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Machine tools — Test conditions for universal spindle heads —

Part 1: Accessory heads for machines with horizontal spindle (horizontal Z-axis)

Machines-outils — Conditions d'essai pour poupées porte-broche universelles —

Partie 1: Têtes accessoires pour machines à broche horizontale (axe Z horizontal)

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Foreword

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

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

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

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

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

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

Accessory spindle heads are used on machine tools such as milling and boring machines, machining centres, portal and gantry type machines, turning centres, with only one built-in spindle in the head or ram, providing fixed or indexing or tilting spindles which can be oriented in directions different from the built-in spindle axis.

In the same way as the built-in spindle, they can perform multiple machining operations including milling, boring, drilling, grinding and tapping, and, in some cases, automatic tool changing as well from a magazine or similar storage unit in accordance with a machining program.

Some types of heads allow to check only the resulting position of the spindle (as the fixed or indexing ones considered in 3.3, 3.4 and 3.5 and in tests G1 to G15), whereas for some others, i.e. those with continuous movement of the two rotary axes (as those considered in 3.6 and 3.7), Annexes A and B allow to make additional analysis of the relative positions between axes and to check the accuracy of their offset compensation as well.

Machine tools — Test conditions for universal spindle heads —

Part 1: Accessory heads for machines with horizontal spindle (horizontal Z-axis)

1 Scope

This document specifies, with reference to the ISO 230 series, some families of tests for accessory spindle heads used on machining centres or numerically controlled milling machines, etc., where applicable, with horizontal spindle (i.e. horizontal Z-axis). The tests considered in this document are also applicable to manual indexing heads.

This document establishes the tolerances or maximum acceptable values for the test results corresponding to general purpose and normal accuracy spindle heads used on different types of machines.

This document specifies several sets of procedures for geometric tests which can be carried out on different types of spindle heads for comparison, acceptance, maintenance, adjustments or any other purpose.

Grinding heads and facing heads are not included in the scope of this document.

This document deals only with the verification of geometric and positioning accuracy of the accessory spindle heads and does not apply to:

— the testing of the machine's head(s) operation (e.g. vibration, abnormal sound noise level, stick slip motion of components);

— the machine's spindle head(s) characteristics (e.g. speeds, feeds and accelerations) which are generally checked separately; or

— the verification of the machining capability under power.

Tests concerning the accuracy of finished test pieces are dealt with in other ISO standards.

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 230-1:2012, *Test code for machine tools — Part 1: Geometric accuracy of machines operating under no-load or quasi-static conditions*

ISO 230-2:2014, *Test code for machine tools — Part 2: Determination of accuracy and repeatability of positioning of numerically controlled axes*

ISO 230-7:2015, *Test code for machine tools — Part 7: Geometric accuracy of axes of rotation*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 230-1, ISO 230-2, ISO 230-7 and the following apply.

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

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

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

3.1
universal head
spindle head with one or more spindles which are oriented, or can be oriented, parallel to more than one coordinate axis

Note 1 to entry: Terminological entries 3.3 to 3.8 define several types of universal heads which are mostly used on horizontal machining centres or numerically controlled milling machines.

Note 2 to entry: Table 1 shows the five possible orientations of the spindle parallel to the coordinate axes and a short definition of the relevant direction.

Table 1 — Spindle orientations

Coordinate axis	Direction	Definition
Z	Negative	Longitudinal
X	Positive	Left
X	Negative	Right
Y	Positive	Upward
Y	Negative	Downward

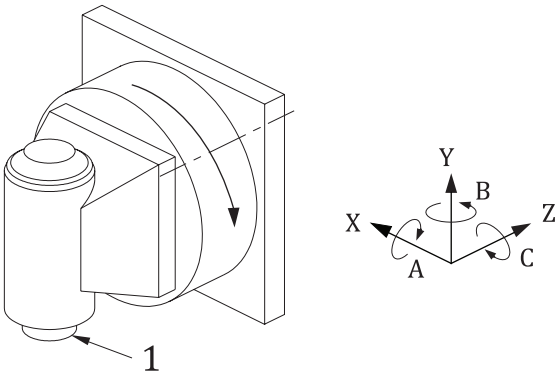
3.2
accessory head
spindle head which can be mounted in front of a ram or a head already provided with its own tool holding spindle

Note 1 to entry: The machine tool can perform machining operations both by its own spindle or by an accessory head, and several different accessory heads can be stored in a head store.

Note 2 to entry: *Square head* (3.3) through *tilting head* (3.8) define several types of accessory heads which are mostly used on horizontal machining centres or numerically controlled milling machines.

3.3
square head
spindle head with only one spindle perpendicular to the Z-axis, which can rotate around the Z-axis

Note 1 to entry: See Figure 1.



Key

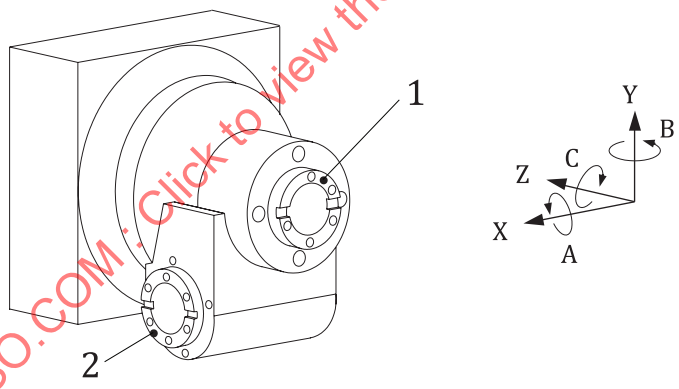
1 spindle

Figure 1 — Square head

3.4
two-spindle square head
square head (3.3) with two spindles located perpendicular to each other, one parallel to the Z-axis and the other perpendicular to the Z-axis, which can rotate around the Z-axis

Note 1 to entry: The two spindles can be coplanar or skew to each other.

Note 2 to entry: See Figure 2.



Key

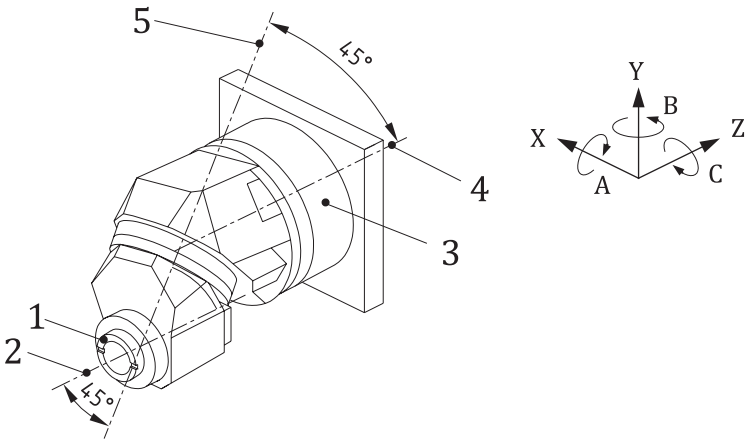
1 longitudinal spindle

2 square spindle

Figure 2 — Two-spindle square head

3.5
45° split indexing head
spindle head with mechanical indexing function in a plane inclined by 45° with respect to the horizontal Z-axis

Note 1 to entry: See Figure 3.



Key

1 spindle
2 spindle axis S
3 head base
4 C-axis (head base rotation)
5 rotary D-axis (45° oriented)

Figure 3 — 45° split head

3.6
45° split continuous head
spindle head provided with continuous positioning function by two numerically controlled axes of rotation, namely the C-axis parallel to the horizontal Z-axis, and the D-axis in a plane inclined by 45° with respect to the Z-axis

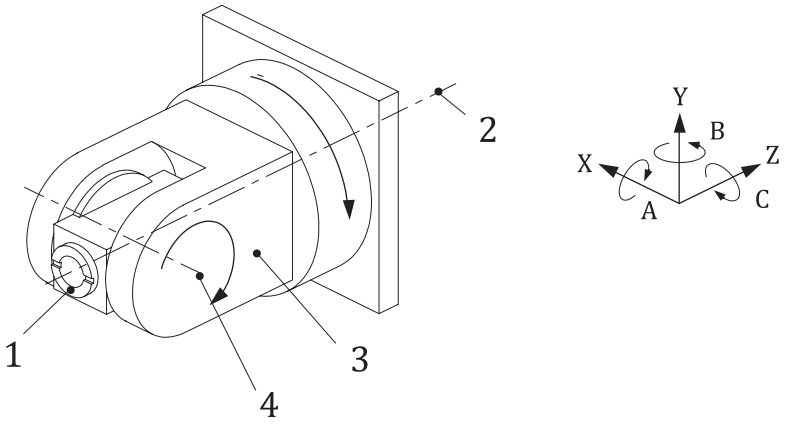
Note 1 to entry: Tests in Annex A check all the geometric features (planes and axes) which contribute to the resulting angular position of the spindle, by-passing the positioning deviations of the two rotary axes; these tests are also intended for a deeper investigation on the *45° split indexing heads* (3.5), if their movements and locks allow to do it.

Note 2 to entry: See Figure 3.

3.7
swivelling head
spindle head with two numerically controlled A-axis and C-axis perpendicular to each other

Note 1 to entry: The spindle axis S can be coplanar with C-axis (see Figure 4) or there can be a built-in offset between the spindle axis S and the C-axis. (see Figure 5).

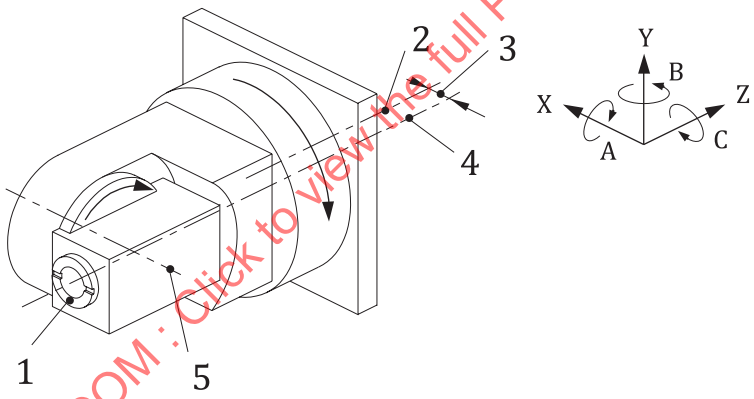
Note 2 to entry: Tests in Annex B check all the relative positions between couples of axes, as A and C, spindle and A, spindle and C and their undesired offsets.



Key

1 spindle
2 C-axis (yoke rotation)
3 yoke body
4 A-axis (head rotation)

Figure 4 — Swivelling head



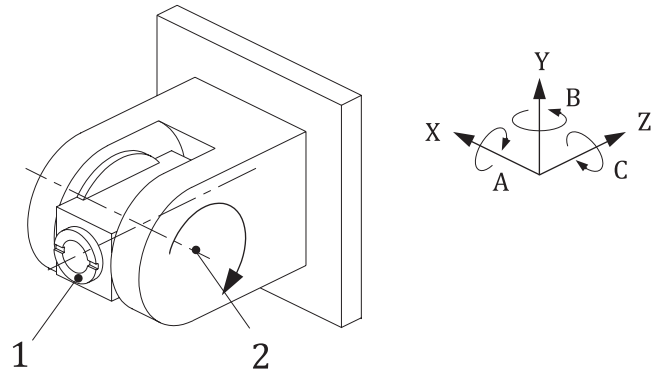
Key

1 spindle
2 C-axis (yoke rotation)
3 built-in offset
4 spindle axis S
5 A-axis (head rotation)

Figure 5 — Swivelling head with spindle offset

3.8
tilting head
spindle head rotating only around the X-axis

Note 1 to entry: See Figure 6.



Key

1 spindle

2 A-axis

Figure 6 — Tilting head

4 Preliminary remarks

4.1 Measurement units

In this document, 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 as the primary method, but in some cases, microradians or arcseconds may be used for clarification purposes. Formula (1) should be used for conversion of the units of angular deviations or tolerances.

$$0{,}010 / 1\,000 = 10\ \mu\text{rad} \cong 2'' \tag{1}$$

4.2 Reference to ISO 230

To apply this document, reference shall be made to ISO 230-1, ISO 230-2 and ISO 230-7 when required, especially for the installation of the machine before testing, warming up of the spindle and other moving components, description of measuring methods and recommended uncertainty of testing equipment.

Where the test concerned is in compliance with the specifications of the relevant part of ISO 230 (i.e. ISO 230-1, ISO 230-2 or ISO 230-7), a reference to the corresponding subclause of that standard is shown before the instructions in the "Observations" block of the tests described in Clauses 5, 6 and 7 and in Annexes A to C.

4.3 Testing sequence

The sequence in which the tests are presented in this document 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.

4.4 Tests to be performed

When testing a machine, it is neither always necessary nor possible to carry out all the tests described in this document. When the tests are required for acceptance purposes, it is up to the user to choose, in agreement with the supplier/manufacturer, the relevant tests relating to the specific type of spindle head and/or the properties of the head. These tests are to be clearly stated when ordering either a machine with accessory head/(s) or a single head. A simple reference to this document 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.

Tests shown in this document check only the resulting position of the spindle axis in the possible orientations of the head, and they are intended to be used for acceptance purposes.

Annexes A and B contain additional tests to check all the geometric features (planes and axes) which contribute to the resulting position of the spindle, by-passing the positioning deviations of the two rotary axes; these tests provide a technical means for a deeper investigation and a diagnostic analysis on the accuracy of the head components and of their assembly, both on a new head and during the working life of a head in use.

Annex C contains tests for checking the accuracy of axes of rotation.

4.5 Measuring instruments

Measuring instruments indicated in the tests described in Clauses 5, 6, 7 and in Annexes A to C are only examples. Other instruments capable of measuring the same quantities and having the same, or a smaller, measurement uncertainty may be used. Reference shall be made to ISO 230-1:2012, Clause 5, which indicates the relationship between measurement uncertainties and the tolerances.

When a dial gauge is referred to, it can mean not only dial test indicators (DTIs), but any type of linear displacement sensor such as analogue or digital dial gauges, linear variable differential transformers (LVDTs), linear scale displacement gauges or noncontacting sensors, when applicable to the test concerned (see ISO 230-1:2012, Clause 4).

Similarly, when a straightedge is referred to, it can mean any type of straightness reference artefact, such as a granite, ceramic, steel, cast iron straightedge, one arm of a square, one generating line on a cylindrical square, any straight path on a reference cube or a special, dedicated artefact manufactured to fit in the T-slots or other references.

In the same way, when a square is mentioned, it can mean any type of squareness reference artefact, such as a granite or ceramic or steel or cast iron square, a cylindrical square, a reference cube or, again, a special, dedicated artefact.

Valuable information for measuring instruments is available in ISO/TR 230-11.

4.6 Software compensation

4.6.1 Head offset compensation

The NC control can compensate offsets between axes, which can result from either of the following:

— the head design: e.g. in two-spindle square heads with rigid body the cross-spindle can lie in a different plane from the longitudinal spindle (see Figure 2) or in swivelling heads with the A-axis perpendicular to the C-axis the spindle axis S can swivel in a plane not containing the C-axis (see Figure 5);

— the natural small inaccuracies in machining and assembling the head components (see Figure 3 and Figure 4).

In this second case, the concerned tests may be carried out with and/or without applying the offset compensation, according to the test purpose, and this should be specified in the test report for every concerned test.

This double option of test allows assessing both the original mechanical accuracy and the offset compensation accuracy. The intended use of the machine tool shall be considered.

4.6.2 Machine geometric compensation

When software facilities are available for compensating certain geometric deviations of the machine, the tests considered in this document should be carried out with these compensations. When the software compensation is used, this shall be stated in the test report. It shall be noted that when software compensation is used, axes cannot be locked for test purposes.

4.7 Diagrams

For reasons of simplicity, the diagrams in this document illustrate only some types of spindle heads and machine configurations. Their main purpose is to show the movements to be operated and the orientation of the coordinate axes.

4.8 Measuring length

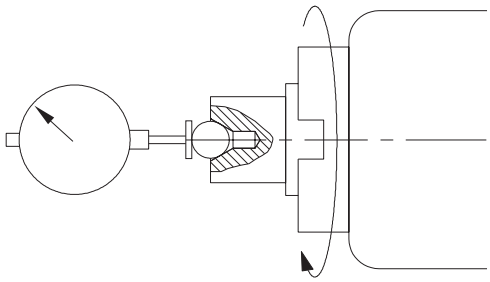
When a test requires the use of a test mandrel, the measuring length is 250 mm for the usual test mandrels 300 mm long. If a different measuring length is required, test mandrels of adequate length shall be provided accordingly.

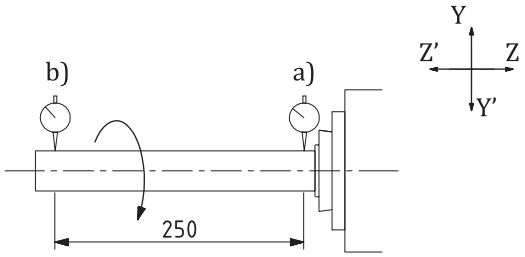
4.9 Tolerances

In this document, all tolerance values (see ISO 230-1:2012, 4.1) are guidelines. When they are used for acceptance purposes, other values may be agreed between the user and the manufacturer/supplier. The required/agreed tolerance values are to be clearly stated when ordering the machine.

When establishing the tolerance for a measuring length different from that given in this document (see ISO 230-1:2012, 4.1.2), it shall be taken into consideration that the minimum value of tolerance is 0,005 mm.

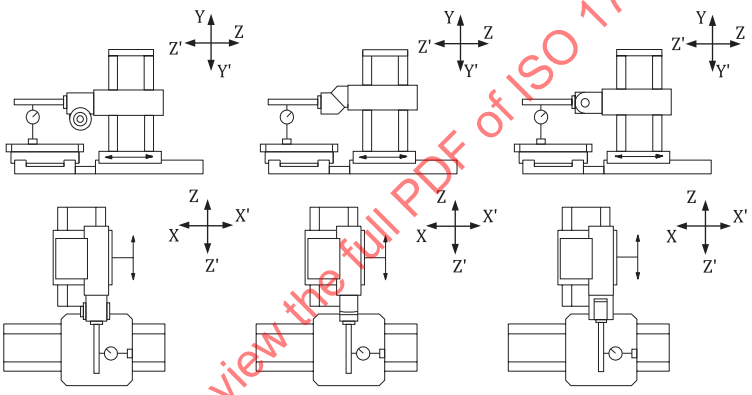
5 Common geometric tests for spindles of all types of heads

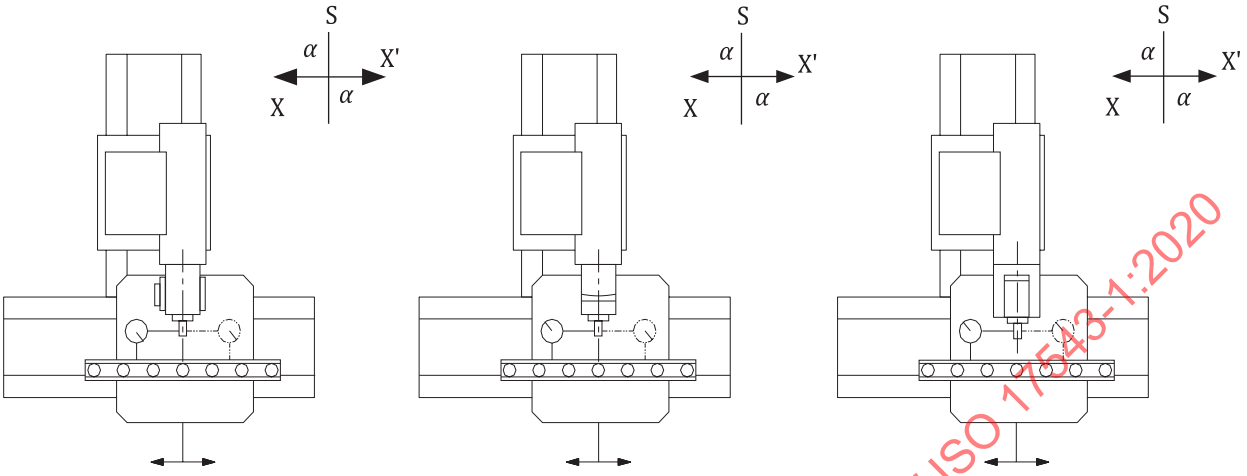
Object	**G1**
Checking of axial error motion of the spindle.	
Diagram 	
Tolerance 0,005	**Measured deviation**
Measuring instruments Dial gauge and precision sphere with special fixture.	
Observations and references to ISO 230-1:2012, 9.1 (see also ISO 230-7) This test shall be performed on all working spindles. NOTE See also test CR1 in Annex C.	

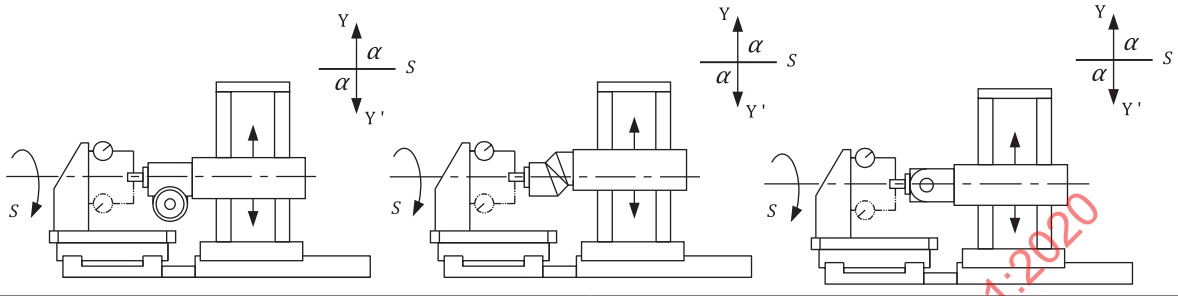
Object	**G2**
Checking of run-out of internal taper of the spindle: a) as close as possible to the spindle nose; b) at a distance of 250 mm from the first measuring position in a).	
Diagram  	
Tolerance a) 0,010 b) 0,020	**Measured deviation** a) b)
Measuring instruments Test mandrel and dial gauge.	
Observations and references to ISO 230-1:2012, 12.5.3 This test shall be performed on all working spindles. NOTE See also test CR1 in Annex C.	

6 Geometric tests for all types of spindle heads

In the following test descriptions, diagrams are provided for square heads, 45° split heads and swivelling heads. Similar setups are used for swivelling heads and tilting heads. Most tests are applicable to all types of heads. Few exceptions are mentioned in the relevant objects.

Object	**G3**
Checking of parallelism of the spindle axis S in the horizontal longitudinal orientation to the Z-axis motion: a) in the vertical YZ plane $E_{A(0Z)SPINDLE}$; b) in the horizontal ZX plane $E_{B(0Z)SPINDLE}$. (This test is applicable to universal heads non-rotating around the C-axis, and is not applicable to heads in Figure 1. For spindle heads capable of rotating 360° around the C-axis, test G13 applies).	
Diagram **a)** **b)** 	
Tolerance For a) and b) 0,100/1 000 (0,025/250)	**Measured deviation** a) b)
Measuring instruments Test mandrel and dial gauge.	
Observations and references to ISO 230-1:2012, 10.1.4 and 10.1.4.3 For a), Y-axis to be locked, if possible. For b), X-axis to be locked, if possible. The orientation of the deviation of the spindle axis S to the Z-axis, in both planes, shall be noted. For tilting heads, the result of test a) includes the possible E_{AA} positioning deviation of the A-axis at 0°.	

Object	**G4**
Checking of squareness of the spindle axis S in the horizontal longitudinal orientation to the X-axis motion $E_{B(0X)SPINDLE}$ (not applicable to universal heads in Figure 1).	
Diagram	
	
Tolerance 0,100/1 000 (0,025/250)	**Measured deviation**
Measuring instruments Straightedge, special arm and dial gauge.	
Observations and references to ISO 230-1:2012, 10.3 and 10.3.3 Z-axis to be locked, if possible. Set the straightedge parallel to the X-axis, or the lack of parallelism shall be considered in the measurement. Set the dial gauge on the special arm mounted to the spindle. Touch the reference surface of the straightedge by the dial gauge stylus and zero the dial gauge. Then, rotate the spindle until the stylus touches the reference face of the straightedge again. The difference between the two readings divided by the distance between the two measuring points is the squareness error. The special arm shall be stiff enough so as to prevent any possible reading errors due to its opposite deflections in the two measurement positions. Alternatively, this test can be carried out without the straightedge, with only one gauge block in the centre of the table. The dial gauge shall touch the same point of the gauge block before and after rotating the spindle through 180° and moving the X-axis through the necessary travel. The value of angle α, being less than, equal to or greater than 90° shall be noted.	

Object	**G5**
Checking of squareness of the spindle axis S in the horizontal orientation to the Y-axis motion $E_{A(0Y)SPINDLE}$ (not applicable to universal heads in Figure 1).	
Diagram	
	
Tolerance 0,100/1 000 (0,025/250)	**Measured deviation**
Measuring instruments Square, special arm and dial gauge.	
Observations and references to ISO 230-1:2012, 10.3 and 10.3.3 Z-axis to be locked, if possible. The measurement side of the square or cylindrical square should be set parallel to the Y-axis, or the lack of parallelism shall be taken into account in the measurement. Set the dial gauge on the special arm mounted to the spindle. Touch the measurement side of the square by the dial gauge stylus and zero the dial gauge. Then, rotate the spindle until the stylus touches the measurement side of the square again. The difference between the two readings divided by the distance between the two measuring points is the squareness error. The special arm shall be stiff enough so as to prevent any possible reading errors due to its opposite deflections in the two measurement positions. Alternatively, the dial gauge shall touch the same point of the square or cylindrical square before and after rotating the spindle through 180° and moving the Y-axis through the necessary travel. The value of angle, α, being less than, equal to or greater than 90°, shall be noted. For swivelling heads and tilting heads, the result of this test includes the possible E_{AA} positioning deviation of the A-axis at 0°.	

Object	**G6**

Checking of parallelism of the spindle axis S in either of the two vertical orientations (upward and downward) to the Y-axis motion:

a) with the spindle in the downward orientation:

1) in the vertical XY plane $E_{C(0Y)SPINDLE,\ DOWNWARD}$;

2) in the vertical YZ plane $E_{A(0Y)SPINDLE,\ DOWNWARD}$;

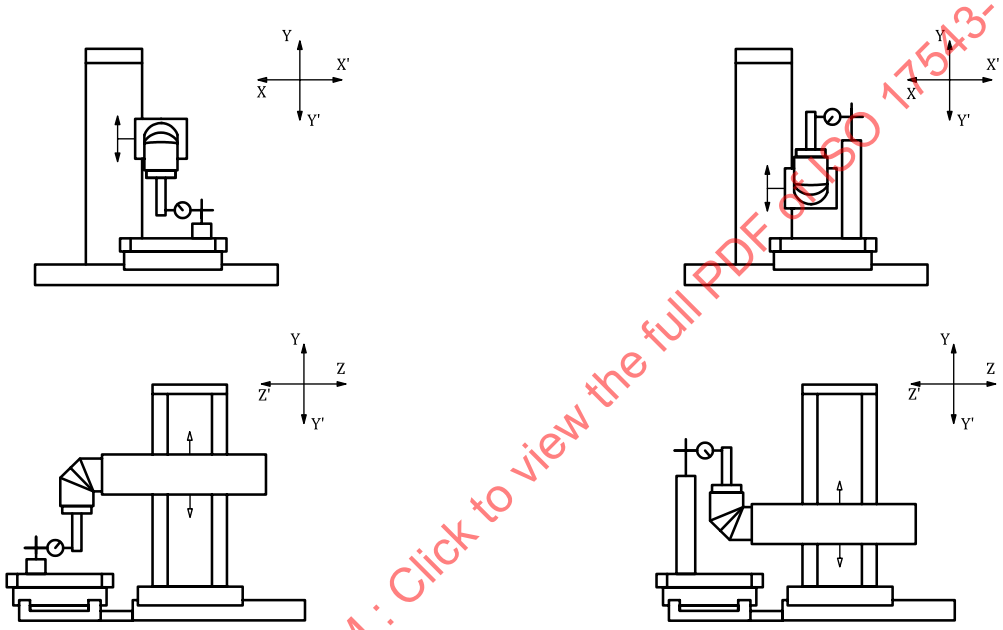
b) with the spindle in the upward orientation:

1) in the vertical XY plane $E_{C(0Y)SPINDLE,\ UPWARD}$;

2) in the vertical YZ plane $E_{A(0Y)SPINDLE,\ UPWARD}$.

(Not applicable to heads where the spindle cannot be oriented parallel to the Y-axis)

Diagram



a) **b)**

Tolerance	**Measured deviation**	
For a) and b)	a1)	b1)
0,100/1 000 (0,025/250)	a2)	b2)

Measuring instruments

Test mandrel and dial gauge.

Observations and references to ISO 230-1:2012, 10.1.4 and 10.1.4.3

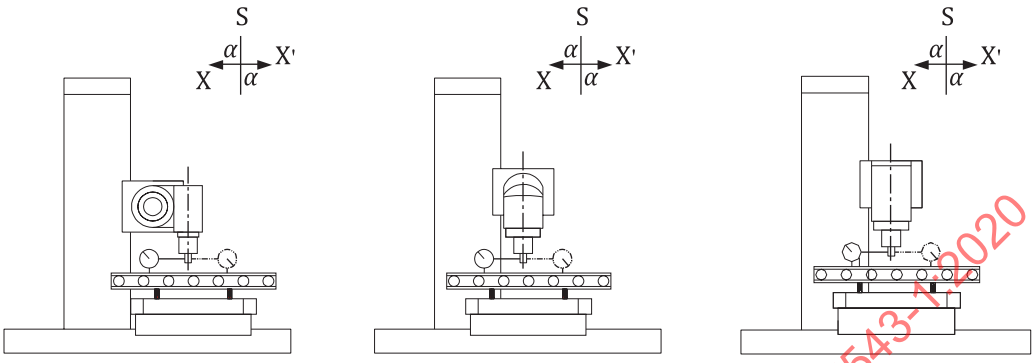
For a1) and b1), X-axis to be locked, if possible.

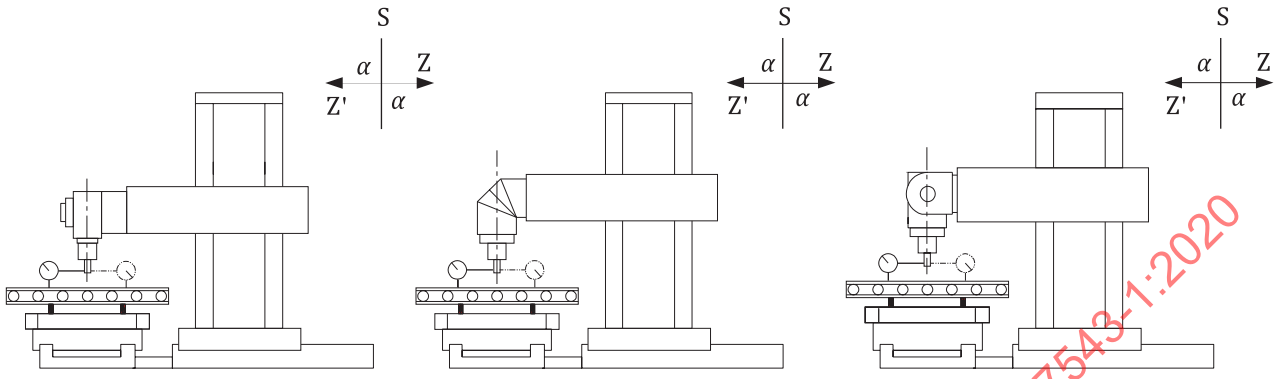
For a2) and b2), Z-axis to be locked, if possible.

The orientation of the deviation of the spindle axis S to the Y-axis, in both positions and in both planes, shall be noted.

For swivelling heads, the result of tests a1) and b1) includes the possible E_{CC} positioning deviation of the C-axis at 0°. For swivelling and tilting heads, the result of tests a2) and b2) includes the possible E_{AA} positioning deviation of the A-axis at –90°.

For swivelling heads, the upward and downward orientation of the spindle can be reached by two combinations of the A- and C-axis. Both combinations shall be checked.

Object	**G7**
Checking of squareness of the spindle axis S in vertical downward orientation to the X-axis motion $E_{C(0X)SPINDLE,\ DOWNWARD}$.	
Diagram	
	
Tolerance 0,100/1 000 (0,025/250)	**Measured deviation**
Measuring instruments Straightedge, special arm and dial gauge.	
Observations and references to ISO 230-1:2012, 10.3 and 10.3.3 Y-axis to be locked, if possible. Set the straightedge parallel to the X-axis, or the lack of parallelism shall be considered in the measurement. Set the dial gauge on the special arm mounted to the spindle. Touch the reference surface of the straightedge by the dial gauge stylus and zero the dial gauge. Then, rotate the spindle until the stylus touches the reference face of the straightedge again. The difference between the two readings divided by the distance between the two measuring points is the squareness error. The special arm shall be stiff enough so as to prevent any possible reading errors due to its deflections in the two measurement positions. Alternatively, this test can be carried out without the straightedge, with only one gauge block in the centre of the table. The dial gauge shall touch the same point of the gauge block before and after rotating the spindle through 180° and moving the X-axis through the necessary travel. The value of angle, α, being less than, equal to or greater than 90°, shall be noted. For continuous heads (both 45° split and swivelling heads), the result of this test includes the possible E_{CC} positioning deviation of the C-axis at 0°. For swivelling heads, the downward orientation of the spindle can be reached by two combinations of the A- and C-axis. Both combinations shall be checked.	

Object	**G8**
Checking of squareness of the spindle axis S in downward orientation to the Z-axis motion $E_{A(0Z)}$ SPINDLE, DOWNWARD·	
Diagram  	
Tolerance 0,100/1 000 (0,025/250)	**Measured deviation**
Measuring instruments Straightedge, special arm and dial gauge.	
Observations and references to ISO 230-1:2012, 10.3 and 10.3.3 Y-axis to be locked, if possible. The straightedge shall be set parallel to the Z-axis, or the lack of parallelism shall be considered in the measurement. Set the dial gauge on the special arm mounted to the spindle. Touch the surface of the straightedge by the dial gauge stylus and zero the dial gauge. Then, rotate the spindle until the stylus touches the reference face of the straightedge again. The difference between the two readings divided by the distance between the two measuring points is the squareness error. The special arm shall be stiff enough so as to prevent any possible reading errors due to its deflections in the two measurement positions. Alternatively, this test can be carried out without the straightedge, with only one gauge block on the table, approximately in the centre of the Z-axis travel. The dial gauge shall touch the same point of the gauge block before and after rotating the spindle through 180° and moving the Z-axis through the necessary travel. The value of angle, α, being less than, equal to or greater than 90°, shall be noted. For swivelling heads and tilting heads, the result of this test includes the possible E_{AA} positioning deviation of the A-axis at –90°. For swivelling heads, the downward orientation of the spindle can be reached by two combinations of the A- and C-axis. Both combinations shall be checked.	

Object	**G9**

Checking of parallelism of the spindle axis S in either of the two horizontal orientations along the X-direction to the X-axis motion:

a) with the spindle in the left position:

   1) in the vertical XY plane $E_{C(0X)SPINDLE,\ LEFT}$;

   2) in the horizontal ZX plane $E_{B(0X)SPINDLE,\ LEFT}$;

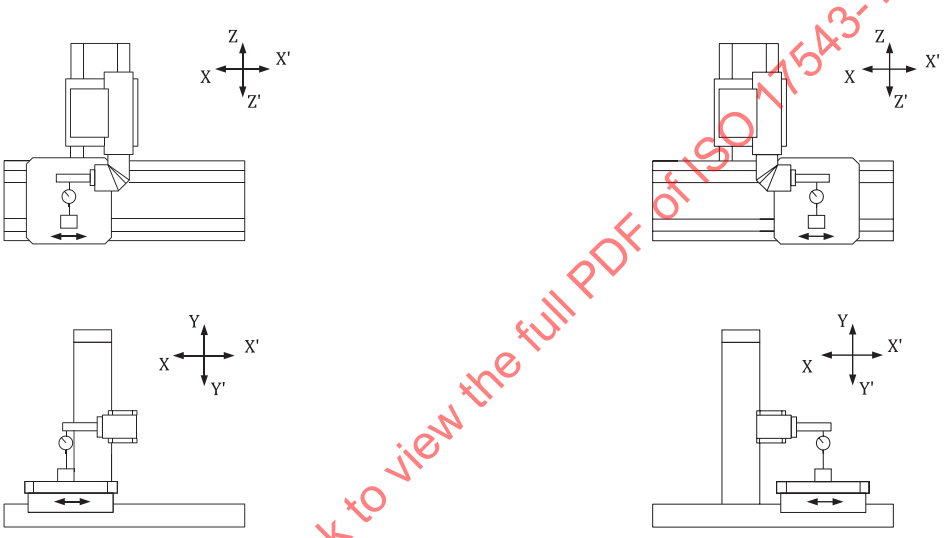
b) with the spindle in the right position:

   1) in the vertical XY plane $E_{C(0X)SPINDLE,\ RIGHT}$;

   2) in the horizontal ZX plane $E_{B(0X)SPINDLE,\ RIGHT}$.

(Not applicable to heads in Figure 6, where the spindle cannot be oriented parallel to the X-axis)

Diagram



a) **b)**

Tolerance	**Measured deviation**	
For a) and b)	a1)	b1)
0,100/1 000 (0,025/250)	a2)	b2)

Measuring instruments

Test mandrel and dial gauge.

Observations and references to ISO 230-1:2012, 10.1.4 and 10.1.4.3

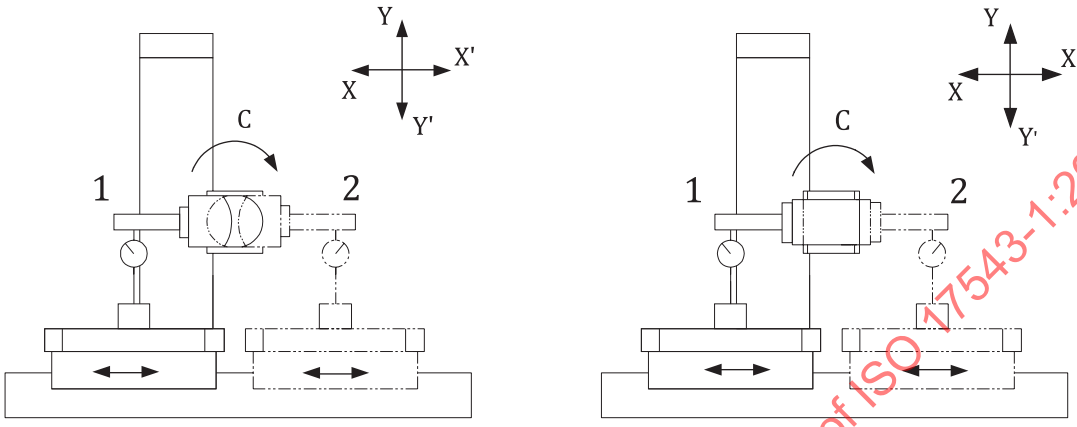
This test is also applicable to square heads if they can be rotated by an angle sufficient to bring the cross-spindle axis to be parallel to the X-axis on both sides.

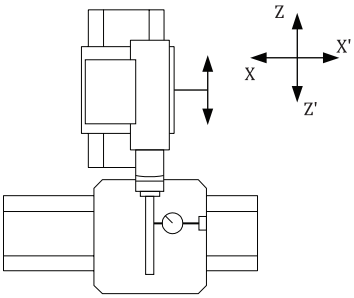
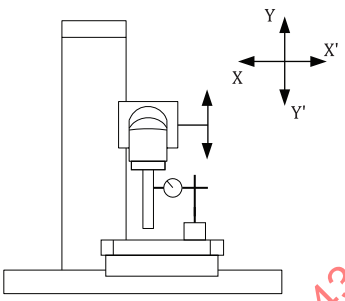
Set the C-axis and the D- or A-axis in the angular position orienting the spindle horizontally, parallel to the X-axis. Between position a) and position b) the C-axis shall be rotated 180°; the D- or A-axis shall not be moved.

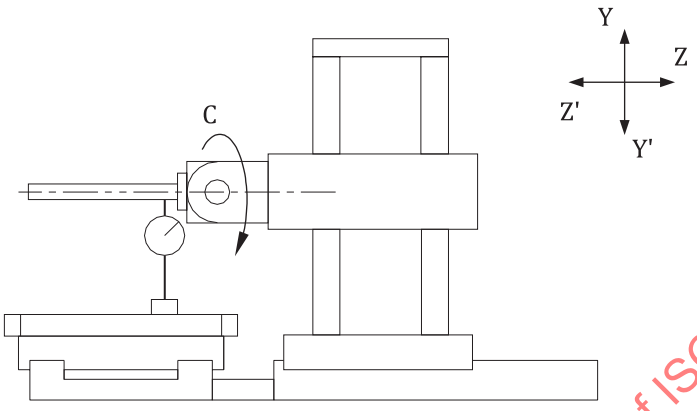
For a1) and b1), Y-axis to be locked, if possible.

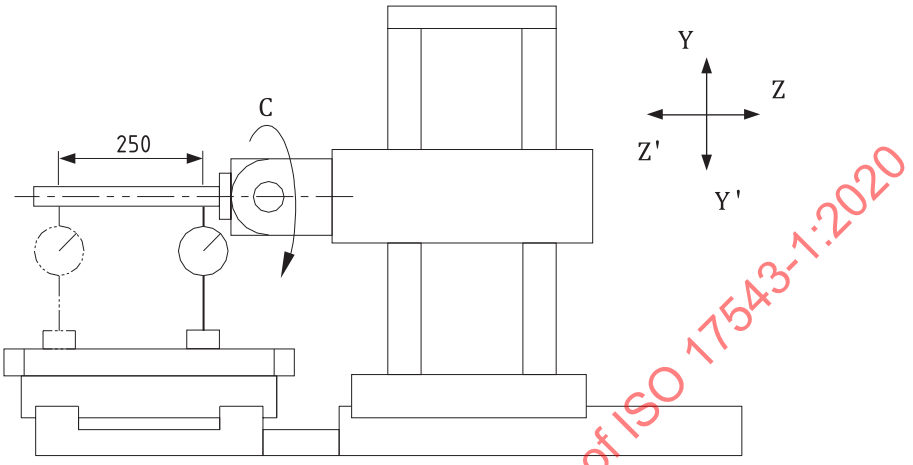
For a2) and b2), Z-axis to be locked, if possible.

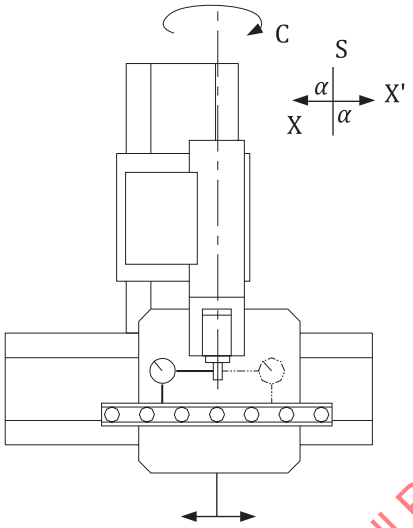
The orientation of the deviation of the spindle axis S to the X-axis, in both positions and in both planes, shall be noted. For continuous heads (both 45° split and swivelling heads), the result of this test includes the possible E_{CC} positioning deviation of the C-axis at 0°.

Object	**G10**
Checking of difference in the Y-direction between the spindle heights in the two horizontal orientations in the X-direction. (Not applicable to universal heads in Figure 6, where the spindle cannot be oriented parallel to the X-axis)	
Diagram  **Key** 1 left position 2 right position	
Tolerance 0,030	**Measured deviation**
Measuring instruments Test mandrel and dial gauge.	
Observations and references to ISO 230-1 This test is also applicable to square heads if they can be rotated by an angle sufficient to bring the cross-spindle axis to be parallel to the X-axis on both sides. Step 1: Set the C-axis and the D- or A-axis in the angular position orienting the spindle horizontally, parallel to the X-axis. Zero the dial gauge. Step 2: Drive away the head by means of movements along X- and Z-axes only, in order to avoid interferences with the dial gauge. Rotate the C-axis 180° without moving the D- or A-axis and again bring the test mandrel into contact with the dial gauge by means of X- and Z-axes movements. Without resetting the dial gauge, again adjust the C-axis until the test mandrel is parallel to the X-axis on the other side. The new reading is the deviation to be reported. This test may be performed with and/or without offset compensation, according to the purpose of the test, for: — square heads in Figure 1; — two-spindle square heads in Figure 2, if the head is designed with two coplanar spindles; and — 45° split heads in Figure 3. If the cross-spindle axis of a square head is not coplanar with the head axis of rotation, this test can only be performed with the offset compensation on.	

Object	**G11**
For 45° split heads — Checking that the spindle axis S and the rotary D-axis (45° oriented) lie in the same YZ plane	
Diagram Step 1)  Step 2) 	
Tolerance 0,020	**Measured deviation**
Measuring instruments Test mandrel and dial gauge.	
Observations and references to ISO 230-1 X-axis to be locked, if possible. Step 1: Set the spindle in horizontal position along the Z-direction. Place the dial gauge on the table, and then zero the dial gauge touching the test mandrel close to the spindle nose. Step 2: In order to avoid interferences with the dial gauge, drive away the head by means of movements along Y- and Z-axis only. Rotate the D-axis in order to set the spindle axis in vertical position, and again bring the test mandrel into contact with the dial gauge by means of Y- and Z-axis movements. When the movements in Step 2 have been completed, half of the reading on the dial gauge is the deviation to be reported. This deviation can be obtained performing test G6 a1) after G3 b) without moving X-axis and without resetting the dial gauge.	

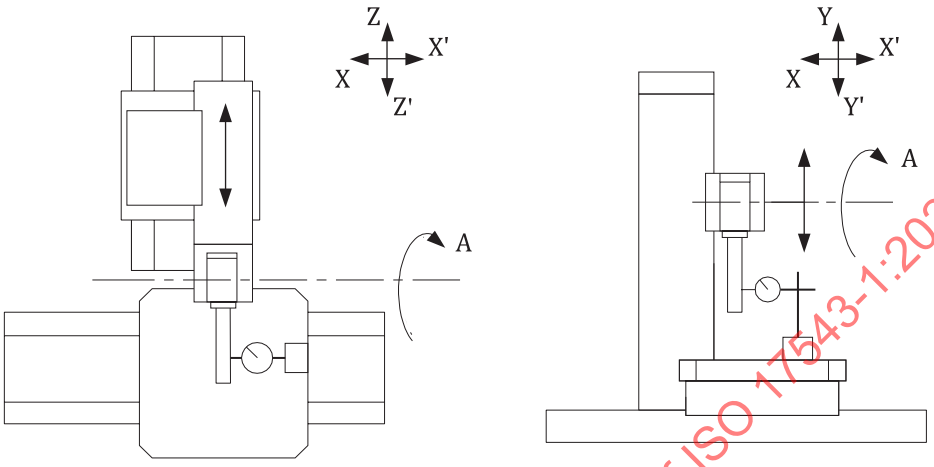
Object	**G12**
Checking of the overall deviation of coaxiality of the spindle axis S to the C-axis during the rotation of the C-axis, measured close to the spindle nose. (Only applicable to swivelling heads without built-in spindle offset, and not applicable to tilting heads in Figure 6, where the head cannot rotate around a C-axis)	
Diagram 	
Tolerance 0,040	**Measured deviation**
Measuring instruments Test mandrel and dial gauge.	
Observations and references to ISO 230-1:2012,10.2 Y-axis to be locked, if possible. Carry out the following steps: Step 1: Turn the spindle head (A-axis) in longitudinal direction and adjust the A-axis until the test mandrel is parallel to the Z-axis in the vertical YZ plane. Step 2: Zero the dial gauge close to the spindle nose. Step 3: Rotate slowly the spindle and note the average reading of the dial gauge (in order to by-pass the spindle run-out) and the angular position of the C-axis. Step 4: Rotate the yoke (C-axis) 90° and repeat Step 3. After taking the four readings every 90°, the algebraic difference between the maximum and the minimum reading is the deviation to be reported. NOTE 1 During the rotation of the C-axis, when the A-axis is vertical, in two positions at 180° from each other, readings are affected by the deviations measured in BG8 a). NOTE 2 Similarly, when the A-axis is horizontal, in two positions at 180° from each other, readings are affected by the deviations measured in BG8 b), i.e. BG6 and BG7.	

Object	**G13**
Checking of the maximum deviation of parallelism of the spindle axis S to the C-axis during the rotation of the C-axis. (Not applicable to heads in Figure 6, where the head cannot rotate around a C-axis)	
Diagram 	
Tolerance 0,160/1 000 (0,040/250)	**Measured deviation**
Measuring instruments Test mandrel and dial gauge.	
Observations and references to ISO 230-1:2012, 10.1 and 10.1.5 Y-axis to be locked, if possible. Carry out the following steps. Step 1: Turn the spindle head (A-axis) in longitudinal direction and adjust the A-axis until the test mandrel is parallel to the Z-axis in the vertical YZ plane. Step 2: Zero the dial gauge in a position close to the spindle nose. Step 3: Rotating slowly the spindle, take the average reading of the dial gauge (in order to by-pass the spindle run-out) close to the spindle nose and at 250 mm distance from the previous reading. Note the parallelism deviation and its direction and the angular position of the C-axis (after adjusting the A-axis in Step 1, the first parallelism deviation can be negligible). Step 4: Rotate the yoke (C-axis) 90° without moving the A-axis and repeat Step 3. The maximum of these four results, divided by the distance between the two measuring points (250 mm), is the deviation to be reported. NOTE During the rotation of the C-axis, when the A-axis is vertical, in two positions at 180° from each other, readings are affected by the deviations measured in BG4 and BG5.	

Object	**G14**
Checking of the maximum deviation of squareness of the spindle axis S to the X-axis during the rotation of the C-axis. (This test is only applicable to universal heads where one spindle is oriented, or can be oriented, parallel to the Z-axis and the C-axis can rotate 360°)	
Diagram  	
Tolerance 0,100/1 000 (0,050/500)	**Measured deviation**
Measuring instruments Straightedge, dial gauge and special arm.	
Observations and references to ISO 230-1:2012, 10.3 and 10.3.3 Z-axis to be locked, if possible. The straightedge shall be set parallel to the X-axis, or the lack of parallelism shall be considered in the measurement. Step 1: Adjust the concerned axes in order to orient the spindle axis S parallel to the Z-axis. Step 2: Set the dial gauge on the special arm mounted to the spindle. Touch the reference surface of the straightedge by the dial gauge stylus and zero the dial gauge. Then rotate the spindle until the stylus touches the reference face of the straightedge again. The difference between the two readings divided by the distance between the two measuring points is the squareness error. Note the direction of the deviation and the angular position of the C-axis. The special arm shall be stiff enough so as to prevent any possible reading errors due to its opposite deflections in the two measurement positions. Step 3: Rotate the C-axis 90° without moving any other rotary axis, and repeat Step 2. If there is an in-built offset between the spindle axis S and the C-axis, additional movements of the Y-axis can be necessary for touching the same measuring points. The maximum absolute value of the four deviations, divided by the distance between two measuring points, is the deviation to be reported. Alternatively, this test can be carried out without the straightedge, with only one gauge block (or a cylindrical square for avoiding sharp edges) in the centre of the table. The dial gauge shall touch the same point of the gauge block (or cylindrical square) before and after rotating the spindle through 180° and moving the X-axis through the necessary travel.	

Object	**G15**
For swivelling heads and tilting heads. Checking of parallelism of the spindle axis S to the YZ plane in several positions of the A-axis.	

Diagram



Tolerance	**Measured deviation**
0,080/1 000 (0,020/250)	

Measuring instruments

Test mandrel and dial gauge.

Observations and references to ISO 230-1

X-axis to be locked, if possible.

Step 1: Set the spindle in horizontal position along the Z-direction. Zero the dial gauge touching the test mandrel close to the spindle nose, with the dial gauge oriented in the X-direction. Lock the dial gauge on the table. Measure the parallelism of the spindle axis S to the Z-axis in the horizontal plane, in two points on the test mandrel 250 mm apart from each other. Mark the two points on the test mandrel.

Step 2: In order to avoid interferences with the dial gauge, drive away the head by means of movements along Y- and Z-axes only. Rotate the A-axis through an angle not exceeding 30° or providing a minimum number of five measurement positions and check again the parallelism without moving the X-axis, without resetting the dial gauge and touching again the test mandrel in the same points.

Step 3: Repeat the same check, up to the vertical position of the spindle axis.

The algebraic difference between the maximum and the minimum deviation among all the angular positions of the A-axis, divided by the distance between the two measuring points (250 mm), is the deviation to be reported.

If test G15 is to be performed, its readings in the extreme horizontal and vertical position of the A-axis provide the deviations to be reported for tests G3 b) and G6 a1).

Object	**G16**

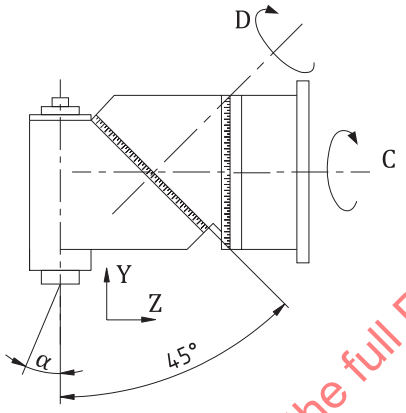
For 45° split continuous heads.

Checking of parallelism of the spindle axis S to the YZ plane in four positions of the path described by angular interpolation of the C- and D-axes, according to the following formula:

$$\tan C = \frac{\sqrt{2}\sin D}{1+\cos D}$$

a)	b)	c)	d)
$C = 0°$	$C = 54° 44' 8"$	$C = 74° 27' 28"$	$C = 90°$
$D = 0°$	$D = 90°$	$D = 137° 3' 31"$	$D = 180°$
$\alpha = 0$	$\alpha = 30°$	$\alpha = 60°$	$\alpha = 90°$

Diagram



Tolerance

To be agreed between the supplier/manufacturer and the user.

a)	b)	c)	d)

Measured deviation

a)	b)	c)	d)

Measuring instruments

Test mandrel and dial gauge.

Observations and references to ISO 230-1:2012, 12.3.2.4

X-axis to be locked, if possible.

Check a) before starting the movement, with two readings, respectively close to the spindle nose and at a distance of 250 mm, rotating slowly the spindle so as to stop it in the average position of the run-out.

Mark the angular position on the mandrel.

Then start the movement and stop at the programmed positions.

In all b), c) and d) angular positions, touch the test mandrel close to the spindle nose in the same point previously marked. Lock the X-axis, if possible, and zero the dial gauge. Moving Y- and Z-axes only, touch the test mandrel at 250 mm from the spindle nose and note the deviation.

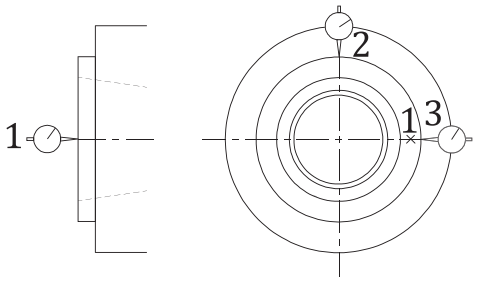
NOTE In the above Object and Diagram the case is shown where the 0° positions of the C- and D-axes are those where the spindle axis starting position is vertical, and α is the angle between the spindle axis S and the Y-axis in the vertical YZ plane.

Object | **G17**

Checking of repeatability of positioning of the tool holding spindle after repeated automatic spindle head changes, measured in the radial and axial direction on the spindle nose of the accessory head.

To be applied to each individual spindle head.

Diagram



Key

1 dial gauge for the axial readings

2, 3 dial gauges for the radial readings

Tolerance

For all measurement positions 0,030

Measured deviation

Spindle orientation	According to the spindle orientation during the test, mark with an asterisk the axis (X, Y or Z) parallel to the spindle axis		
A or D (°)			
C (°)			
Deviations (µm)	X	Y	Z
1			
2			
3			
4			
5			
Range (max-min)			

Measuring instruments

Dial gauges.

Observations and references to ISO 230-1

This test shall be performed on all types of accessory spindle heads which can be automatically changed from a head store.

Step 1: Place three dial gauges on the table, and set the styli of the dial gauges in directions parallel to the three coordinate axes. Zero the dial gauges with the head clamped.

Step 2: Drive the head apart from the dial gauges with a diagonal movement of the linear axes.

Step 3: Unclamp the head and store it in the head store, move back the linear axes to the original position (where the dial gauges have been zeroed) without head, and then pick up again the head from the store, clamping it onto the machine.

Step 4) Move back the linear axes to the original position (where the dial gauges have been zeroed) in order to bring again the spindle into contact with the dial gauges and note the readings.

Step 5) Take five consecutive sets of readings repeating steps 2), 3) and 4).

For each dial gauge, the algebraic difference between maximum and minimum reading is the deviation to be reported. The readings include the repeatability of the linear axes involved.

7 Angular positioning tests

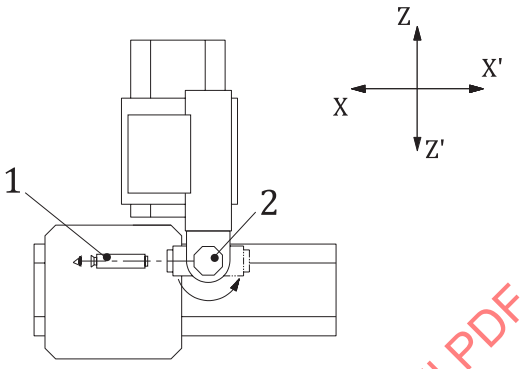
The tests are only applied to accessory heads numerically controlled for rotary positioning axes. To apply the tests, reference should be made to ISO 230-2, especially for the environmental conditions, warming up of the machine, measuring methods, evaluation and interpretation of the results.

Object | **P1**

Checking of accuracy and repeatability of angular positioning of all rotary axes of spindle heads (A-axis or D-axis), head bases and yokes (C-axis) by numerical control:

NOTE This test applies to all rotary axes associated with the spindle head.

Diagram



Key

1 autocollimator

2 optical polygon

Tolerance (30° or 45° interval positioning)		**For angles ≤360°**		**Measured deviation**
		arcsec-onds	degrees	
Bi-directional positioning error	$E_{CC,A}$	22	≈0,006	
Unidirectional positioning repeatability	$E_{CC,R\uparrow}$ or $E_{CC,R\downarrow}$	11	≈0,003	
Bi-directional positioning repeatability	$E_{CC,R}$	15	≈0,004	
Mean reversal error	$E_{CC,\bar{B}}$	4	≈0,001	
Bi-directional systematic positioning error[a]	$E_{CC,E}$	15	≈0,004	
Mean bi-directional positioning error[a]	$E_{CC,M}$	7	≈0,002	

[a] Can provide a basis for machine acceptance.

Measuring instruments

Optical polygon and autocollimator or laser measuring equipment.

Observations and references to ISO 230-2:2014, 5.3.4

Fix the autocollimator on the machine tool table and fix the optical polygon on the axis of rotation, in alignment with the autocollimator at the first measuring rotary position.

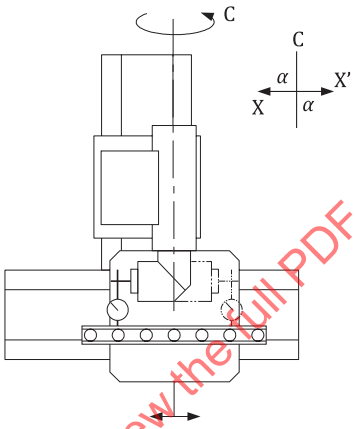
Target position shall be 30° or 45° intervals or selected according to ISO 230-2.

Angular positioning feed rate may be rapid feed, provided it does not affect the safe clamping of the reflector or optical polygon, but it may be any feed rate by agreement between user and supplier/ manufacturer.

Annex A
(informative)

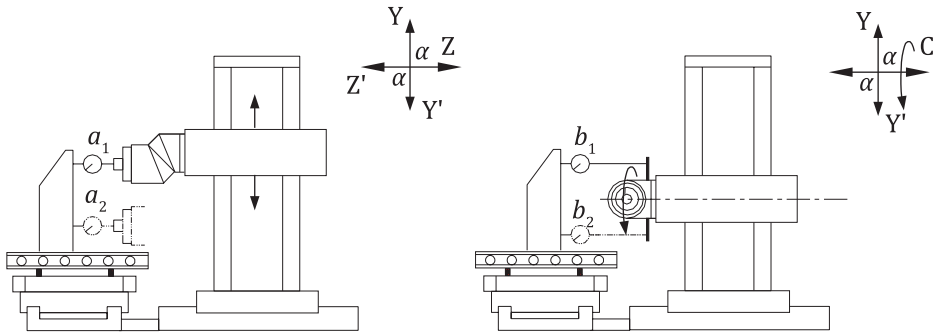
Supplementary geometric tests for 45° split continuous heads

In Figure 3, the 45° split head is shown.

Object	**AG1**
Checking of squareness of the C-axis (head base rotation) to the X-axis motion $E_{B(0X)C}$	
Diagram  	
Tolerance 0,060/1 000 (0,030/500)	**Measured deviation**
Measuring instruments Straightedge, dial gauge and special arm.	
Observations and references to ISO 230-1:2012, 10.3 and 10.3.3 Z-axis to be locked, if possible. D-axis in any angular position. The dial gauge shall be fixed to the spindle head and oriented in the Z-direction, with a known offset from the C-axis of the head base. Set the straightedge parallel to the X-axis, or the lack of parallelism shall be considered in the measurement. Set the dial gauge on the special arm mounted to the spindle, or the dial gauge may be mounted on the head base. Touch the reference surface of the straightedge by the dial gauge stylus and zero the dial gauge. Then, rotate the head base (C-axis) until the stylus touches the reference face of the straightedge again. The difference between the two readings divided by the distance between the two measuring points is the squareness error $E_{B(0X)C}$. Alternatively, this test can be carried out without the straightedge, with only one gauge block (or a cylindrical square for avoiding sharp edges) in the centre of the table. The dial gauge shall touch the same point of the gauge block before and after rotating the C-axis through 180° and moving the X-axis through the necessary travel. The value of angle, α, being less than, equal to or greater than 90°, shall be noted. The special arm shall be stiff enough so as to prevent any possible reading errors due to its opposite deflections in the two measurement positions. The X-axis position and the Y-axis position of the test shall be recorded.	

Object	**AG2**
Checking of squareness of the C-axis (head base rotation) to the Y-axis motion $E_{A(0Y)C}$.	

Diagram



Key

a_1, a_2, b_1, b_2 dial gauge readings

Tolerance	**Measured deviation**
0,060/1 000 (0,030/500)	

Measuring instruments

Straightedge, square, special arm and dial gauge.

Observations and references to ISO 230-1:2012, 10.3 and 10.3.3

Z-axis to be locked, if possible.

D-axis in any angular position. The dial gauge shall be fixed to the spindle head and oriented in the Z-direction, with a known offset from the C-axis of the head base.

Place a straightedge on the table and a square upon the straightedge:

Step 1: Measure the parallelism deviation $(a_1 - a_2) / L_b$ of the *Y*-axis to the vertical side of the square, and note it with its algebraic sign.

Step 2: Measure the squareness deviation $(b_1 - b_2) / L_b$ of the *C*-axis to the vertical side of the square, and note it with its algebraic sign. The dial gauge may be mounted on the head base.
If a special arm is used, it shall be stiff enough so as to prevent any possible reading errors due to its opposite deflections in the two measurement positions.

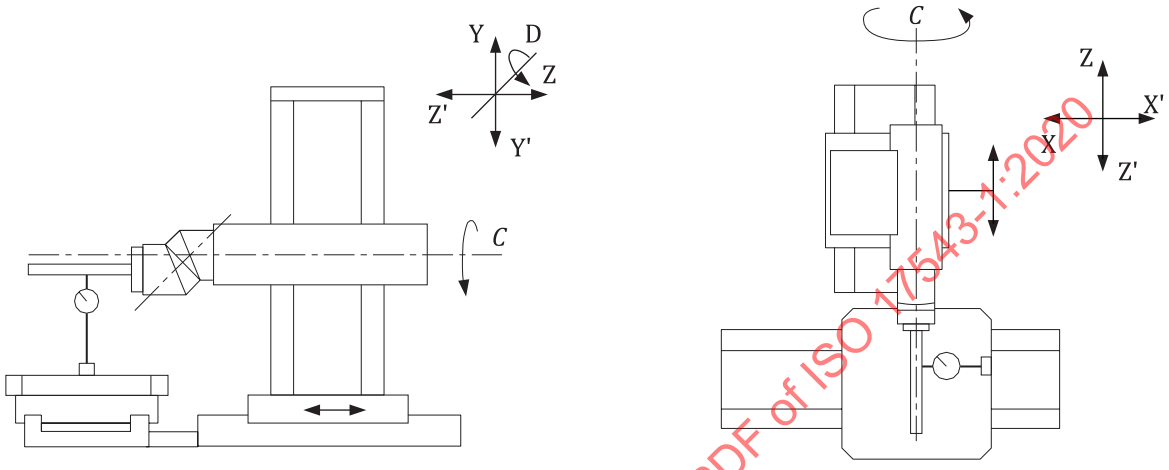
The difference $[(b_1 - b_2) - (a_1 - a_2)] / L_b$ is the deviation to be reported, where L_b is the distance between measurement points b_1 and b_2 as well as between a_1 and a_2.

The value of angle, α, being less than, equal to or greater than 90°, shall be noted.

If test AG5 is to be performed, test AG2 is better carried out after AG4 and AG5, without moving the square.

Object	**AG3**
Checking of parallelism of the C-axis (head base rotation) to the Z-axis motion: a) in the vertical YZ plane $E_{A(0Z)C}$; b) in the horizontal ZX plane $E_{B(0Z)C}$.	

Diagram



Tolerance	**Measured deviation**
For a) and b), 0,080/1 000 (0,020/250)	a) b)

Measuring instruments

Test mandrel and dial gauge.

Observations and references to ISO 230-1:2012, 10.1.4 and 10.1.4.3

This test can be performed only if the C-axis can rotate at least 180°.

For a), Y-axis to be locked, if possible.

For b), X-axis to be locked, if possible.

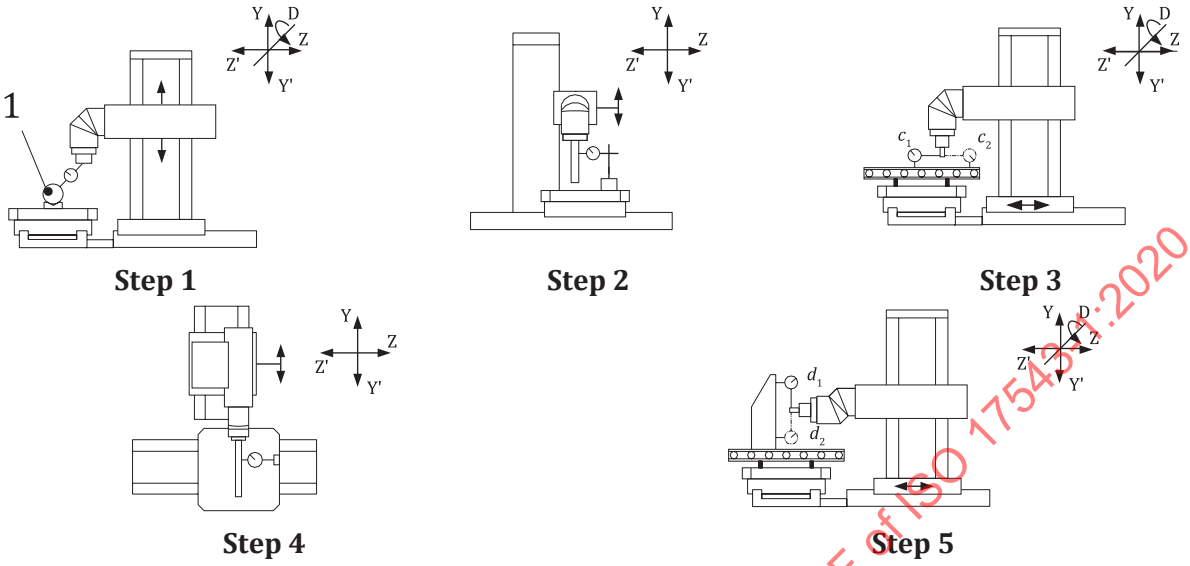
Set the D-axis in the position where the spindle is in the horizontal Z-direction. Check the parallelism of the spindle axis S to the Z-axis both in the vertical YZ plane and in the horizontal ZX plane.

Rotate the head base (C-axis) 180° without moving the D-axis, and again, measure the parallelism in the two planes.

In both planes, the mean value of the two deviations read before and after the 180° rotation is the deviation to be reported.

Object	**AG4**
Checking of accuracy of the 45° angle between the spindle axis S and the D-axis (head rotation).	

Diagram



Key

1 cylindrical square

c_1, c_2, d_1, d_2 dial gauge readings

Tolerance	**Measured deviation**
0,080/1 000 (0,020/250)	

Measuring instruments

V-blocks, cylindrical square, straightedge, square, test mandrel and dial gauge

Observations and references to ISO 230-1

Step 1: Align a cylindrical square parallel to the X-axis travel. Adjust the D-axis perpendicular to the X-axis by iteratively adjusting the head base (C-axis) and rotating the spindle head (D-axis) over 180° to swing the dial gauge across the cylinder at two points until the same reading is obtained. Lock the head base.

Step 2: Adjust the D-axis until the spindle head is in the vertical position with the spindle axis S parallel to the Y-axis in the XY plane.

Step 3: Measure the squareness deviation $(c_1 - c_2) / L_{cd}$ of the spindle axis S to a straightedge set parallel to the Z-axis and note it with its algebraic sign.

Step 4: Then adjust the D-axis until the spindle head is in the horizontal position with the spindle axis parallel to the Z-axis in the horizontal ZX plane.

Step 5: Measure the squareness deviation $(d_1 - d_2) / L_{cd}$ of the spindle axis S to a square placed on the straightedge and note it with its algebraic sign.

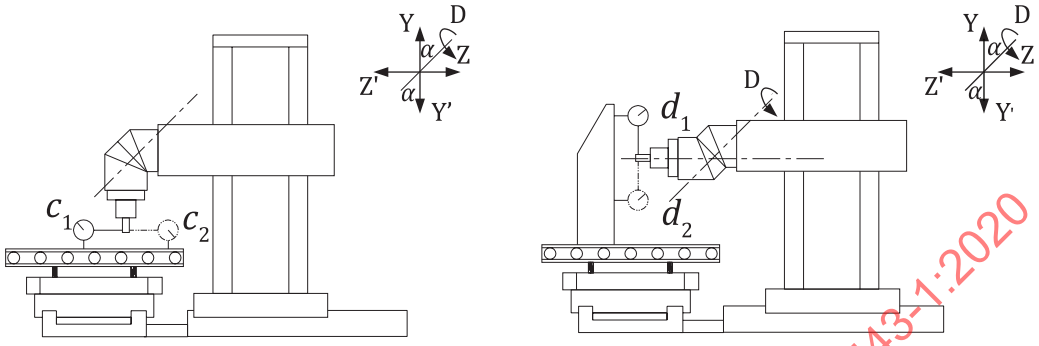
Half the algebraic difference between the readings in Step 3 and Step 5, i.e. $[(d_1 - d_2) - (c_1 - c_2)] / 2L_{cd}$, is the deviation to be reported, where L_{cd} is the distance between measurement points c_1 and c_2, the same as the distance between measurement points d_1 and d_2. This half algebraic difference shall not be confused with half the algebraic sum, which has a different meaning, and is needed for test AG5.

Value and sign of the deviation, making the angle less than, equal to or greater than 45°, shall be noted.

If Steps 3 and 5 are not in the same Z- and Y-positions, measurement results will be affected by E_{AY} and E_{AZ} deviations.

Object	**AG5**
Checking of accuracy of the 45° angle between the D-axis (head rotation) and the C-axis (head base rotation).	

Diagram



Key

c_1, c_2, d_1, d_2 dial gauge readings

Tolerance	**Measured deviation**
0,080/1 000 (0,020/250)	

Measuring instruments

Straightedge, square, cylindrical square and dial gauge.

Observations and references to ISO 230-1

Carry out all adjustments and readings of test AG4.

Half the algebraic sum (i.e. the average) of the readings in Step 3: and step 5), i.e. $[(d_1 - d_2) + (c_1 - c_2)] / 2L_{cd}$ shall be noted, with its algebraic sign.

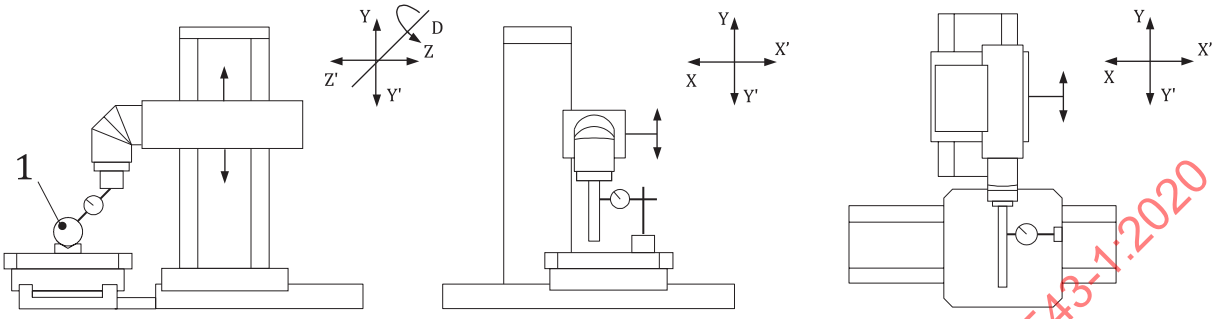
The difference between this average and the readings taken in AG2, i.e. $[(d_1 - d_2) + (c_1 - c_2)] / 2L_{cd} - [(b_1 - b_2) - (a_1 - a_2)] / L_b$ is the deviation to be reported, where L_{cd} is the distance between measurement points c_1 and c_2, the same as the distance between measurement points d_1 and d_2.

Value and sign of the deviation, making the angle less than, equal to or greater than 45°, shall be noted.

If test AG5 is to be performed, test AG2 is better carried out after AG4 and AG5, without moving the square.

Object	AG6
Checking the error of intersection between the spindle axis S and the D-axis (head rotation) (i.e. checking that the spindle axis S in the horizontal position and in the vertical position lie in the same vertical plane).	

Diagram



Step 1) **Step 2)** **Step 3)**

Key

1 cylindrical square

Tolerance	Measured deviation
0,020	

Measuring instruments

V-blocks, cylindrical square, test mandrel and dial gauge.

Observations and references to ISO 230-1

X-axis to be locked, if possible.

Step 1: Adjust the head base (C-axis) as in Step 1 in test AG4.

Step 2: Adjust the D-axis until the spindle head is in the vertical position with the spindle axis S parallel to the Y-axis in the XY plane (same as in Step 2 in test AG4). Zero the dial gauge.

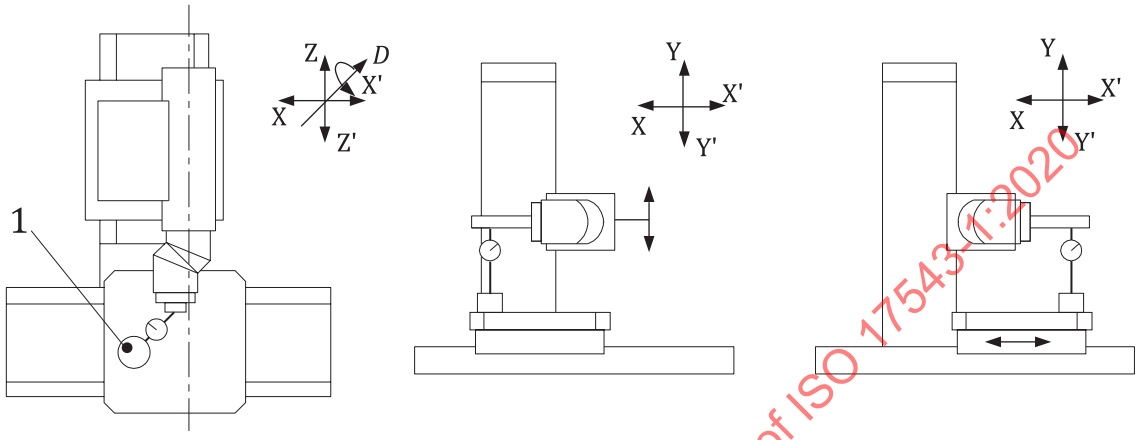
Step 3: Adjust the D-axis until the spindle head is in the horizontal position with the spindle axis S parallel to the Z-axis in the horizontal ZX plane (same as in Step 4 in test AG4), without resetting the dial gauge and only moving Y- and Z-axis.

When the adjustment in Step 3 has been completed, half of the reading on the dial gauge is the deviation to be reported. Note carefully the direction of the deviation, because it is one of the components of deviation AG7.

This test may be performed with and/or without offset compensation, according to the purpose of the test.

Object	**AG7**
Checking the error of intersection between the D-axis (head rotation) and the C-axis (head base rotation) (i.e. checking that the spindle axis S on the right side and on the left side lie in the same horizontal plane).	

Diagram



Step 1) **Step 2)** **Step 3)**

Key

1 cylindrical square

Tolerance	**Measured deviation**
0,020	

Measuring instruments

Cylindrical square, test mandrel and dial gauge.

Observations and references to ISO 230-1

Step 1: Align a cylindrical square parallel to the Y-axis travel. Adjust the D-axis perpendicular to the Y-axis by iteratively adjusting the head base (C-axis) and rotating the spindle head (D-axis) over 180° to swing the dial gauge across the cylindrical square at two points until the same reading is obtained. Lock the head base.

Step 2: Adjust the spindle head (D-axis) until the spindle axis S is parallel to the X-axis in the vertical XY plane. Zero the dial gauge and lock Y-axis, if possible.

Step 3: Rotate the head base (C-axis) 180° and adjust it until the spindle is parallel to the X-axis on the other side, without resetting the dial gauge and only moving X- and Z-axes.

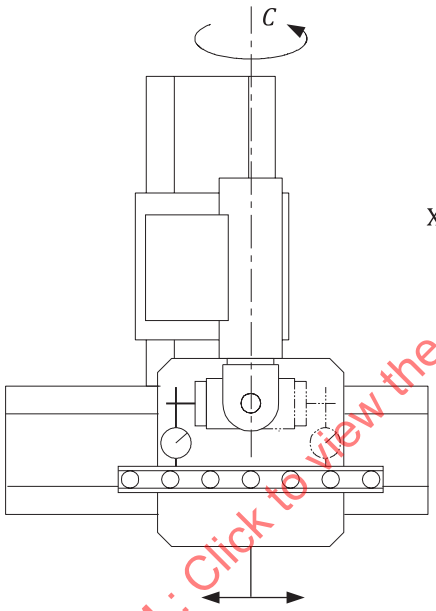
Half of the reading on the dial gauge equals the algebraic sum of the deviation to be reported for this test and the deviation to be reported for test AG6.

This test may be performed with and/or without offset compensation, according to the purpose of the test.

Annex B
(informative)

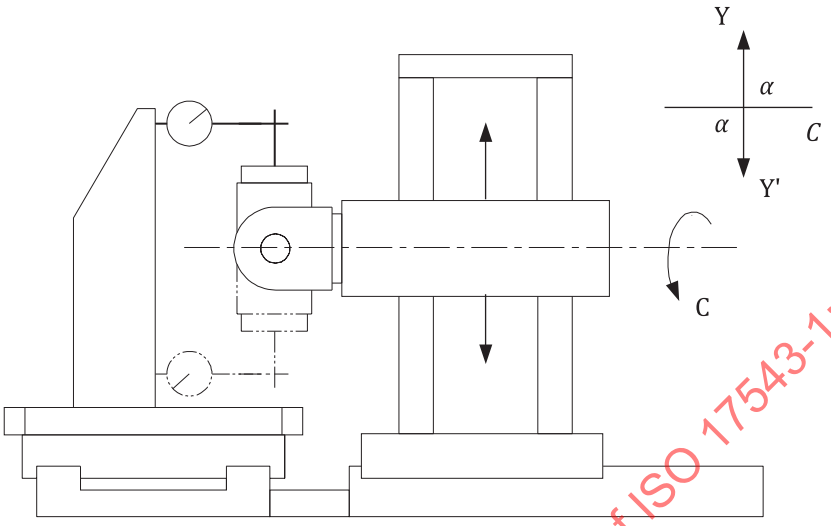
Supplementary geometric tests for swivelling heads

In Figures 4 and 5, the swivelling head with and without spindle offset are shown.

Object	**BG1**
Checking of squareness of the C-axis (yoke rotation) to the X-axis motion $E_{B(0X)C}$.	
Diagram 	
Tolerance 0,040/1 000 (0,020/500)	**Measured deviation**
Measuring instruments Straightedge, or gauge block, dial gauge and special arm.	
Observations and references to ISO 230-1:2012, 10.3 and 10.3.3 Z-axis to be locked, if possible. Set the straightedge parallel to the X-axis, or the lack of parallelism shall be considered in the measurement. Set the dial gauge on the special arm mounted to the spindle, or the dial gauge may be mounted on the head base. Touch the reference surface of the straightedge by the dial gauge stylus and zero the dial gauge. Then, rotate the head base (C-axis) until the stylus touches the reference face of the straightedge again. The difference between the two readings divided by the distance between the two measuring points is the squareness error. Alternatively, this test can be carried out without the straightedge, with only one gauge block in the centre of the table. The dial gauge shall touch the same point of the gauge block before and after rotating the yoke (C-axis) through 180° and moving the X-axis through the necessary travel. The dial gauge may be mounted either on the yoke body or on the spindle head. The value of angle, α, being less than, equal to or greater than 90°, shall be noted.	

Object	**BG2**
Checking of squareness of the C-axis (yoke rotation) to the Y-axis motion $E_{A(0Y)C}$.	

Diagram



Tolerance	**Measured deviation**
0,040/1 000 (0,020/500)	

Measuring instruments

Square or cylindrical square, dial gauge and special arm.

Observations and references to ISO 230-1:2012, 10.3 and 10.3.3

Z-axis to be locked, if possible.

Set the measurement side of the square or cylindrical square parallel to the Y-axis, or the lack of parallelism shall be taken into account in the measurement.

Set the dial gauge on the special arm mounted to the spindle, or the dial gauge may be mounted on the head base. Touch the measurement side of the square by the dial gauge stylus and zero the dial gauge.

Then, rotate the head base (C-axis) until the stylus touches the measurement side of the square again. The difference between the two readings divided by the distance between the two measuring points is the squareness error.

Alternatively, the dial gauge shall touch the same point of the square or cylindrical square before and after rotating the yoke (C-axis) through 180° and moving the Y-axis through the necessary travel.

The dial gauge may be mounted either on the yoke body or on the spindle head. If a special arm is used, it shall be stiff enough so as to prevent any possible reading errors due to its opposite deflections in the two measurement positions.

The value of angle, α, being less than, equal to or greater than 90°, shall be noted.