	Measured deviation
Category 1 **Categories 2 and 3** 0,03 0,04	

Measuring instruments

Linear displacement sensor

Observations and references to ISO 230-1

Position the linear displacement sensor styli at positions a), b) and c) so that they contact the turret reference holes or grooves. Record the turret axis position. Record the linear displacement sensor readings. If the turret reference face is used, use the linear displacement sensor at position f) instead of at position c).

To allow indexing of the turret, separate the measuring instrument from the turret measurement surfaces by appropriate linear axis travel, index the turret to the next location, and return the measuring instrument to its previous measuring position. The maximum difference of all linear displacement sensor readings is the accuracy of the turret indexing.

Repeat the test three times for each turret location, then average the readings at each location in order to minimize the effect of turret repeatability. The maximum difference of all averaged linear displacement sensor readings is the accuracy of the turret indexing.

NOTE Position a) is also influenced by the axial movement of turret indexing, while position b) is also influenced by turret indexing repeatability, position c) by the radial movement of turret indexing, and position f) by the radial movement.

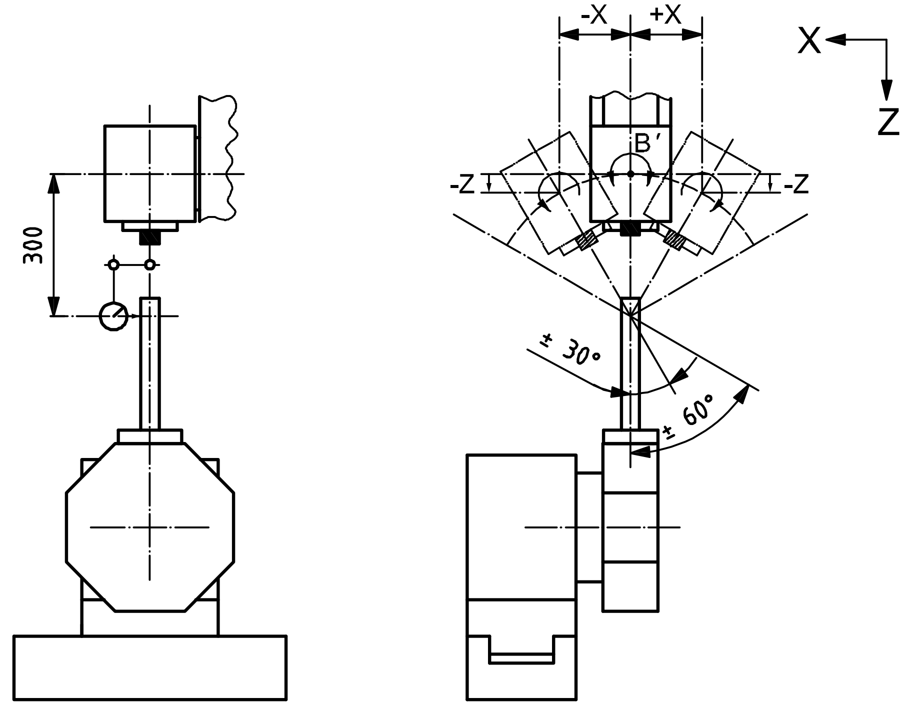
If the turret has a locating feature, then make the measurement at position b) on the location side and not the clamping clearance sector of the bore location.

5.5 Swivelling workholding spindle head

Object | **G20**

Checking of parallelism between the swivelling plane of the workholding spindle head axis (B′ axis) and the ZX plane.

Diagram



Tolerance

Swivel angle: 30° ± 60°

At a radius of 300: 0,01 0,02

Measured deviation

Measuring instruments

Linear displacement sensor and test mandrel

Observations and references to ISO 230-1:1996, 5.432

Set the test mandrel to the turret head.

Touch the stylus of the linear displacement sensor to the test mandrel at a position about 300 mm apart from the axis of rotation B′, then move the workholding spindle head stock to the +30° (and +60°) positions and touch the test mandrel again at the same positions.

Index the workholding spindle head stock to the –30° (and –60°) positions and check the height of the mandrel at the same positions on the test mandrel.

Repeat the test at least three times. The maximum difference of the readings is the parallelism deviation.

6 Tests for checking accuracy of axes of rotation

6.1 Rotational accuracy of workholding spindle

R1

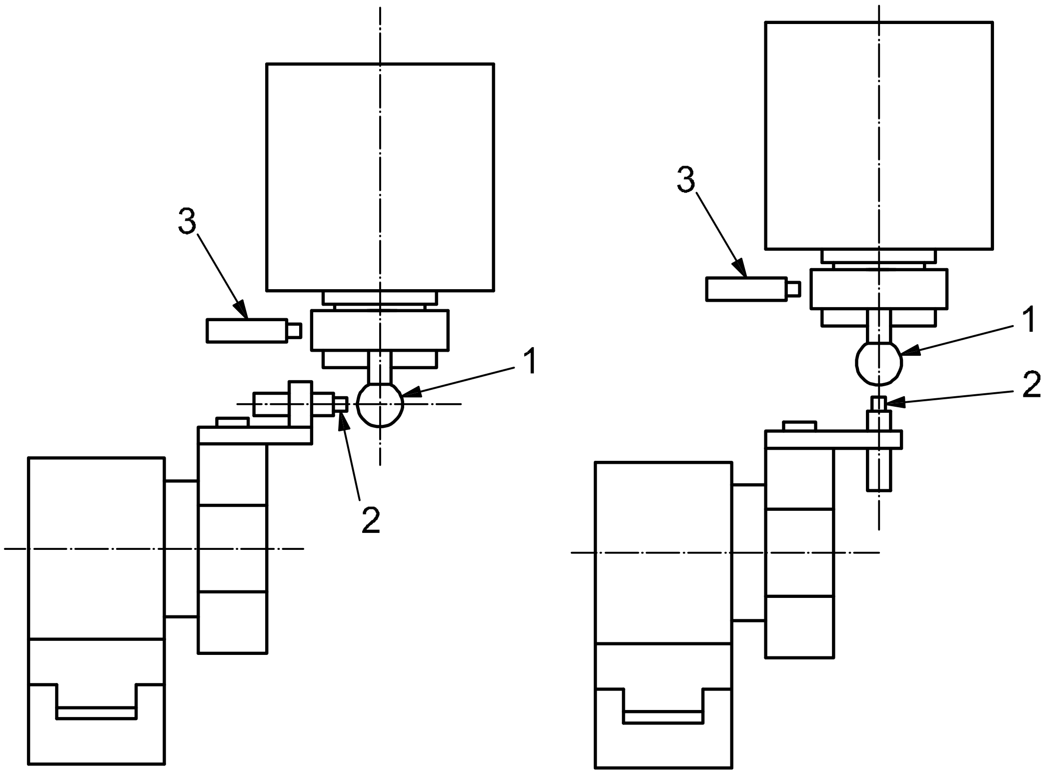
Object

Checking the accuracy of the axis of rotation of the workholding spindle:

a) radial error motion of the spindle, EXC;

b) axial error motion of the spindle, EZC.

Diagram



a) b)

Key

1 reference artefact (test ball)

2 displacement sensor

3 angular measuring device (or trigger sensor)

Tolerance

	At percentage of maximum speed		
	10 %	50 %	100 %
a) Total radial error motion value, EXC			
b) Total axial error motion value, EYC			

If the minimum speed is greater than 10 % of the maximum speed, then the spindle should be operated at the minimum speed instead.

If the supplier/manufacturer and user decide by mutual agreement to include this test in the contractual machine acceptance procedures, then they should also define, by mutual agreement, the corresponding tolerances to be applied.

NOTE Tolerances for this test may be provided at the next revision of this part of ISO 13041, depending on the availability of solid data from such measurements for spindle performance in an industrial environment.

Measured deviation

	At percentage of maximum speed		
	10 %	50 %	100 %
a)			
b)			

Measuring instruments

Precision sphere, non-contacting linear displacement sensors and angular measuring device

Alternatively, precision sphere located slightly eccentric to spindle axis average line and non-contacting linear displacement sensors

Observations and references to ISO 230-7

This test is a spindle test with fixed sensitive direction according to ISO 230-7:2006, 5.5.

After setting up the measuring instrument, unless otherwise agreed between the manufacturer/supplier and user, warm up the spindle at 50 % of the maximum spindle speed for 10 min.

Total error motion and total error motion value are defined in ISO 230-7:2006, 3.2.4 and 3.5.1, respectively.

a) Total radial error motion (EXC)

   Perform the radial error motion measurement in accordance with ISO 230-7:2006, 5.4.2. The radial error motion shall be measured at as close a point as possible to the spindle nose.

   For the radial error motion, EXC, a total error motion polar plot (see ISO 230-7:2006, 3.3.1) with a least squares circle (LSC) centre (see ISO 230-7:2006, 3.4.3) shall be provided.

b) Total axial error motion (EZC)

   Perform the total axial error motion measurement in accordance with ISO 230-7:2006, 5.4.4.

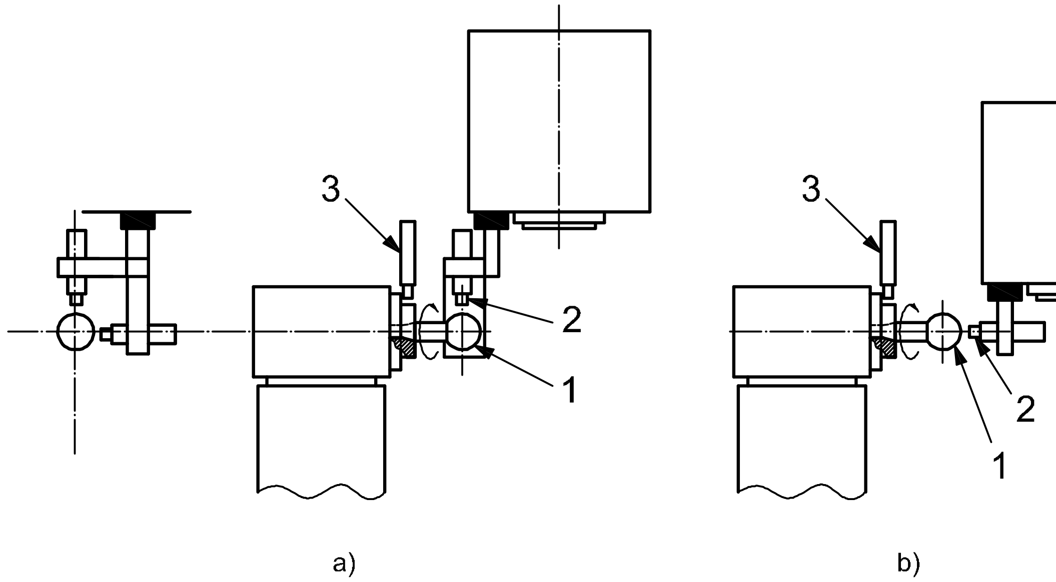
   For the axial error motion, EZC, a total error motion polar plot (see ISO 230-7:2006, 3.3.1) with a polar chart (PC) centre (see ISO 230-7:2006, 3.4.1) shall be provided.

For these tests the following parameters shall be provided:

— the radial and axial locations at which the measurements are made;
— identification of all artefacts, targets and fixtures used;
— the location of the measurement setup;
— the position of any linear or rotary positioning stages that are connected to the device under test;
— the direction angle of the sensitive direction, e.g. axial, radial or intermediate angles as appropriate;
— presentation of the measurement result, e.g. error motion value, polar plot, time-based plot, frequency content plot;
— the rotational speed of the spindle (zero for static error motion);
— the time duration in seconds or number of spindle rotations;
— appropriate warm-up or break-in procedure;
— the frequency response of the instrumentation, given as hertz or cycles per revolution, including roll-off characteristics of any electronic filters, and — in the case of digital instrumentation — the displacement resolution and sampling rate;
— the structural loop, including the position and orientation of sensors relative to the spindle housing from which the error motion is reported, specified objects with respect to which the spindle axes and the reference coordinate axes are located and the elements connecting these objects;
— the time and date of measurement;
— the type and calibration status of all measurement instrumentation;
— other operating conditions that could influence the measurement, e.g. ambient temperature.

This test may be carried out with the three-point measuring method described in Annex A.

6.2 Rotational accuracy of tool spindle

<table>
<tr><td colspan="2">Object
Checking the accuracy of the axis of rotation of the tool spindle:
a) radial error motion of the tool spindle, ERA;
b) axial error motion of the tool spindle, EXA.</td><td>R2</td></tr>
<tr><td colspan="3">Diagram


Key
1 reference artefact (test ball)
2 displacement sensors
3 angular measuring device (or trigger sensor)</td></tr>
<tr><td>Tolerance
At percentage of maximum speed
10 % 50 % 100 %
a) Total radial error motion value, ERA
b) Total axial error motion value, EXA
If the minimum speed is greater than 10 % of the maximum speed, then the spindle should be operated at the minimum speed instead.
If the supplier/manufacturer and user decide by mutual agreement to include this test in the contractual machine acceptance procedures, then they should also define, by mutual agreement, the corresponding tolerances to be applied.
NOTE Tolerances for this test may be provided at the next revision of this part of ISO 13041, depending on the availability of solid data from such measurements for spindle performance in an industrial environment.</td><td colspan="2">Measured deviation
At percentage of maximum speed
10 % 50 % 100 %
a)
b)</td></tr>
<tr><td colspan="3">Measuring instruments
Precision sphere, non-contacting linear displacement sensors and angular measuring device
Alternatively, precision sphere located slightly eccentric to spindle axis average line and non-contacting linear displacement sensors</td></tr>
</table>

Observations and references to ISO 230-7

This test is a spindle test with rotating sensitive direction according to ISO 230-7:2006, 5.4.

After setting up the measuring instrument, and unless otherwise agreed between the manufacturer/supplier and the user, warm up the spindle at 50 % of maximum spindle speed for 10 min.

Total error motion and total error motion value are defined in ISO 230-7:2006, 3.2.4 and 3.5.1, respectively.

a) Total radial error motion (ERA)

   Perform the radial error motion measurement in accordance with ISO 230-7:2006, 5.4.2. The radial error motion shall be measured at as close a point as possible to the spindle nose.

   For the radial error motion, ERA, a total error motion polar plot (see ISO 230-7:2006, 3.3.1) with a least squares circle (LSC) centre (see ISO 230-7:2006, 3.4.3) shall be provided.

b) Total axial error motion (EXA)

   Total axial error motion measurement is described in ISO 230-7:2006, 5.4.4.

   For the axial error motion, EXA, a total error motion polar plot (ISO 230-7:2006, 3.3.1) with a polar chart (PC) centre (see ISO 230-7:2006, 3.4.1) shall be provided.

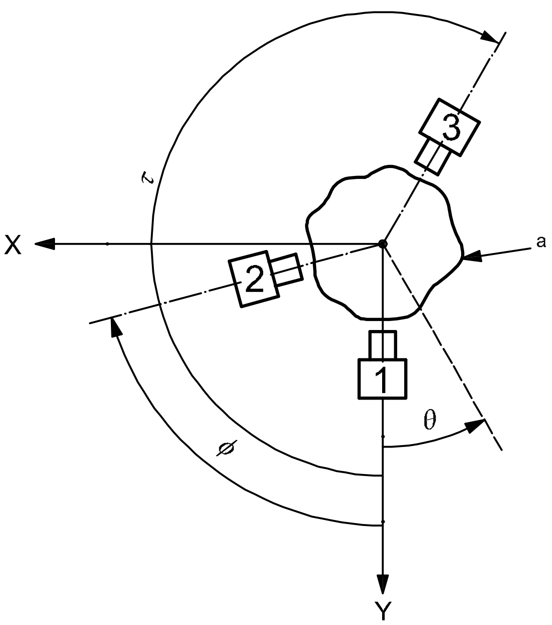
For these tests, the following parameters shall be provided:

— the radial and axial locations at which the measurements are made;
— identification of all artefacts, targets and fixtures used;
— the location of the measurement setup;
— the position of any linear or rotary positioning stages that are connected to the device under test;
— the direction angle of the sensitive direction, e.g. axial, radial or intermediate angles as appropriate;
— presentation of the measurement result, e.g. error motion value, polar plot, time-based plot, frequency content plot;
— the rotational speed of the spindle (zero for static error motion);
— the time duration in seconds or number of spindle rotations;
— appropriate warm-up or break-in procedure;
— the frequency response of the instrumentation, given as hertz or cycles per revolution, including roll-off characteristics of any electronic filter, and — in the case of digital instrumentation — the displacement resolution and sampling rate;
— the structural loop, including the position and orientation of sensors relative to the spindle housing from which the error motion is reported, specified objects with respect to which the spindle axes and the reference coordinate axes are located and the elements connecting these objects;
— the time and date of measurement;
— the type and calibration status of all measurement instrumentation;
— other operating conditions that could influence the measurement, e.g. ambient temperature.

Annex A
(informative)

Three-point measuring method

Roundness deviation of the artefact used in the measurement of axis of rotation error influences the measurement results. The method of measurement presented in this annex, which utilizes three radially arranged linear displacement sensors against an “imperfect” artefact, is one way to eliminate the influence of artefact roundness deviations on the axis of rotation measurements.



Key

1 to 3 sensors

θ angle measured from the Y axis

τ angle between sensor 1 and sensor 3

ϕ angle between sensor 1 and sensor 2

a Roundness profile.

Figure A.1 — Three-point measuring method

As shown in Figure A.1, the angle between sensor 1 and sensor 2 is expressed as ϕ, and the angle between sensor 1 and sensor 3 is expressed as τ. The angle measured from the Y axis is . The roundness profile of the reference artefact (test bar) is expressed as $r(\theta)$. Furthermore, $x($ $)$ and $y(\theta)$ represent the radial error motion in the X and Y directions. The output signal of these three sensors is given by Equation (A.1).

$$\begin{cases} S_1(\theta) = r(\theta) + y(\theta) \\ S_2(\theta) = r(\theta + \phi) + y(\theta)\cos\phi + x(\theta)\sin\phi \\ S_3(\theta) = r(\theta + \tau) + y(\theta)\cos\tau + x(\theta)\sin\tau \end{cases} \tag{A.1}$$

After multiplying the coefficients, 1, p, q, to the output signal of sensor 1, sensor 2 and sensor 3, total summation is given as $S(\theta)$:

$$\begin{aligned} S(\theta) &= S_1(\theta) + pS_2(\theta) + qS_3(\theta) \\ &= r(\theta) + pr(\theta+\phi) + qr(\theta+\tau) + (1 + p\cos\phi + q\cos\tau)x(\theta) + (p\sin\phi + q\sin\tau)y(\theta) \end{aligned} \tag{A.2}$$

$$\begin{cases} 1 + p\cos\phi + q\cos\tau = 0 \\ p\sin\phi + q\sin\tau = 0 \end{cases} \Leftrightarrow \begin{cases} p = -\dfrac{\sin\tau}{\sin(\tau-\phi)} \\ q = \dfrac{\sin\phi}{\sin(\tau-\phi)} \end{cases} \tag{A.3}$$

If p, q, ϕ, τ are chosen so as to satisfy Equation (A.3), then Equation (A.2) becomes independent of error motion, $x(\ )$ and $y(\theta)$. The roundness profile of the reference artefact $r(\theta)$ is expressed as:

$$r(\theta) = \sum_{k=2}^{N} \left(A_k \cos k\theta + B_k \sin k\theta \right) \tag{A.4}$$

Thus, $S(\theta)$ is given as:

$$\begin{aligned} S(\theta) = \sum_{k=2}^{N} \Big\{ & \left[(1 + p\cos k\phi + q\cos k\tau) A_k + (p\sin k\phi + q\sin k\tau) B_k \right] \cos k\theta + \\ & \left[-(p\sin k\phi + q\sin k\tau) A_k + (1 + p\cos k\phi + q\cos k\tau) B_k \right] \sin k\theta \Big\} \end{aligned} \tag{A.5}$$

$$\begin{cases} \alpha_k = 1 + p\cos k\phi + q\cos k\tau \\ \beta_k = p\sin k\phi + q\sin k\tau \end{cases} \tag{A.6}$$

Substituting α_k, β_k by Equation (A.6), Fourier coefficients of $S(\theta)$, that is, F_k, G_k, are given by Equation (A.7):

$$\begin{cases} F_k = \alpha_k A_k + \beta_k B_k \\ G_k = -\beta_k A_k + \alpha_k B_k \end{cases} \tag{A.7}$$

Then, Fourier coefficients of the roundness profile of the reference artefact, A_k, B_k, are obtained as follows.

$$\begin{cases} A_k = \dfrac{\alpha_k F_k - \beta_k G_k}{\alpha_k{}^2 + \beta_k{}^2} \\ B_k = \dfrac{\alpha_k G_k + \beta_k F_k}{\alpha_k{}^2 + \beta_k{}^2} \end{cases} \tag{A.8}$$

Then, the radial error motion in the X and Y direction are estimated as follows. Here, $\hat{r}$ represents the estimated roundness profile of the reference artefact:

$$\begin{cases} x(\theta) = \dfrac{\left\{ S_2(\theta) - \hat{r}(\theta+\phi) - \left[S_1(\theta) - \hat{r}(\theta) \right] \cos\phi \right\}}{\sin\phi} \\ y(\theta) = S_1(\theta) - \hat{r}(\theta) \end{cases} \tag{A.9}$$

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