International Standard

ISO 8636-2

Third edition
2024-09

Machine tools — Test conditions for bridge-type milling machines —

Part 2: Testing of the accuracy of travelling bridge (gantry-type) machines

Machines-outils — Conditions d'essai des machines à fraiser à portique —

Partie 2: Contrôle de l'exactitude des machines à portique mobile

Reference number
ISO 8636-2:2024(en)

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Published in Switzerland

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Foreword

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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 document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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

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

This third edition cancels and replaces the second edition (ISO 8632-2:2007), which has been technically revised.

The main changes are as follows:

— the references in the Observations section of test tables have been updated to ISO 230-1:2012;

— the terminology and designation of axes have been revised to better represent current technology;

— preliminary remarks subclauses have been revised to be consistent with the latest revisions of machine-tool specific standards;

— tolerances for tests related to long axes (with travel lengths greater than 5 000 mm) have been introduced;

— tests for straightness and angular errors of Z-axis motion have been added;

— tests for straightness and angular errors of cross-rail W-axis motion have been added;

— tests for rotary table, C'-axis, have been added;

— tests for geometric accuracy of axis of rotation have been moved to Annex A;

— machining tests have been excluded considering that such tests can typically be the object of agreement between the manufacturer/supplier and the user, (possibly) including tests that are specified in ISO 10791-7;

— the test for table flatness (former G9) has been deleted because the table surface is not normally used as a reference for the orientation of the workpiece, and, for tests made during the working life of the machine tool, the surface can be unsuitable for accurate measurements on these large machine tools;

— the tests for swivelling spindle heads (former G15 and P7) have been deleted as such heads are not in the scope of this document; they will be considered in a future standard.

A list of all parts in the ISO 8636 series can be found on the ISO website.

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

Introduction

A bridge-type milling machine is a numerically controlled machine tool capable of performing multiple machining operations, including milling, boring, drilling and tapping, as well as automatic tool changing from a tool magazine or similar storage unit according to a machining program. Its main difference from the typical vertical machining centre, dealt with in ISO 10791-2, is in the size (the X-axis is longer than 5 m) and its typical configuration is based on the following features:

— a large fixed table where large workpieces can be located;

— all motions along the three coordinate axes belong to the tool, in the following order:

  — a vertical slide or ram moves vertically along the Z-axis.

  — a horizontal slide moves on the cross-rail along the Y-axis;

  — the travelling bridge moves on the bed along the X-axis.

Common configurations of the gantry machine tool are:

— the travelling bridge can be a complete portal made by two columns, moving on slideways on the floor level, connected by a top-bridge, where

  — the top-bridge can be fixed and used as cross-rail, or

  — the top-bridge can be fixed and the cross-rail can be movable on vertical slideways on the columns, as a vertical motion additional to the Z-axis;

— the travelling bridge can be made by a simple cross-rail, moving on horizontal slideways placed on top of tall fixed columns, often a multiple modular structure which can be assembled up to the required X-axis length.

An additional feature of the gantry machine tool can be a large rotary table, usually located at one end of the workholding table, to be used for turning operations on large workpieces. In this case, the gantry machine with rotary table becomes very similar to a vertical lathe with moving gantry, with the following differences:

— if the machine is designed and intended to be a bridge-type milling machine with additional rotary table, the gantry motion on the bed is called X-axis, the horizontal slide motion on the cross-rail is called Y-axis and the relevant geometric tests are considered in this document;

— if the machine is designed and intended to be a vertical lathe with additional gantry motion, the horizontal slide motion on the cross-rail is called X-axis, the gantry motion on the bed is called Y-axis and the relevant geometric tests are considered in ISO 13041-2.

The object of this document is to supply information as wide and comprehensive as possible on tests which can be carried out for comparison, acceptance, maintenance or any other purpose deemed necessary by the user or by the manufacturer/supplier.

Machine tools — Test conditions for bridge-type milling machines —

Part 2: Testing of the accuracy of travelling bridge (gantry-type) machines

1 Scope

This document specifies, with reference to ISO 230-1, ISO 230-2 and ISO 230-7, geometric tests and tests to check the accuracy and repeatability of positioning of numerically controlled axes for general-purpose, normal accuracy bridge-type milling machines with a travelling bridge (gantry-type). This document also specifies the applicable tolerances corresponding to the above-mentioned tests.

This document provides the terminology used for the identification of the principal components of the relevant machine tools and the designation of axes with reference to ISO 841.

This document is applicable to machine tools with travelling bridge and fixed table. This document does not include single-column (open-sided) machine tools and those with fixed bridge and moving table.

This document deals only with the verification of the accuracy of the machine tool. This document does not apply to the testing of the machine tool operation (vibration, abnormal noise, stick-slip motion of components, etc.) nor to machine tool characteristics (such as speeds and feeds), which are generally checked before testing the accuracy.

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 terminology databases for use in standardization at the following addresses:

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

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

3.1
travelling bridge (gantry-type) milling machine
milling machine with one fixed workpiece-holding table, two slideways on two beds on either side of the table and a travelling bridge (gantry) on which the spindle head(s) are mounted

Note 1 to entry: The beds can be dependent or independent of the table and can be supported by fixed columns [see Figure 1 a) and Figure 1 b)].

Note 2 to entry: The gantry, composed of a left-hand column and a right-hand column supported by respective column slides and made integral with a fixed top bridge, is moved along the bed slideways. The gantry supports a horizontal cross-rail, movable or fixed in the vertical plane, on which one or more spindle heads are mounted with vertical spindles.

Note 3 to entry: Some gantry-type milling machines are equipped with a rotary table [see Figure 1 b)].

4 Classification and description of travelling bridge (gantry-type) milling machines

4.1 Classification

These machine tools are classified into the following types depending upon construction:

— travelling bridge (gantry-type) milling machines with a cross-rail movable along the Z-(W-) axis [see Figure 1 a)];

— travelling bridge (gantry-type) milling machines with a cross-rail fixed along the Z-axis [see Figure 1 b)].

The principal components of these machines are shown in Figure 1 and described in 4.2.

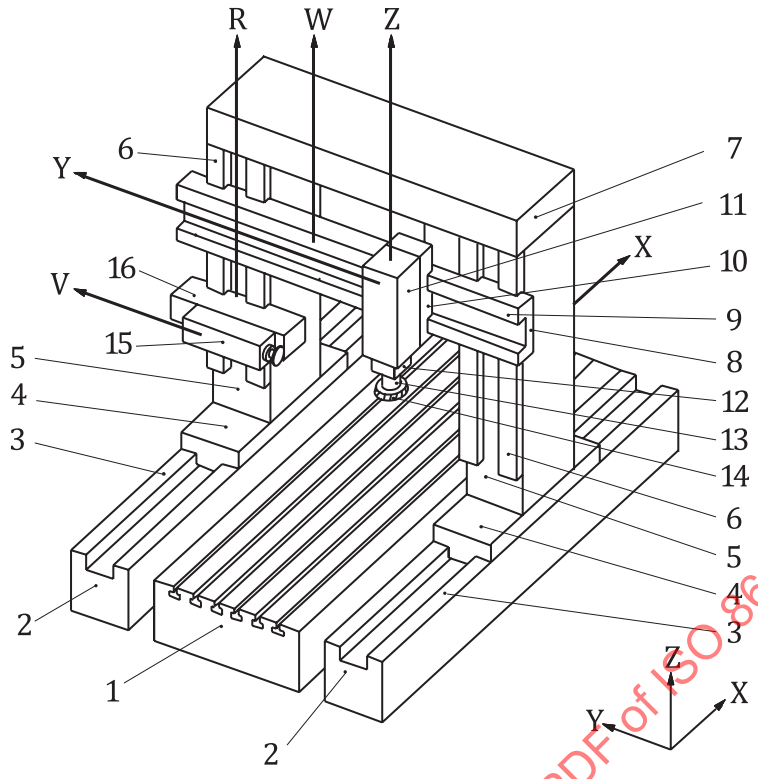
4.2 Descriptions of the principal components

4.2.1 Bed and table

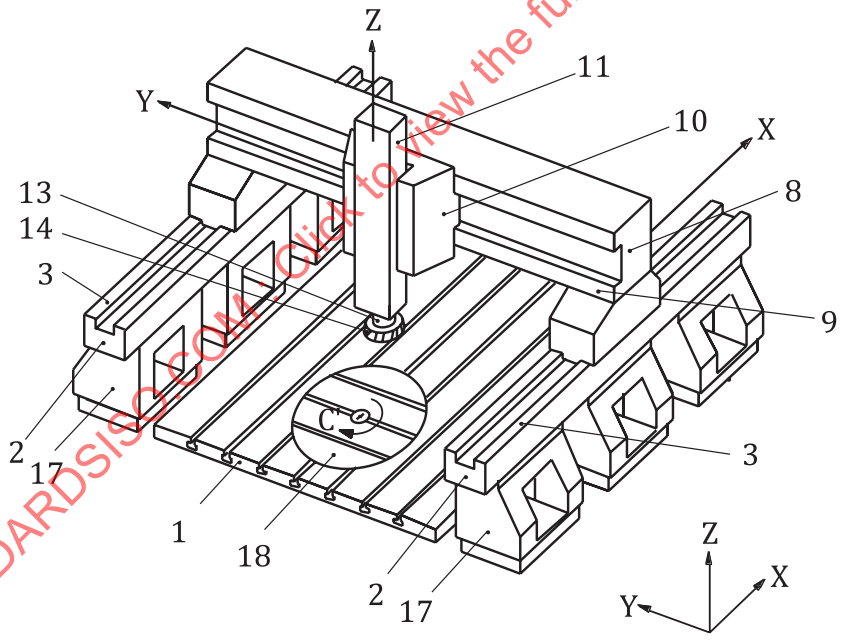
The table (Figure 1 Key 1) is located between two slideways that form the bed (Figure 1 Key 2). The table and the slideways can be constructed in one piece. Alternatively, the assembly can be made of several pieces rigidly connected through the foundation or directly to each other.

NOTE 1 The table can be replaced by a floorplate.

NOTE 2 A rotary table (Figure 1 Key 18) can be incorporated in the worktable.



a) Bridge-type milling machine with a cross-rail movable along the W-axis



b) Bridge-type milling machine with a fixed cross-rail and X-axis beds supported by fixed columns

Key

1	table (or floorplate)	9	cross-rail slideways	17	fixed columns
2	bed	10	vertical head saddle	18	rotary table (C'-axis)
3	bed slideways	11	vertical spindle head	R	vertical motion of the side spindle head (R-axis)
4	column slide	12	quill (ram)	V	horizontal motion of the side spindle head (V-axis)
5	column	13	tool-holding spindle	W	movable cross-rail vertical motion (W-axis)
6	column slideways	14	tool (milling cutter)	X	X-axis

7	top bridge	15	horizontal spindle head	Y	Y-axis
8	movable or fixed cross-rail	16	column head saddle	Z	Z-axis

NOTE For terms in French, German, Italian, Japanese and Persian, see Annex B.

Figure 1 — Travelling bridge (gantry-type) machine tools with movable and fixed cross-rail

4.2.2 Columns, top bridge and cross-rail

With reference to Figure 1 a), columns (Figure 1 Key 5) are rigid parts with vertical slideways, which either slide on the bed or are rigidly fixed to column slides (Figure 1 Key 4) which slide horizontally on the beds.

The top bridge (Figure 1 Key 7) is a fixed part connecting the two columns near their top ends.

The cross-rail (Figure 1 Key 8) is a part whose horizontal slideways are parallel to the plane of the table. In the case of machines with fixed cross-rails, the cross-rail is made integral with the columns and can be used as a top bridge. In the case of machines with movable cross-rails, the cross-rail slides vertically on the columns´ slideways (Figure 1 Key 6).

With reference to Figure 1 b), the cross-rail is not moving along the W-axis. Cross-rail and top bridge (Figure 1 Key 8) are one-piece, not mounted on columns, but sliding directly along the X-axis, on horizontal slideways mounted on multiple fixed columns.

4.2.3 Spindle head(s)

One or more spindle heads with vertical or horizontal spindles are mounted on the cross-rail slideways.

The portion in direct contact with the cross-rail slideways is called the head saddle (Figure 1 Keys 10 and 16).

Spindle heads (Figure 1 Keys 11 and 15) are mounted on head saddles (Figure 1 Keys 10 and 16) which move on the cross-rail or column slideways.

The vertical spindle head can slide vertically on the head saddle; it is then called a ram. The spindle can be mounted in a quill (Figure 1 Key 12) sliding vertically in the spindle head. Integral or universal spindle heads can be applied on the bottom of the spindle head or ram.

4.2.4 Movable cross-rail motion

The vertical motion of the movable cross-rail can be either a feed motion (in which case, the cross-rail is said to be movable when working) or a movement between fixed working positions (the cross-rail is then said to be movable when being positioned).

5 Examples of machine tool components and designation of axes

See Figure 1 for a comprehensive illustration of machine components.

See Figures 1 to 3 for the designation of axes.

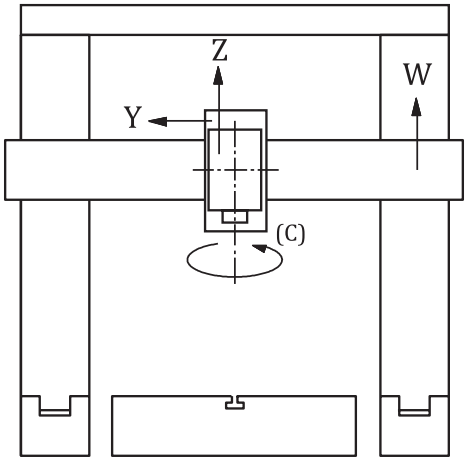
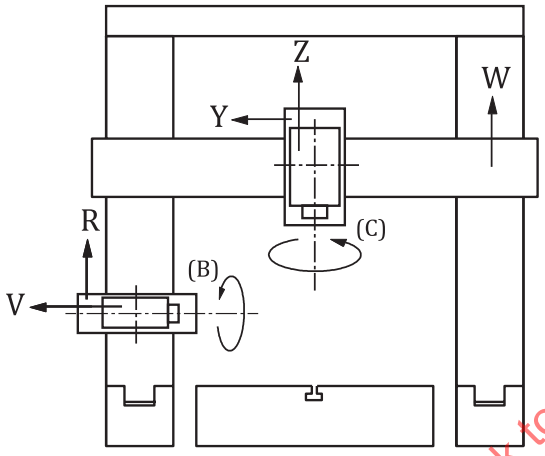
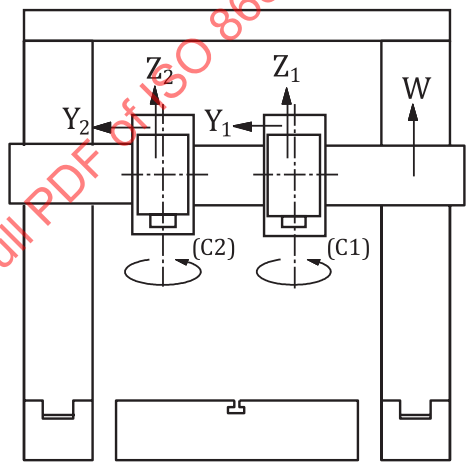


Figure 2 — Example of a machine tool with one spindle head



a) One vertical spindle head mounted on the cross-rail and one horizontal spindle head mounted on the left-hand column



b) Two vertical spindle heads mounted on the cross-rail

Figure 3 — Examples of machine tools with two spindle heads

6 Preliminary remarks

6.1 Measuring units

In this document, all linear dimensions, deviations, errors and corresponding tolerances are expressed in millimetres; angular dimensions are expressed in degrees and angular errors, and the corresponding tolerances are primarily expressed in ratios (e.g. 0,010/1 000), but in some cases microradians (µrad) or arcseconds (″) are used for clarification purposes. Formula (1) should be used for the conversion of the units of angular errors or tolerances:

$$0{,}010/1\,000 = 10\ \mu\text{rad} \approx 2'' \quad (1)$$

6.2 Reference to ISO 230-1, ISO 230-2 and ISO 230-7

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, the warm up of the spindle(s) and other moving components, the measuring methods and recommended accuracies of testing equipment.

In the "Observations" box of the tests described in Clauses 7 to 13, the instructions are preceded by a reference to the corresponding clause in ISO 230-1, ISO 230-2 or ISO 230-7 in cases where the test concerned is in compliance with the specifications of one of those parts of the ISO 230 series.

6.3 Machine levelling

Prior to conducting tests on a machine tool, the machine tool should be levelled according to the recommendations of the supplier/manufacturer (see ISO 230-1:2012, 6.1).

6.4 Temperature conditions

The temperature conditions throughout the tests shall be specified by agreement between the manufacturer/supplier and the user.

6.5 Testing sequence

The sequence in which the tests are presented in this document does not define the practical order of testing. In order to facilitate the mounting of instruments or measuring, tests may be performed in any order.

6.6 Tests to be performed

When testing a machine, it is not always necessary nor possible to carry out all the tests described in this document. If the tests are required for acceptance purposes, it is the responsibility of the user to choose, in agreement with the supplier/manufacturer, those tests relating to the components and/or the properties of the machine which are of interest. ISO 230-1:2012, Annex A provides valuable information about selection of primary and secondary axes and associated tests. These tests shall be clearly stated when ordering a machine. 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.

6.7 Measuring instruments

Measuring instruments indicated in the tests described in Clauses 7 to 13 are examples only. Other instruments capable of measuring the same quantities and having the same, or a smaller, measurement uncertainty can 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 (DTI), but any type of linear displacement sensor, such as analog or digital dial gauges, linear variable differential transformer (LVDTs), linear scale displacement gauges or non-contact sensors, when applicable to the test concerned.

Similarly, when a "straightedge" is referred to, it can mean any type of straightness reference artefact, such as a granite or ceramic or steel or 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.

When a "precision level" is referred to, it can mean any type of level, such as bubble tube, digital and analogue electronic levels.

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

6.8 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 manufacturer/supplier and the user, with due consideration to the machine tool intended use, e.g. if the intended use of the machine tool is with or without software compensation for geometric errors. When the software compensation is used, this shall be stated in the test report. It shall be noted that when software compensation is used, some machine tool axes cannot be locked for test purposes.

Valuable information on numerical compensation of geometric errors is given in ISO/TR 16907.

6.9 Minimum tolerance

By mutual agreement, the manufacturer/supplier and the user can establish the tolerance for a measuring length different from that given in the tests described in Clauses 7 to 13. However, it should be considered that the recommended minimum value of tolerance is 0,005 mm, unless otherwise specified.

In specifying the minimum tolerance, measurement uncertainty associated with the test and the recommended instrument, shall be taken into account, see 6.7.

6.10 Positioning tests

Positioning tests for numerically controlled machine tools shall refer to ISO 230-2. Tolerances in this document are given only for some parameters. The presentation of the test results shall comply with ISO 230-2.

6.11 Diagrams

For reasons of simplicity, the diagrams in Clauses 7 to 13 and in Annex A illustrate only one type of machine.

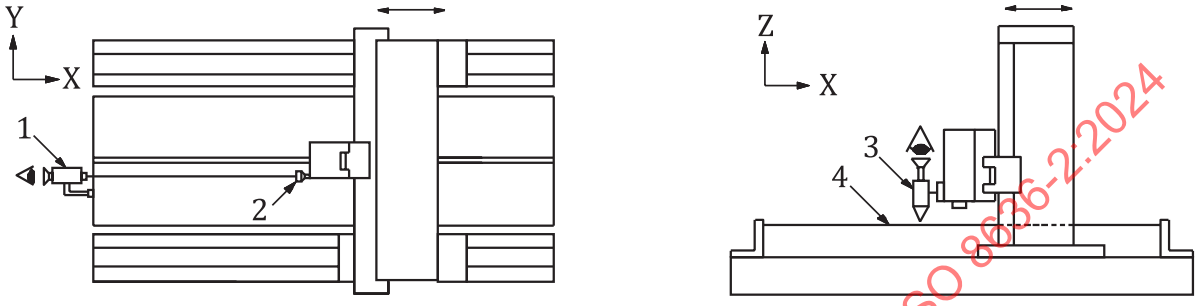
Where applicable, the diagram box provides for each test a), b) and c) identified in the object box, a schematic representation of a possible test setup, including the identification of the relevant coordinate plane (e.g. XY, YZ, ZX).

7 Geometric tests for axes of linear motion

Object | **G1**

Checking of the straightness of motion of the gantry (X-axis):
a) in the vertical ZX plane, E_{ZX};
b) in the horizontal XY plane, E_{YX}.

Diagram



a) b)

Key

1 alignment telescope 2 telescope target 3 microscope 4 taut wire

Tolerance

	For a measuring length up to			
	5 000	10 000	15 000	20 000
For a) and b):	0,070	0,140	0,210	0,280

The local tolerance for a) and b) is 0,020 for any measuring length of 1 000.
For measuring lengths over 20 000, the tolerance shall be agreed between the manufacturer/supplier and the user.

Measurement results

a) For a measuring length of: b)

Measuring instruments

a) Straightness measurement optical instruments excluding microscope and taut wire.
b) Straightness measurement optical instruments including microscope and taut wire.

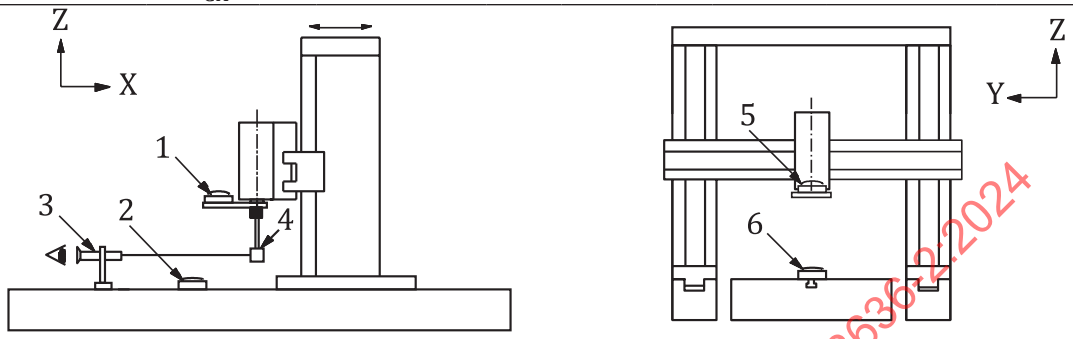
Observations and references to ISO 230-1:2012, 8.2.2.1, 8.2.2.2, 8.2.2.3 and 8.2.2.4

For a), taut wire is not recommended because of the sag of the wire.
The alignment telescope can be mounted on the workholding table such that the optical beam is parallel to the X-axis motion of the gantry, or the lack of parallelism shall be considered in the measurement.
If the spindle can be locked, the telescope target may be mounted on it. If the spindle cannot be locked, mount the telescope target on the spindle head.
For b), the microscope shall be fixed on the spindle, if it can be locked, or on the spindle head.
When optical instruments are used, it should be considered that, their measurement uncertainty for long measurement length can be higher than the measurement uncertainty of microscope and taut wire.
For a) and b), measurements shall be carried out on at least six positions along the travel, with equally spaced steps not exceeding 500. Traverse the gantry in the X-axis direction and note the readings.
Measurements shall be with Y-axis and Z-axis at their mid travel positions, otherwise, the measurement location shall be reported.

Object	**G2**

Checking of the angular errors of the gantry motion (X-axis):
a) in the vertical ZX plane (E_{BX}: pitch);
b) in the vertical YZ plane (E_{AX}: roll);
c) in the horizontal XY plane (E_{CX}: yaw).

Diagram



a) and c) b)

Key

1 measuring level for pitch
2 reference level for pitch
3 autocollimator for yaw/pitch
4 mirror for yaw/pitch
5 measuring level for roll
6 reference level for roll

Tolerance

	For measuring length up to			
	5 000	10 000	15 000	20 000
For a), b) and c)	0,060/1 000	0,070/1 000	0,080/1 000	0,100/1 000

The local tolerance for a), b) and c) is 0,020/1 000 for any measuring length of 1 000.

For measuring lengths over 20 000, the tolerance shall be agreed between the manufacturer/supplier and the user.

Measurement results — For a measuring length of:

a) b) c)

Measuring instruments

a) Precision level or optical instruments.
b) Precision level.
c) Autocollimator or other optical instruments.

Observations and references to ISO 230-1:2012, 8.4.2.1, 8.4.2.2 and 8.4.2.3

The measuring level or the mirror shall be placed on the ram:
— for a), E_{BX} (pitch): in the X-axis direction;
— for b), E_{AX} (roll): in the Y-axis direction;
— for c) E_{CX} (yaw): set autocollimator horizontally in the X-axis direction.

If the X-axis motion causes angular deviation of both the spindle head and table, differential measurements of the two angular motions shall be taken.

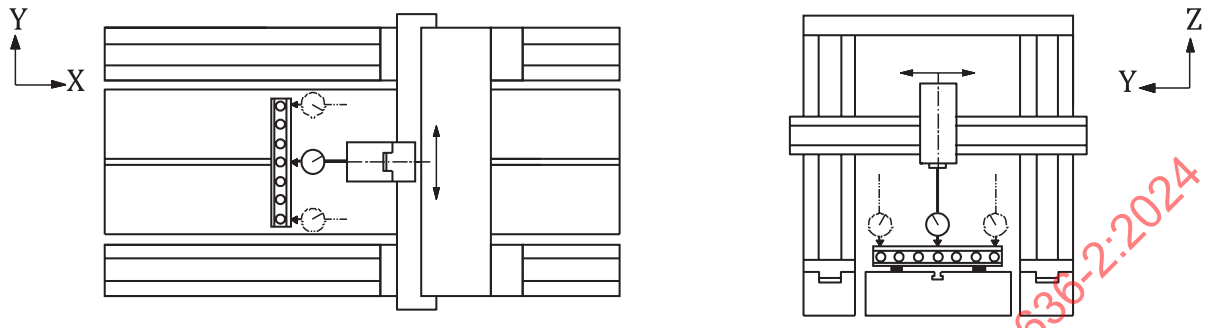
For a), b) and c), measurements shall be carried out on at least six positions along the travel, with equally spaced steps not exceeding 500.

For a), b) and c), the angular error to be reported is the difference between the maximum and the minimum readings. The measurement location shall be reported.

Object	**G3**

Checking of the straightness of the horizontal motion of the spindle head on the cross-rail (Y-axis):
a) in the horizontal XY plane, E_{XY};
b) in the vertical YZ plane, E_{ZY}.

Diagram



a) b)

Tolerance

	For measuring length up to			
	2 000	3 000	4 000	5 000
For a) and b)	0,030	0,040	0,050	0,060

The local tolerance for a) and b) is 0,015 for any measuring length of 800.

For measuring lengths over 5 000, the tolerance shall be agreed between the manufacturer/supplier and the user.

Measurement results

For a measuring length of:	
a)	b)

Measuring instruments

Dial gauge, straightedge and gauge blocks or optical instruments.

Observations and references to ISO 230-1:2012, 8.2.2.1, 8.2.2.3, 8.2.2.4 and 8.2.2.5

Fix the movable cross-rail in the mid travel and move the gantry in mid travel.

Set a straightedge on the table, with the reference surface approximately parallel to the Y-axis: in the horizontal plane for a) and in the vertical plane for b).

If the spindle can be locked, the dial gauge may be mounted on it. If the spindle cannot be locked, the dial gauge shall be mounted on the ram.

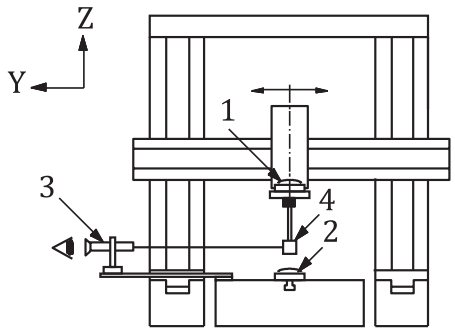
Traverse the spindle head in the Y-direction through the measuring length and record the readings. The measuring length is normally the length between the two columns (not the full length of cross-rail). In other cases, this shall be agreed upon between the manufacturer/supplier and the user.

Measurements shall be carried out on at least six positions along the travel, with equally spaced steps not exceeding 400.

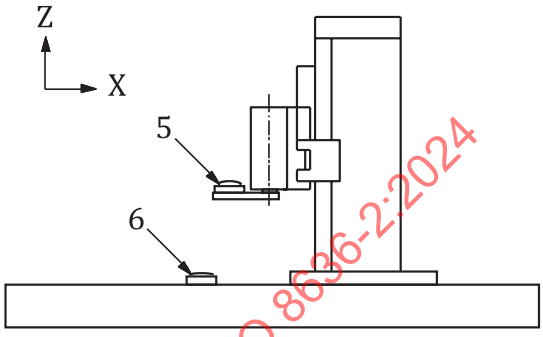
Object **G4**

Checking of the angular errors of the horizontal motion of the spindle head (Y-axis):
a) in the vertical YZ plane (E_{AY});
b) in the vertical ZX plane (E_{BY}, roll);
c) in the horizontal XY plane (E_{CY}).

Diagram



a) and c)



b)

Key

1 measuring level for E_{AY}	3 autocollimator for E_{CY} / E_{AY}	5 measuring level for E_{BY}, roll
2 reference level for E_{AY}	4 mirror for E_{CY} / E_{AY}	6 reference level for E_{BY}, roll

Tolerance

	For measuring length up to			
	2 000	3 000	4 000	5 000
For a), b) and c)	0,035/1 000	0,050/1 000	0,060/1 000	0,060/1 000

For a), b) and c), the local tolerance is 0,015/1 000 for any measuring length of 800.

For measuring lengths over 5 000, the tolerance shall be agreed between the manufacturer/supplier and the user.

Measurement results For a measuring length of:

a) b) c)

Measuring instruments

a) Precision level or optical instruments.
b) Precision level.
c) Autocollimator or other optical instruments.

Observations and references to ISO 230-1:2012, 8.4.2.1, 8.4.2.2 and 8.4.2.3

The level or mirror or retro-reflector shall be placed on the movable component:
— for a), (E_{AY}): the level shall be placed in the Y-axis direction;
— for b), (E_{BY}): the level shall be placed in the X-axis direction;
— for c), (E_{CY}): set autocollimator horizontally in the Y-axis direction.

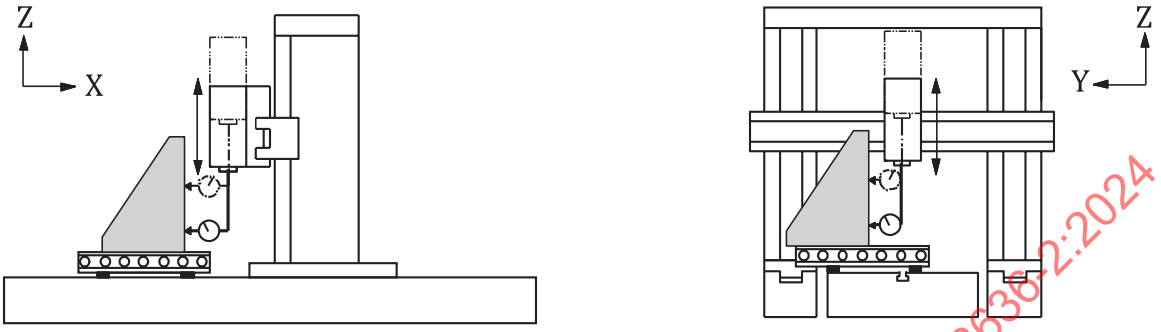
Measurements shall be carried out on at least six positions along the travel, with equally spaced steps not exceeding 400.

For a), b) and c), the angular error to be reported is the difference between the maximum and the minimum readings.

Object **G5**

Checking of the straightness of the spindle head vertical motion (Z-axis):
a) in the vertical ZX plane, E_{XZ};
b) in the vertical YZ plane, E_{YZ}.

Diagram



a) b)

Tolerance

	For measuring length up to			
	1 000	2 000	3 000	4 000
For a) and b)	0,015	0,020	0,030	0,040

The local tolerance for a) and b) is 0,010 for any measuring length of 600.
For measuring lengths over 4 000, the tolerance shall be agreed between the manufacturer/supplier and the user.

Measurement results

a) For a measuring length of:
b)

Measuring instruments

Square, straightedge, adjustable blocks and dial gauge or optical instruments or microscope and taut wire.

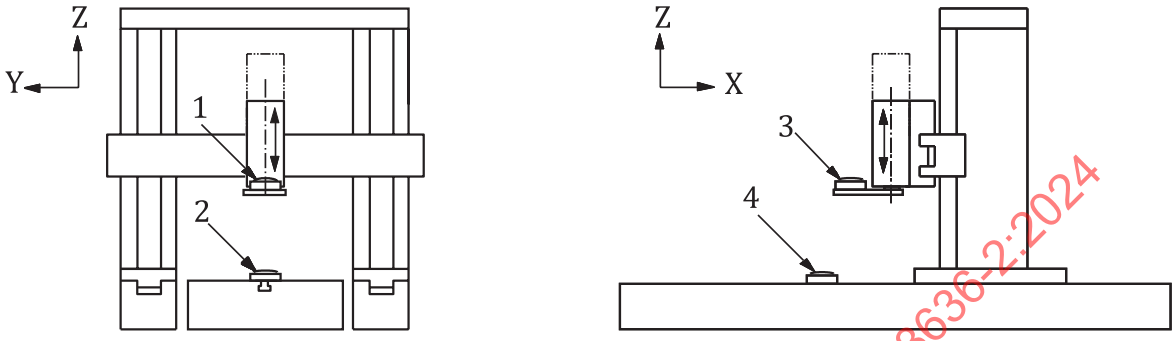
Observations and references to ISO 230-1:2012, 8.2.2.1

Place gantry, movable cross-rail and spindle head at mid travel.
If used, the taut wire shall be tightened between the table and another fixed part independent from the gantry.
For a), set a straightedge oriented along the X-axis and place a square on it. Fix a dial gauge on the spindle head. Lock cross-rail on columns, where possible. Apply the stylus of the dial gauge to the square measuring in the X-direction. Move the Z-axis and record the dial gauge readings.
Measurements shall be carried out on at least six positions along the travel, with equally spaced steps not exceeding 300.
For b), set a straightedge oriented along the Y-axis and place a square on it. Apply the stylus of the dial gauge to the square measuring in the Y-direction. Move the Z-axis and record the dial gauge readings.
Measurements shall be carried out on at least six positions along the travel, with equally spaced steps not exceeding 300.
NOTE The test setup depicted in diagram is also applicable to tests G9, G10 and G13. The use of the straightedge is optional.

Object **G6**

Checking of the angular errors of the spindle head vertical motion (Z-axis):
a) in the vertical YZ plane, E_{AZ};
b) in the vertical ZX plane, E_{BZ}.

Diagram



a) b)

Key

1 measuring level for E_{AZ}
2 reference level for E_{AZ}
3 measuring level for E_{BZ}
4 reference level for E_{BZ}

Tolerance

	For measuring length up to			
	1 000	2 000	3 000	4 000
For a) and b)	0,020/1 000	0,030/1 000	0,040/1 000	0,050/1 000

The local tolerance for a) and b) is 0,015/1 000 for any measuring length of 600.
For measuring lengths over 4 000, the tolerance shall be agreed between the manufacturer/supplier and the user.

Measurement results

	For a measuring length of:
a)	b)

Measuring instruments

Precision level or optical instruments.

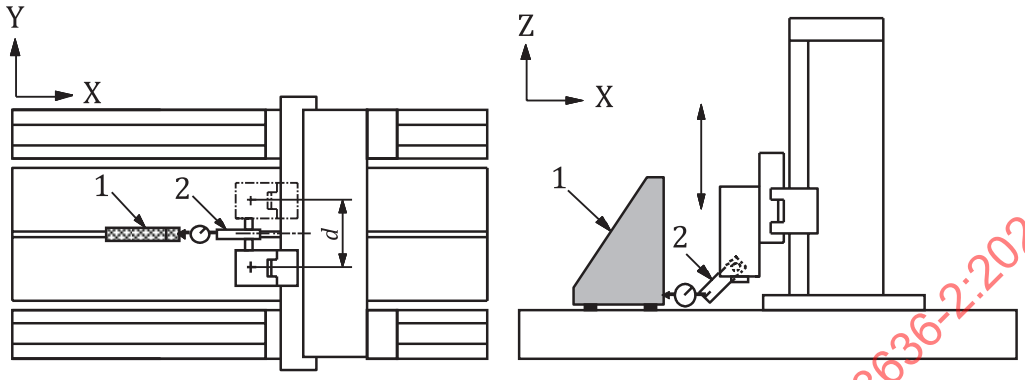
Observations and references to ISO 230-1:2012

The level or mirror or retro-reflector shall be placed on the movable component:
— for a), (E_{AZ}): the level shall be placed in the Y-axis direction;
— for b), (E_{BZ}): the level shall be placed in the X-axis direction.
Measurements shall be carried out on at least six positions along the travel, with equally spaced steps not exceeding 300.
For a) and b), the angular error to be reported is the difference between the maximum and the minimum readings.

Object **G7**

Checking of the angular error of the spindle head vertical motion (Z-axis) in the horizontal XY plane, E_{CZ} (roll).

Diagram



Key

1 square 2 special arm *d* travelled distance along Y-axis

Tolerance

For measuring length up to			
1 000	2 000	3 000	4 000
0,020/1 000	0,030/1 000	0,040/1 000	0,050/1 000

The local tolerance is 0,015/1 000 for any measuring length of 600.

For measuring lengths over 4 000, the tolerance shall be agreed between the manufacturer/supplier and the user.

Measurement results For a measuring length of:

Measuring instruments

Square, dial gauge mounted on special arm or taut wire and microscope or sweeping laser.

Observations and references to ISO 230-1:2012, 8.4.2.4

Measure the E_{XZ} straightness deviation of the Z-axis by an instrument mounted on a special arm with a horizontal offset $d/2$ from the spindle axis, alternatively: by a dial gauge against a square set up as in G5 a) and in G9 a), as depicted in diagram, by a microscope targeting a vertical taut wire or by a target of a sweeping laser generating an optical YZ-plane. Note the readings and the relevant measuring positions on the spindle head travel (Z-axis).

Position or turn the special arm (carrying the instrument) to the opposite side of the spindle head and move the Y-axis of *d* in order to repeat the same readings against the same reference; the possible roll of the Y-axis motion shall be measured and taken into account.

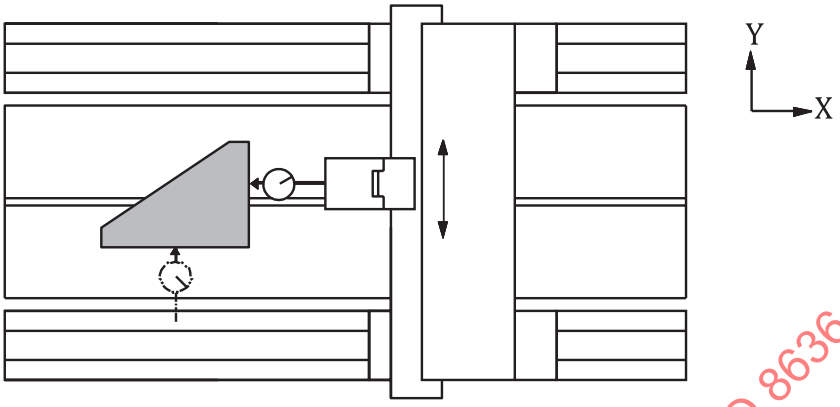
When using a sweeping laser, no Y-axis movement is required.

The instrument shall be reset, the new measurements shall be taken at the same heights of the previous ones and the results shall be noted.

Measurements shall be carried out on at least six positions along the travel, with equally spaced steps not exceeding 300.

For each measurement position, calculate the algebraic difference between the two readings, and then calculate the difference between maximum and minimum divided by the distance, *d,* for obtaining the angular deviation.

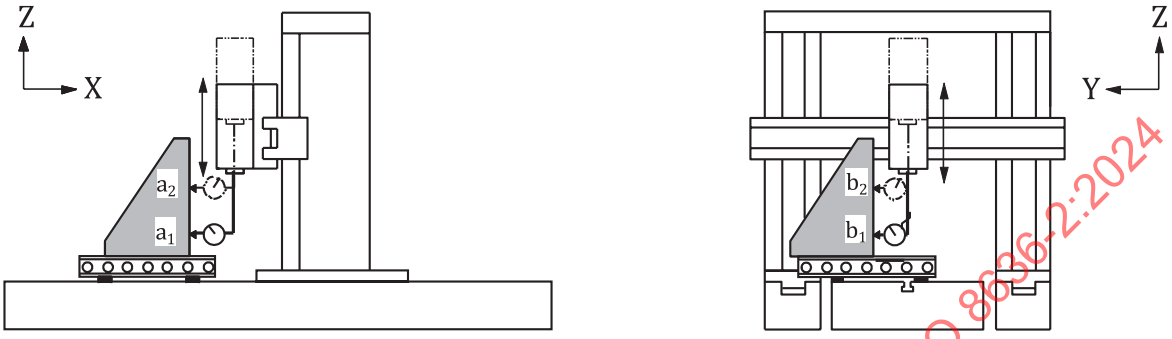
NOTE This setup is also applicable for test G12.

Object	**G8**
Checking of the squareness of the spindle head horizontal motion on cross-rail (Y-axis) to the gantry motion (X-axis), $E_{C(0X)Y}$.	
Diagram  	
Tolerance 0,040/1 000	
Measurement results	
Measuring instruments Square and dial gauge or optical instruments.	
Observations and references to ISO 230-1:2012, 10.3.2.2 Place the gantry in mid travel. Fix the dial gauge on the spindle head. Set a square on the table and align one side parallel to the gantry motion (X-axis), or the lack of parallelism shall be considered in the measurement. Place the dial gauge stylus against the other arm of the square measuring in the X-direction. Position the Y-axis close to one end of the square surface and zero the dial gauge. Move the Y-axis to measure close to the other end of the square surface and note the reading. The squareness error, $E_{C(0X)Y}$, to be reported is the ratio between the reading and the travelled distance along the Y-axis. For large machines, the measurement should be repeated at the two extreme gantry positions.	

Object **G9**

Checking of the squareness of the spindle head vertical motion (Z-axis) to:
a) the X-axis motion, $E_{B(0X)Z}$;
b) the Y-axis motion, $E_{A(0Y)Z}$.
This test is also applicable to additional vertical spindle heads on the cross-rail.

Diagram



a) b)

Key

a_1, a_2, b_1 and b_2 measurement positions

Tolerance

For a) and b): 0,050/1 000

Measurement results

a) b)

Measuring instruments

Square, straightedge, adjustable blocks and dial gauge or optical instruments.

Observations and references to ISO 230-1:2012, 10.3.2.2

Place gantry, movable cross-rail and spindle head at mid travel.

For a), set a straightedge parallel to the X-axis motion using adjustable blocks or the lack of parallelism shall be considered in the measurement and then place a square on it. Fix a dial gauge on the spindle head. Lock movable cross-rail on columns, where possible.

Apply the stylus of the dial gauge to the square in position a_1, measuring in the X-direction and zero the dial gauge. Move the Z-axis to position a_2 and record the dial gauge reading. The squareness error, $E_{B(0X)Z}$, to be reported is the ratio between the reading in a_2 and the travelled distance along the Z-axis.

For b), set the straightedge parallel to the Y-axis motion using adjustable blocks or the lack of parallelism shall be considered in the measurement and then place the square on it.

Apply the stylus of the dial gauge to the square in position b_1, measuring in the Y-direction and zero the dial gauge. Move the Z-axis to position b_2 and record the dial gauge reading. The squareness error, $E_{A(0Y)Z}$, to be reported is the ratio between the reading in b_2 and the travelled distance along the Z-axis.

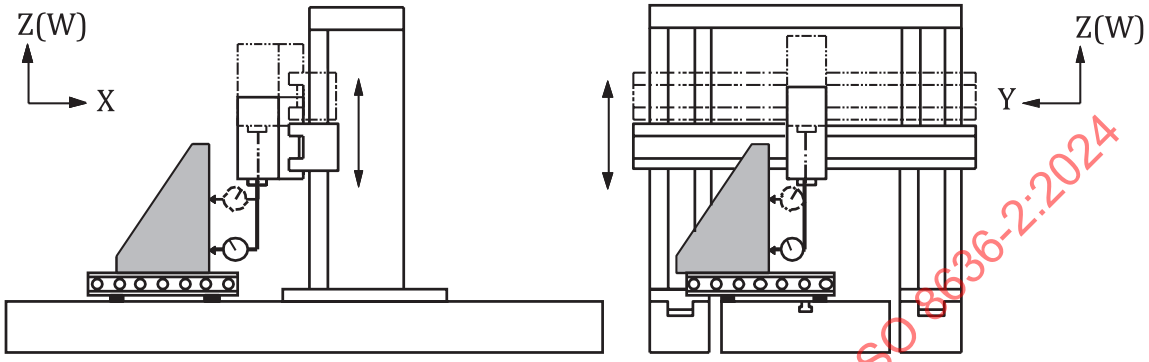
For large machines, checking of the squareness error of Z- to X-axis, $E_{B(0X)Z}$, should be repeated at the two extreme gantry positions.

NOTE This test setup is also applicable to tests G5, G10 and G13. The use of the straightedge is optional.

Object **G10**

Checking of the straightness of the movable cross-rail in its W-axis motion:
a) in the vertical ZX plane, E_{XW};
b) in the vertical YZ plane, E_{YW}.
This test is not applicable to cross-rails that are only movable when being positioned in fixed steps.

Diagram



Tolerance

	For measuring length up to			
	2 000	3 000	4 000	5 000
For a) and b)	0,020	0,030	0,040	0,050

The local tolerance for a) and b) is 0,015 for any measuring length of 1 000.
For measuring lengths over 5 000, the tolerance shall be agreed between the manufacturer/supplier and the user.

Measurement results

For a measuring length of:

a) b)

Measuring instruments

Square, straightedge, adjustable blocks and dial gauge or optical instruments or microscope and taut wire.

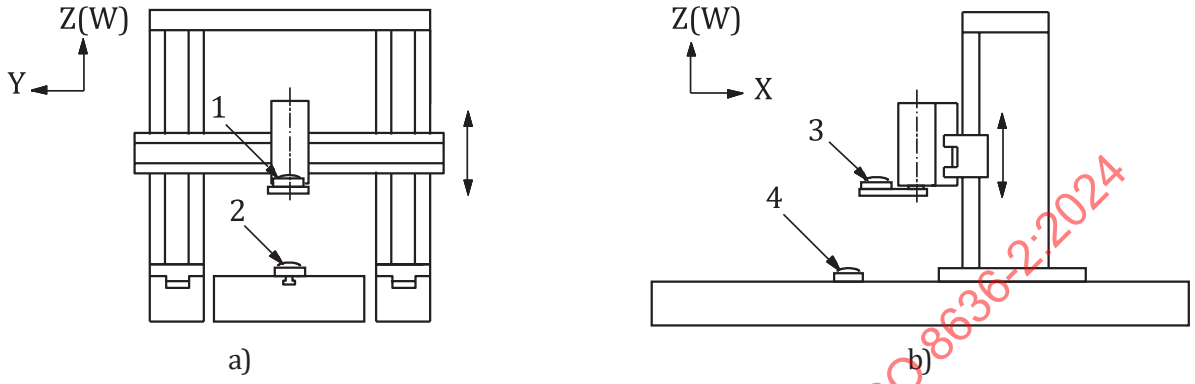
Observations and references to ISO 230-1:2012, 8.2.2.1

Place gantry and spindle head at mid travel.
If used, the taut wire shall be tightened between the table and another fixed part independent from the gantry.
For a), set a straightedge oriented along the X-axis and place a square on it. Fix a dial gauge on the spindle head.
Apply the stylus of the dial gauge to the square measuring in the X-direction. Move the W-axis and record the dial gauge readings.
Measurements shall be carried out on at least six positions along the travel, with equally spaced steps not exceeding 500.
For b), set a straightedge oriented along the Y-axis and place a square on it.
Apply the stylus of the dial gauge to the square measuring in the Y-direction. Move the W-axis and record the dial gauge readings.
Measurements shall be carried out on at least six positions along the travel, with equally spaced steps not exceeding 500.
NOTE The setup depicted in diagram is also applicable to tests G5, G9 and G13. The use of the straightedge is optional.

Object **G11**

Checking of the angular errors of the movable cross-rail in its W-axis motion:
a) in the vertical YZ plane, E_{AW};
b) in the vertical ZX plane, E_{BW}.

Diagram



Key

1 measuring level for E_{AW}	3 measuring level for E_{BW}
2 reference level for E_{AW}	4 reference level for E_{BW}

Tolerance

	For measuring length up to			
	2 000	3 000	4 000	5 000
For a) and b)	0,030/1 000	0,040/1 000	0,050/1 000	0,060/1 000

The local tolerance for a) and b) is 0,015/1 000 for any measuring length of 1 000.
For measuring lengths over 5 000, the tolerance shall be agreed between the manufacturer/supplier and the user.

Measurement results For a measuring length of:
a) b)

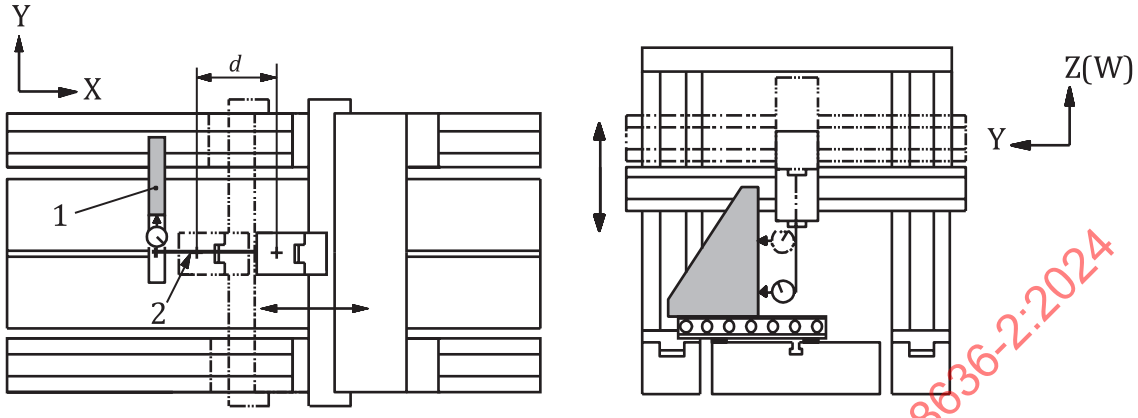
Measuring instruments
Precision level or optical instruments.

Observations and references to ISO 230-1:2012, 8.4.2.1, 8.4.2.2 and 8.4.2.3
For a) and b), place the level at the mid travel of the cross-rail or, in case of machines with only one vertical spindle head, place the level on the spindle head.
Place vertical spindle heads symmetrically relative to the table.
For machines with only one vertical spindle head, it shall be placed in a central position.
Lock the cross-rail at each position, where possible.
Measurements shall be carried out on at least six positions along the travel, with equally spaced steps not exceeding 500. If the cross-rail is only movable when being positioned in fixed steps, measurements positions shall be selected accordingly.
For a) and b), the angular error to be reported is the difference between the maximum and the minimum readings.

Object	**G12**

Checking of the angular error of the movable cross-rail in its W-axis motion in the horizontal XY plane, E_{CW}.

Diagram



Key

1 square 2 special arm(s) *d* travelled distance along the X-axis

Tolerance

For measuring length up to			
2 000	3 000	4 000	5 000
0,030/1 000	0,040/1 000	0,050/1 000	0,060/1 000

Local tolerance: 0,015/1 000 for any measuring length of 1 000

For measuring lengths over 5 000, the tolerance shall be agreed between the manufacturer/supplier and the user.

Measurement results For a measuring length of:

Measuring instruments

Square, dial gauge mounted on two special arms with different length, or taut wire and microscope, or sweeping laser.

Observations and references to ISO 230-1:2012, 8.4.2.4

Set a square oriented to measure in the Y-direction.

Mount a dial gauge on the special arm with the long length; take readings at different W-axis positions and record them.

Measurements shall be carried out on at least six positions along the W-axis travel, with equally spaced steps not exceeding 500. If the cross-rail is only movable when being positioned in fixed steps, measurements positions shall be selected accordingly.

Mount the dial gauge on the special arm with the short length.

Move the gantry to bring the dial gauge to contact the square at the same point(s) where the previous readings were taken and repeat the measurements at the same W-axis positions.

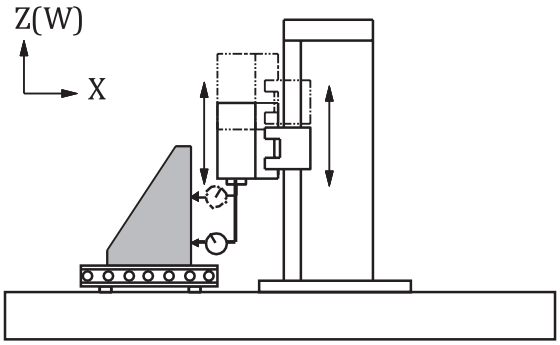
The W-axis roll, E_{CW}, to be reported is the maximum difference in the dial gauge readings in two different X-axis positions. at each measured W-axis position, divided by the distance, *d*, travelled along the X-axis.

The X-axis roll, E_{AX}, shall be measured and accounted for.

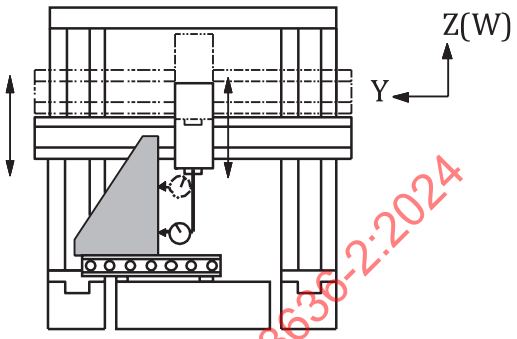
Object	**G13**

Checking of the parallelism of the movable cross-rail vertical motion (W-axis) to the Z-axis motion:
a) in the vertical ZX plane, $E_{B(0Z)W}$;
b) in the vertical YZ plane $E_{A(0Z)W}$.

Diagram



a)



b)

Tolerance

For a) and b): 0,030/1 000

Measurement results

a) b)

Measuring instruments

Square, straightedge on adjustable blocks and dial gauge.

Observations and references to ISO 230-1:2012, 10.1.2.2

This test uses the same test setup as G5, G9 and G10.

For a), execute the straightness measurement E_{XZ} described in G5 a) and record the computed slope then, without altering the square alignment, execute the straightness measurement E_{XW} described in G10 a) and record the computed slope.

The parallelism error, $E_{B(0Z)W}$, to be reported, is the difference of the slopes obtained in G5 a) and in G10 a).

For b), execute the straightness measurement E_{YZ} described in G5 b) and record the computed slope then, without altering the square alignment, execute the straightness measurement E_{YW} described in G10 b) and record the computed slope.

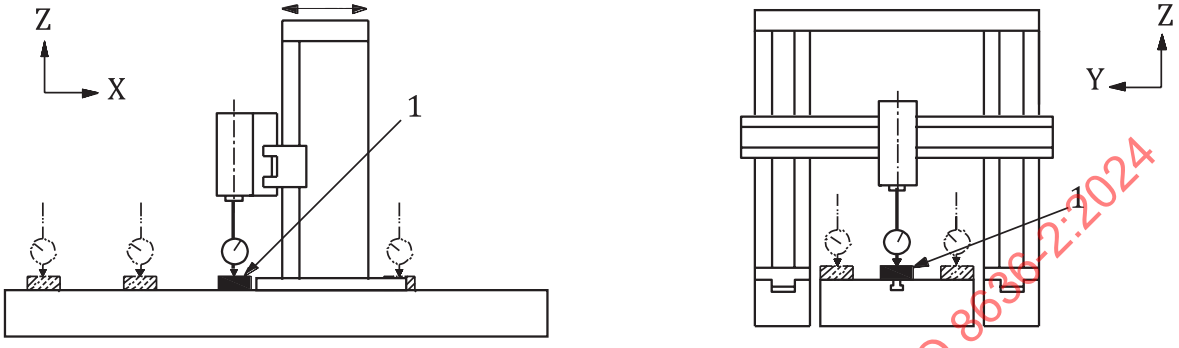
The parallelism error, $E_{A(0Z)W}$, to be reported, is the difference of the slopes obtained in G5 b) and in G10 b).

8 Geometric tests for the table

Object **G14**

Checking of the parallelism of the table surface to the motion of the gantry (X-axis).

Diagram



Key

1 gauge block

Tolerance

	For the lengths of the longest side of the table up to			
	5 000	10 000	15 000	20 000
Parallelism tolerance	0,100	0,200	0,300	0,400

For table lengths over 20 000, the tolerance shall be agreed upon between the manufacturer/supplier and the user.

The above tolerances are specified assuming that finish-machining of the table is not carried out in situ after assembly. If the table is finished in situ, the tolerances shall be agreed upon between the manufacturer/supplier and the user.

Measurement results For a measurement distance of: Over a table length of:

Measuring instruments

Dial gauge and gauge block.

Observations and references to ISO 230-1:2012, 12.3.2.5.2

Attach a dial gauge to the tool-holding spindle or to the head near the spindle. The dial gauge stylus shall be touching the table surface directly or touching a gauge block located on the table surface.

The spindle head is at mid travel.

Move the gantry in the X-direction and record the dial gauge readings.

Measurements shall be carried out at a number of positions equally spaced at steps not exceeding 1/10 of the longest side of the table [see diagram a)].

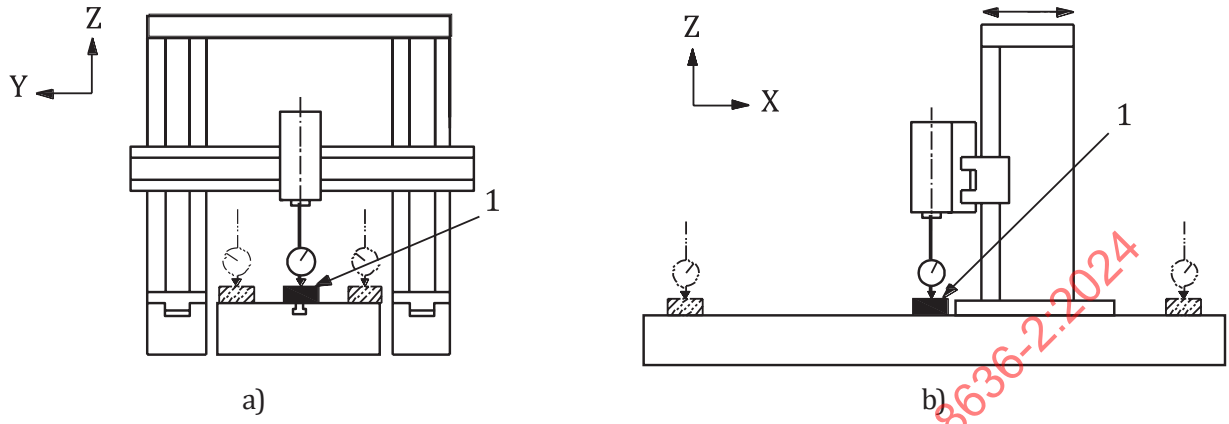
Repeat the test in two other Y-axis positions of the spindle head, symmetrical to the previous position and record the maximum difference of the readings in the same way [see diagram b)].

The parallelism error to be reported is the largest of the maximum differences recorded at each Y-axis position.

Object **G15**

Checking of the parallelism of the table surface to the motion of the spindle head (Y-axis).

Diagram



a) b)

Key

1 gauge block

Tolerance

	For the lengths of the shortest side of the table up to			
	3 000	4 000	5 000	6 000
Parallelism tolerance	0,030	0,050	0,070	0,090

For the table with shortest side lengths over 6 000, the tolerance shall be agreed upon between the manufacturer/supplier and the user.

The above tolerances are specified assuming that finish-machining of the table is not carried out in situ after assembly. If the table is finished in situ, the tolerances shall be agreed upon between the manufacturer/supplier and the user.

Measurement results For a measurement distance of: Over a table width of:

Measuring instruments

Dial gauge and gauge block.

Observations and references to ISO 230-1:2012, 12.3.2.5.2

Attach a dial gauge to the tool-holding spindle or to the head near the spindle. The dial gauge stylus shall be touching the table surface directly or touching a gauge block located on the table surface.

The gantry is at mid travel.

Move the spindle head in the Y-direction and record the dial gauge readings.

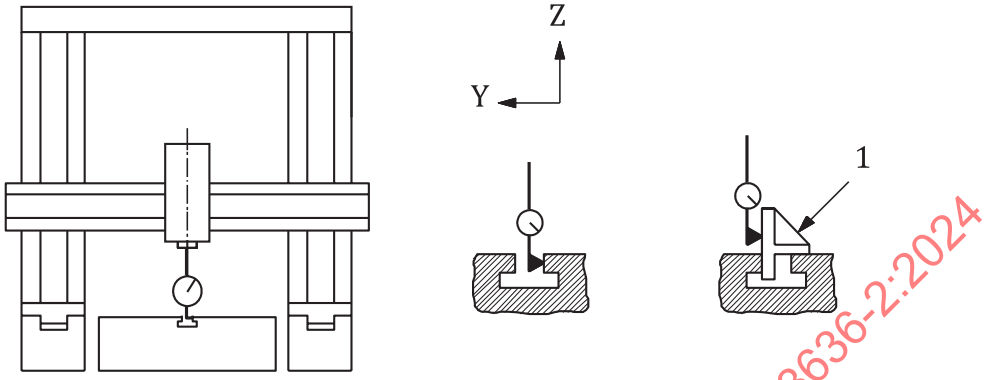
Measurements shall be carried out at a number of positions equally spaced at steps not exceeding 1/5 of the shortest side of the table [see diagram a)].

Repeat the test in the two extreme positions of the gantry and record the maximum differences of the reading in the same way [see diagram b)].

The parallelism error to be reported is the largest of the maximum differences recorded at each position of the gantry.

Object	**G16**
Checking of the parallelism of the median or reference T-slot (where present) to the motion of the gantry (X-axis).	

Diagram



Key

1 cross-square

Tolerance

	For length of the longest side of the table up to			
	5 000	10 000	15 000	20 000
Parallelism tolerance	0,150	0,200	0,250	0,300

For table lengths over 20 000, the tolerance shall be agreed upon between the manufacturer/supplier and the user.

Measurement results For a measurement distance of: Over a table length of:

Measuring instruments

Dial gauge and cross-square.

Observations and references to ISO 230-1:2012, 12.3.2.5.2

Attach a dial gauge to the tool-holding spindle or to the head near the spindle.

Place the gauge stylus in contact with the measuring face of the reference T-slot or use a cross-square.

Move the gantry and record the dial gauge readings.

Measurements shall be carried out at a number of positions equally spaced at steps not exceeding 1/10 of the longest side of the table.

Traverse the X-axis from one measurement position to the following one without contact between the stylus and the reference surface. At each measurement position either move down the Z-axis to bring the dial gauge into contact with the reference surface or insert the cross-square between the stylus and the table surface.

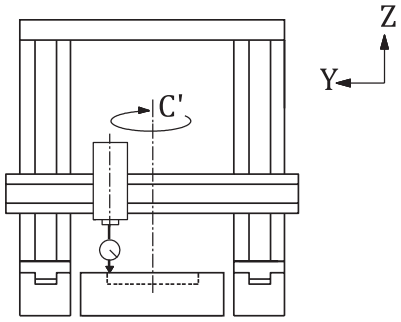
The parallelism error to be reported is the difference between the maximum and the minimum readings.

9 Geometric tests for the rotary table

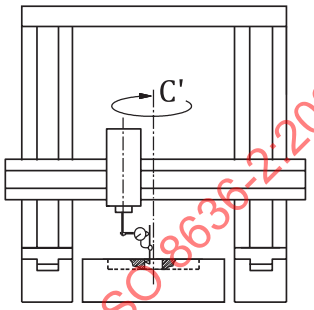
Object | **G17**

Checking of:
a) the face run-out of the rotary table;
b) the run-out of the rotary table centre bore, if it is used for centring purposes.

Diagram



a)



b)

Tolerance

	$D \leq 3\,000$	$3\,000 < D \leq 5\,000$	$D > 5\,000$
For a)	0,030	0,050	0,080
For b)	0,015	0,020	0,025

where D is the rotary table diameter.

Measurement results

a) b)

Measuring instruments

Dial gauge.

Observations and references to ISO 230-1:2012, 12.5.2 and 12.5.3

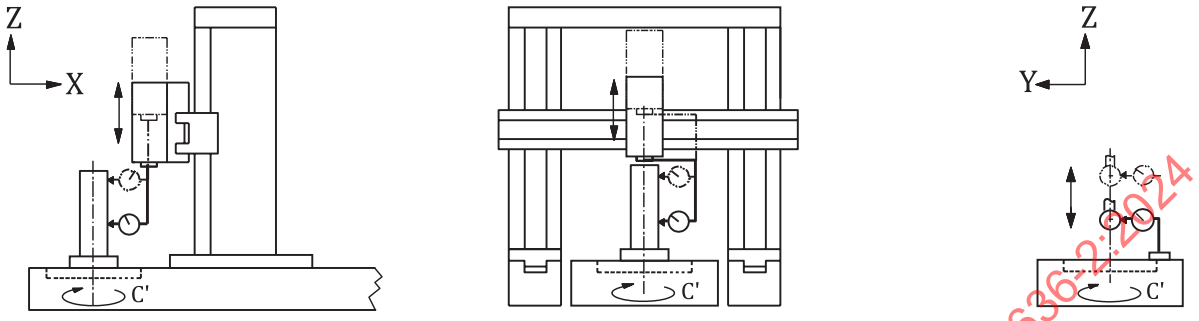
Movable cross-rail and railhead locked in position, if possible.

For a), the dial gauge shall be mounted on the vertical spindle head or on the spindle, if it can be locked, and its stylus shall contact the periphery of the upper surface of the rotary table.

If the table surface was machined in situ, the stylus shall contact the surface approximately at 180° from the relative position of the tool used for the machining.

For b), the dial gauge stylus shall be placed approximately 180° from the position occupied by the tool if the rotary table centre bore was machined in situ.

See also test AR2 in Annex A.

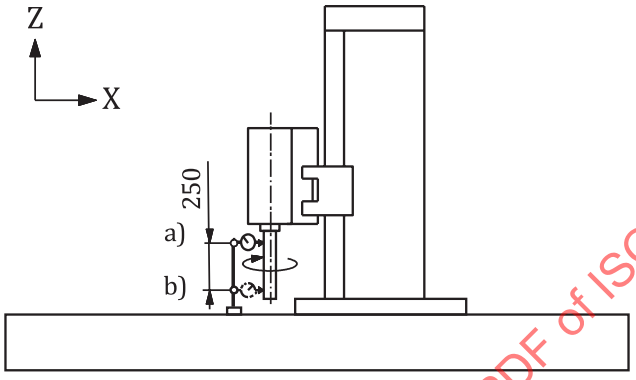
Object	**G18**
Checking of the parallelism of the Z-axis motion to the rotary table axis of rotation: a) in the ZX plane, $E_{B(0C')Z}$; b) in the YZ plane, $E_{A(0C')Z}$.	
Diagram  a) b) Alternative	
Tolerance For a) and b): 0,040/1 000	
Measurement results a) b)	
Measuring instruments Cylindrical square with flange base and dial gauge or optical instruments or, for the alternative method, test sphere and dial gauge.	
Observations and references to ISO 230-1:2012, 3.6.4, 10.1.4, 10.1.4.3, or 10.1.4.4 as an alternative If the spindle can be locked, the dial gauge may be mounted on it. If the spindle cannot be locked, the dial gauge shall be mounted on the spindle head. For a), X-axis to be locked, if possible. For b), Y-axis to be locked, if possible. Place a cylindrical square with a flange base on the table, centre it approximately on the axis of rotation and fix the dial gauge with the stylus oriented in the X-axis direction for a) and in the Y-axis direction for b). Step 1) Touch the cylinder square by the stylus, close to the cylinder bottom and find the maximum reading by making small movements along the Y-axis for a) and along X-axis for b). Zero the dial gauge. Step 2) Move the head away from the table along the Z-axis, and touch again the cylinder close to its top. Note the Z-axis travel length. Find the maximum reading by making small movements along the Y-axis for a) and along the X-axis for b) and note the new reading. Turn the table by 180° and repeat steps 1) and 2). For both measurements a) and b), the parallelism error to be reported is the average value (half the algebraic sum) of the two readings near the top of the cylinder, divided by the length travelled along the Z-axis. Alternative method: A test sphere shall be mounted on the spindle head of the machine and the dial gauge shall be mounted on the table. The test sphere shall be centred with respect to the C'-axis average line by moving X- and Y-axes, while rotating the C'-axis. The Z-axis shall then be moved to another location. The dial gauge is re-positioned to read against the test sphere at this new location. The error in the centre position shall be recorded as half the difference of the readings of the dial gauge at opposite points on the sphere. This alternative method can be used when it is possible to touch a complete horizontal circumference of the sphere (e.g. the sphere equator).	

10 Geometric tests for the vertical spindle head

Object **G19**

Checking of the run-out of internal taper of the tool-holding spindle:
a) close to the spindle nose;
b) at a distance of 250 mm from position a).
Carry out these tests for each tool-holding spindle of the machine.

Diagram



Key

a) and b) measurement positions

Tolerance

	$D \leq 125$	$125 < D \leq 200$	$D > 200$
For a)	0,010	0,015	0,020
For b)	0,020	0,025	0,030

where D is the diameter of the spindle-nose face (see G20 diagram).

Measurement results

a) b)

Measuring instruments

Dial gauge and test mandrel.

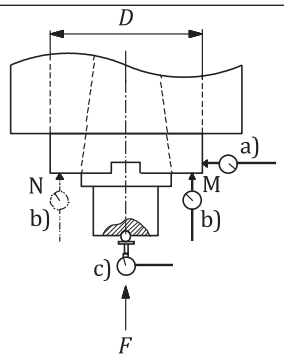
Observations and references to ISO 230-1:2012, 12.5.2

Attach a dial gauge to a fixed part of the machine and insert the test mandrel in the spindle.
For a), place the dial gauge stylus as close as possible to the spindle nose, rotate the spindle and record the reading.
Repeat the same operation at position b) at a distance of 250 mm from position a).
See also test AR1 in Annex A.

Object **G20**

Checking of the tool-holding spindle for:
a) run-out of external surface, where accessible;
b) face run-out;
c) axial error motion, $E_{Z(C)}$.
Carry out these tests for each vertical and horizontal tool-holding spindles of the machine.

Diagram



Key

N, M	measurement positions
F	force
D	diameter of the spindle nose face

Tolerance

	$D \leq 125$	$125 < D \leq 200$	$D > 200$
For a) and c)	0,010	0,015	0,020
For b)	0,020	0,025	0,030

where *D* is the diameter of the spindle-nose face.

Measurement results

a) b) c)

Measuring instruments

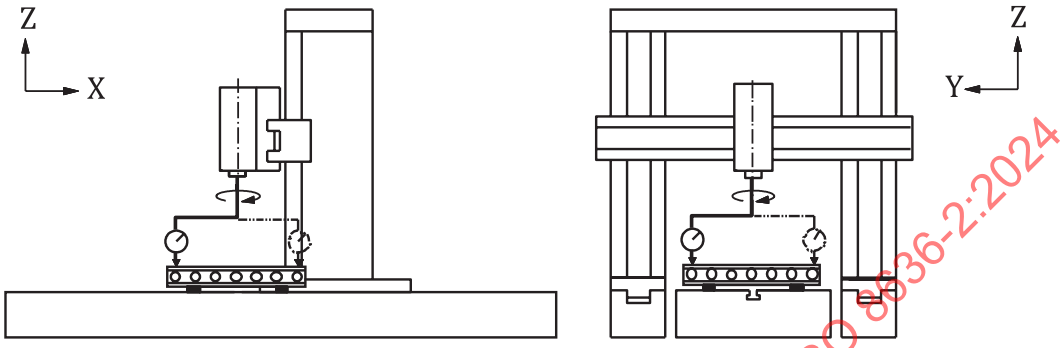
For a) and b): dial gauge.
For c): dial gauge with flat ended stylus and test sphere.

Observations and reference to ISO 230-1:2012, 12.5 [for a) and b)] and to ISO 230-7:2015, 5.4.4 [for c)]

Attach a dial gauge support and a dial gauge to the table.
For a), place the dial gauge stylus to contact the cylindrical external surface of the spindle, rotate the spindle and record the reading.
For b), place the dial gauge stylus as close as possible to the outside edge of the flat face at position M, rotate the tool-holding spindle and record the reading. Repeat the same operation at position N after moving the dial gauge. Determine the average value.
For c), insert a steel ball in the spindle centre.
Position the dial gauge stylus to contact the steel ball, rotate the spindle and record the reading.
The value and the direction of the force to be applied shall be specified by the manufacturer/supplier. When axially preloaded bearings are used, there is no need to apply the force, *F*.
See also test AR1 in Annex A.

Object	**G21**
Checking of the squareness of the vertical tool-holding spindle axis of rotation, (C) to: a) the X-axis motion, $E_{B(0X)(C)}$; b) the Y-axis motion, $E_{A(0Y)(C)}$. This test is also applicable to additional vertical spindle heads on the gantry.	

Diagram



Tolerance

For a) and b): 0,040/1 000 (0,020/500[a])

[a] Distance between the two measuring points touched.

Measurement results

a) b)

Measuring instruments

Dial gauge mounted on special arm and straightedge or surface plate.

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

Movable cross-rail at mid travel and locked, vertical spindle head at mid travel and locked, where possible. Quill or ram at 1/3 travel range from the upper end of travel.

For a), place a straightedge at the centre of the table parallel to the X-axis motion of the gantry in the vertical plane or the lack of parallelism shall be considered in the measurement. Attach the special arm with dial gauge to the tool-holding spindle and adjust the stylus of the dial gauge to touch the straightedge, and record the reading. Then rotate the spindle by 180° and record the new reading. The squareness error, $E_{B(0X)(C)}$, to be reported is the difference between the two readings over the distance between the two measurement points.

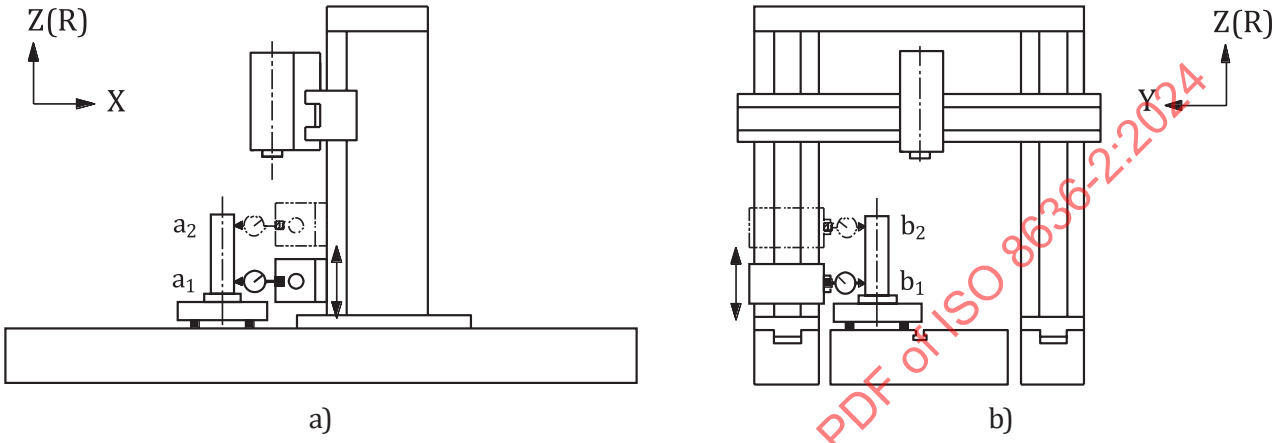
For b), place a straightedge at the centre of the table parallel to the Y-axis in the vertical plane or the lack of parallelism shall be considered in the measurement. Attach the special arm with dial gauge to the tool-holding spindle and adjust the stylus of the dial gauge to touch the straightedge, and record the reading. Then rotate the spindle by 180° and record the new reading. The squareness error, $E_{A(0Y)(C)}$, to be reported is the difference between the two readings over the distance between the two measurement points.

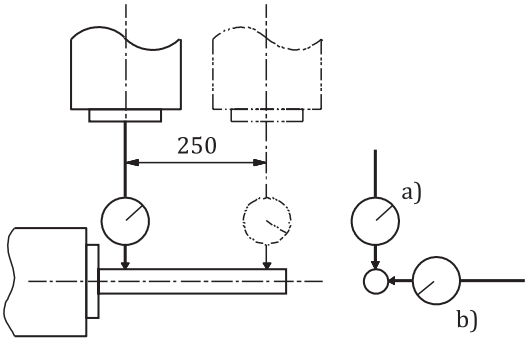
This test can be performed without straightedge.

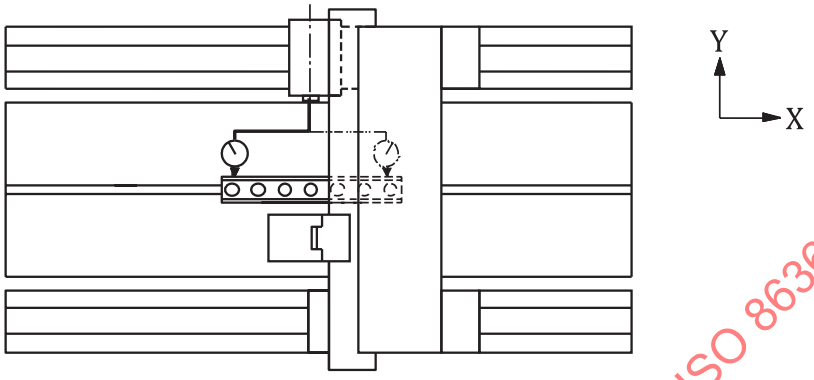
Mount the dial gauge on special arm and touch a gauge block placed on a specific point of the table. Set the dial gauge to zero and mark the point. Rotate the arm by 180° and move the X-axis for a) and the Y-axis for b) to touch the marked point and read the dial gauge. The difference between the two readings divided by the distance of the movement of the axis is the error to be reported.

The error motions of moving axis E_{ZX} and E_{BX} for a) and E_{ZY} and E_{AY} for b), influence the test results.

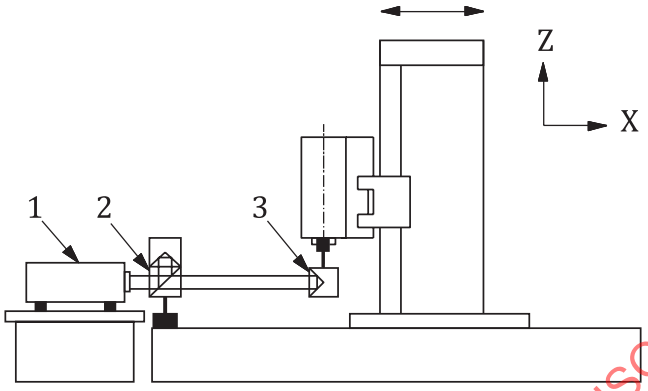
11 Geometric tests for the horizontal spindle head (side spindle head)

Object	**G22**
Checking of the squareness of the vertical motion of the side spindle head (R-axis) on a column to: a) the X-axis motion, $E_{B(0X)R}$; b) the Y-axis motion, $E_{A(0Y)R}$.	
Diagram  	
Key a_1, a_2, b_1 and b_2 measurement positions	
Tolerance For a) and b): 0,050/1 000	
Measurement results a) b)	
Measuring instruments Cylindrical square, surface plate, adjustable blocks and dial gauge or optical instruments.	
Observations and references to ISO 230-1:2012, 10.3.2.2 Place movable cross-rail and vertical spindle head at mid travel. Fix the dial gauge to the side spindle head. If the spindle can be locked, the dial gauge may be mounted on it. If the spindle cannot be locked, the dial gauge shall be placed on a fixed part of the side spindle head. Place a cylindrical square, or a regular square, on a surface plate oriented parallel to the reference plane defined by the X-axis motion of the gantry and the Y-axis motion of the vertical spindle head, or the lack of parallelism shall be considered in the measurement; then orient the dial gauge stylus in the X-axis direction to touch at point a_1 on the cylindrical square and zero the dial gauge. Move side spindle head to point a_2 and record the dial gauge reading. Rotate the cylindrical square by 180° and repeat the checking in the same order. Then carry out checking in the Y-axis direction at points b_1 and b_2 for the determination of the squareness error, $E_{A(0Y)R}$. The squareness errors, $E_{B(0X)R}$ and $E_{A(0Y)R}$, to be reported are the average values of the recorded dial gauge readings divided by the distance between points a_1 and a_2 for a) and between points b_1 and b_2 for b).	

Object	**G23**
Checking of the parallelism of the horizontal spindle head spindle axis, (B), to the Y-axis motion: a) in the vertical YZ plane, $E_{A(0Y)(B)}$; b) in the horizontal XY plane, $E_{C(0Y)(B)}$. Applicable only for the spindle head with a horizontal spindle axis. This test does not apply to removable spindle heads.	
Diagram  	
Tolerance For a) and b): 0,060/1 000 (0,015/250)	
Measurement results a) b)	
Measuring instruments Test mandrel and dial gauge or optical instruments.	
Observations and references to ISO 230-1:2012, 10.1.4 Attach the dial gauge to the vertical spindle head and adjust its stylus to touch the test mandrel mounted on the horizontal tool-holding spindle, for a) vertically and for b) horizontally, as near as possible to the spindle nose. Horizontal spindle head is locked in low-position. Movable cross-rail is locked in mid travel, where possible. Move the vertical spindle head (Y-axis) for the measuring length and record the readings. Record the maximum difference of dial gauge readings, then rotate the spindle axis, (B), by 180° and record again the maximum difference of dial gauge readings. The measurement results to be reported are the averages of the maximum readings recorded with spindle axis, (B), at 0° and at 180° respectively.	

Object	**G24**
Checking of the squareness of the axis of rotation of the horizontal tool-holding spindle, (B), to the motion of the gantry (X-axis), $E_{C(0X)(B)}$. Applicable only for the spindle head with a horizontal spindle axis. This test does not apply to removable spindle heads.	
Diagram  	
Tolerance 0,060/1 000 (0,030/500[a]) [a] Distance between the two measuring points touched.	
Measurement results	
Measuring instruments Straightedge, dial gauge mounted on special arm.	
Observations and references to ISO 230-1:2012, 10.3.3 Place a straightedge at the centre of the table parallel to the X-axis motion of the column in the horizontal plane or the lack of parallelism shall be considered in the measurement. The column is locked at mid travel, where possible. Horizontal spindle head at low-position and locked, where possible. Quill or ram at 1/3 travel from the horizontal spindle head. Attach the special arm with dial gauge to the horizontal tool-holding spindle and adjust the stylus of the dial gauge to touch the straightedge and record the reading. Then rotate the spindle by 180° and record the new reading. The squareness error, $E_{C(0X)(B)}$, to be reported is the ratio of the difference between the two readings over the distance between the two measurement points.	

12 Accuracy and repeatability of positioning of linear axes

Object					**P1**
Checking of the accuracy and repeatability of the X-axis motion of the gantry, E_{XX}.					
Diagram  **Key** 1 laser head 2 interferometer 3 retro-reflector					
Tolerance For axes up to 2 000		**Measured length** ≤500	≤1 000	≤2 000	**Measurement results**
Bi-directional positioning accuracy of X-axis[a]	$E_{XX,A}$	0,020	0,025	0,032	
Unidirectional positioning repeatability of X-axis[a]	$E_{XX,R\uparrow}$; $E_{XX,R\downarrow}$	0,008	0,010	0,013	
Bi-directional positioning repeatability of X-axis	$E_{XX,R}$	0,011	0,014	0,017	
Mean reversal value of X-axis	$E_{XX,\bar{B}}$	0,010	0,013	0,016	
Bi-directional systematic positioning error of X-axis[a]	$E_{XX,E}$	0,016	0,020	0,025	
Mean bi-directional positioning error of X-axis[a]	$E_{XX,M}$	0,010	0,013	0,016	
For axes exceeding 2 000					
Bi-directional systematic positioning error of X-axis[a]	$E_{XX,E}$	0,025 + 0,005 for each additional 1 000			
Mean bi-directional positioning error of X-axis[a]	$E_{XX,M}$	0,016 + 0,003 for each additional 1 000			
[a] Possible basis for machine acceptance.					
Measuring instruments Laser measuring equipment or linear scale.					

Observations and references to ISO 230-1:2012, 3.4.3; ISO 230-2:2014, Clause 3, 5.3.2 and 5.3.3

Relative measurement between the tool position and workpiece position is desired. When a linear scale is used, it shall be set on the table parallel to the X-axis, the scale reader being on the tool position. When laser equipment is used, the reflector should be set on the vertical spindle head and the interferometer on the table.

For axes exceeding 2 000, measure one or more segments of 2 000 with five runs forward and backward each. Tolerances for axis lengths ≤2 000 shall be applied.

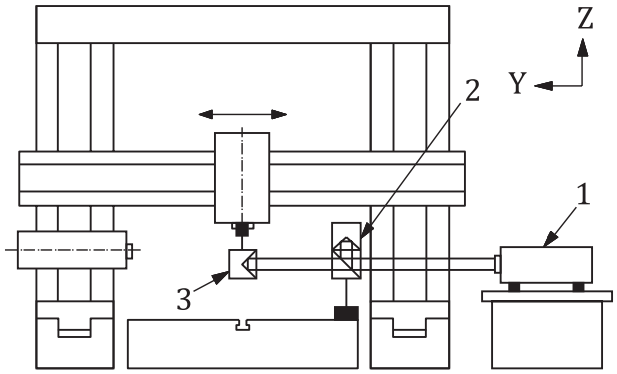
For axes up to 4 000, one measurement over one 2 000 segment is recommended; for axes over 4 000 and up to 8 000, two 2 000 segments are recommended, and so forth.

Test segments shall be equally spaced along the full axis length, with any excess length equally divided at the beginning, in between, and at the end of the test segments.

Other number of 2 000 mm segments, other lengths of segments, as well as the positions of the segments within the working area, can be subject to agreement between the manufacturer/supplier and the user. Additionally, one test over the total travel of the axis (once forward and once backward) shall be performed.

Concerning the test conditions, test program and presentation of results, ISO 230-2:2014, Clauses 3, 4 and 7 and 8.2.4 shall be referred to. The starting point of measurement shall be stated.

Object					**P2**
Checking of the accuracy and repeatability of the Y-axis motion of the vertical spindle head saddle, E_{YY}.					
Diagram					



Key

1 laser head 2 interferometer 3 retro-reflector

Tolerance For axes up to 2 000		**Measured length** ≤500	≤1 000	≤2 000	**Measurement results**
Bi-directional positioning accuracy of Y-axis[a]	$E_{YY,A}$	0,020	0,025	0,032	
Unidirectional positioning repeatability of Y-axis[a]	$E_{YY,R\uparrow}$; $E_{YY,R\downarrow}$	0,008	0,010	0,013	
Bi-directional positioning repeatability of Y-axis	$E_{YY,R}$	0,011	0,014	0,017	
Mean reversal value of Y-axis	$E_{YY,\bar{B}}$	0,010	0,013	0,016	
Bi-directional systematic positioning error of Y-axis[a]	$E_{YY,E}$	0,016	0,020	0,025	
Mean bi-directional positioning error of Y-axis[a]	$E_{YY,M}$	0,010	0,013	0,016	
For axes exceeding 2 000					
Bi-directional systematic positioning error of Y-axis[a]	$E_{YY,E}$	0,025 + 0,005 for each additional 1 000			
Mean bi-directional positioning error of Y-axis[a]	$E_{YY,M}$	0,016 + 0,003 for each additional 1 000			

[a] Possible basis for machine acceptance.

Measuring instruments

Laser measuring equipment or linear scale.

Observations and references to ISO 230-1:2012, 3.4.3; ISO 230-2:2014, Clause 3, 5.3.2 and 5.3.3

Relative measurement between the tool position and workpiece position is desired. When a linear scale is used, it shall be set on the table parallel to the Y-axis, the scale reader being on the tool position. When laser equipment is used, the reflector should be set on the vertical spindle head and the interferometer on the table.

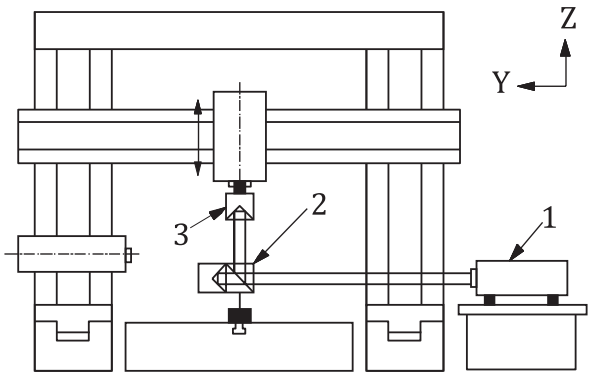
For axes exceeding 2 000, measure one or more segments of 2 000 with five runs forward and backward each. Tolerances for axis lengths ≤2 000 shall be applied.

For axes up to 4 000, one measurement over one 2 000 segment is recommended; for axes over 4 000 and up to 8 000, two 2 000 segments are recommended, and so forth.

Test segments shall be equally spaced along the full axis length, with any excess length equally divided at the beginning, in between, and at the end of the test segments.

Other number of 2 000 mm segments, other lengths of segments, as well as the positions of the segments within the working area can be subject to agreement between the manufacturer/supplier and the user. Additionally, one test over the total travel of the axis (once forward and once backward) shall be performed.

Concerning the test conditions, test program and presentation of results, ISO 230-2:2014, Clauses 3, 4 and 7 and 8.2.4 shall be referred to. The starting point of measurement shall be stated.

Object					**P3**
Checking of the accuracy and repeatability of the Z-axis motion of the vertical spindle head ram or quill, E_{ZZ}.					
Diagram					
					
Key 1 laser head 2 interferometer 3 retro-reflector					
Tolerance For axes up to 2 000		**Measured length**			**Measurement results**
		≤500	≤1 000	≤2 000	
Bi-directional positioning accuracy of Z-axis[a]	$E_{ZZ,A}$	0,020	0,025	0,032	
Unidirectional positioning repeatability of Z-axis[a]	$E_{ZZ,R\uparrow}$; $E_{ZZ,R\downarrow}$	0,008	0,010	0,013	
Bi-directional positioning repeatability of Z-axis	$E_{ZZ,R}$	0,011	0,014	0,017	
Mean reversal value of Z-axis	$E_{ZZ,\bar{B}}$	0,010	0,013	0,016	
Bi-directional systematic positioning error of Z-axis[a]	$E_{ZZ,E}$	0,016	0,020	0,025	
Mean bi-directional positioning error of Z-axis[a]	$E_{ZZ,M}$	0,010	0,013	0,016	
For axes exceeding 2 000					
Bi-directional systematic positioning error of Z-axis[a]	$E_{ZZ,E}$	0,025 + 0,005 for each additional 1 000			
Mean bi-directional positioning error of Z-axis[a]	$E_{ZZ,M}$	0,016 + 0,003 for each additional 1 000			
[a] Possible basis for machine acceptance.					
Measuring instruments Laser measuring equipment or linear scale.					

Observations and references to ISO 230-1:2012, 3.4.3 and ISO 230-2:2014, Clause 3, 5.3.2 and 5.3.3

Relative measurement between the tool position and workpiece position is desired. When a linear scale is used, it shall be set on the table parallel to the Z-axis, the scale reader being on the tool position. When laser equipment is used, the reflector should be set on the vertical spindle head and the interferometer on the table.

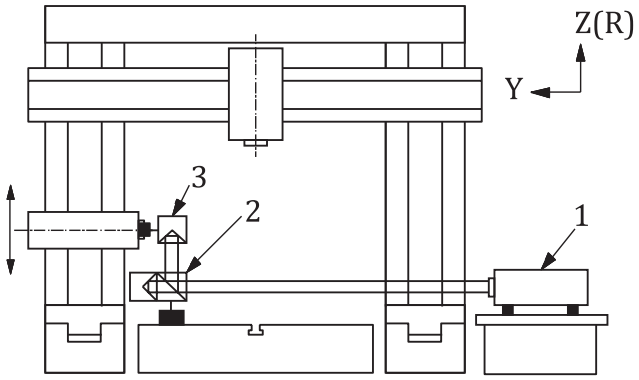
For axes exceeding 2 000, measure one or more segments of 2 000 with five runs forward and backward each. Tolerances for axis lengths ≤2 000 shall be applied.

For axes up to 4 000, one measurement over one 2 000 segment is recommended; for axes over 4 000 and up to 8 000, two 2 000 segments are recommended, and so forth.

Test segments shall be equally spaced along the full axis length, with any excess length equally divided at the beginning, in between, and at the end of the test segments.

Other numbers of 2 000 mm segments, lengths of segments and positions of the segments within the working area can be subject to agreement between the manufacturer/supplier and the user. Additionally, one test over the total travel of the axis (once forward and once backward) shall be performed.

Concerning the test conditions, test program and presentation of results, ISO 230-2:2014, Clauses 3, 4 and 7 and 8.2.4 shall be referred to. The starting point of measurement shall be stated.

Object					**P4**
Checking of the accuracy and repeatability of the vertical R-axis motion of the horizontal spindle head, E_{ZR}.					
Diagram					
					
Key 1 laser head 2 interferometer 3 retro-reflector					
Tolerance For axes up to 2 000		**Measured length**			**Measurement results**
		≤500	≤1 000	≤2 000	
Bi-directional positioning accuracy of R-axis[a]	$E_{ZR,A}$	0,020	0,025	0,032	
Unidirectional positioning repeatability of R-axis[a]	$E_{ZR,R\uparrow}$; $E_{ZR,R\downarrow}$	0,008	0,010	0,013	
Bi-directional positioning repeatability of R-axis	$E_{ZR,R}$	0,011	0,014	0,017	
Mean reversal value of R-axis	$E_{ZR,\bar{B}}$	0,010	0,013	0,016	
Bi-directional systematic positioning error of R-axis[a]	$E_{ZR,E}$	0,016	0,020	0,025	
Mean bi-directional positioning error of R-axis [a]	$E_{ZR,M}$	0,010	0,013	0,016	
For axes exceeding 2 000					
Bi-directional systematic positioning error of R-axis[a]	$E_{ZR,E}$	0,025 + 0,005 for each additional 1 000			
Mean bi-directional positioning error of R-axis [a]	$E_{ZR,M}$	0,016 + 0,003 for each additional 1 000			
[a] Possible basis for machine acceptance.					
Measuring instruments Laser measuring equipment or linear scale.					

Observations and references to ISO 230-1:2012, 3.4.3; ISO 230-2:2014, Clause 3, 5.3.2 and 5.3.3

Relative measurement between the tool position and workpiece position is desired. When a linear scale is used, it shall be set on the table parallel to the R-axis, the scale reader being on the tool position. When laser equipment is used, the reflector should be set on the horizontal spindle head and the interferometer on the table.

For axes exceeding 2 000, measure one or more segments of 2 000 with five runs forward and backward each. Tolerances for axis lengths ≤2 000 shall be applied.

For axes up to 4 000, one measurement over one 2 000 segment is recommended, for axes over 4 000 and up to 8 000, two 2 000 segments are recommended, and so forth.

Test segments shall be equally spaced along the full axis length, with any excess length equally divided at the beginning, in between, and at the end of the test segments.

Other number of 2 000 mm segments, other lengths of segments, as well as the positions of the segments within the working area can be subject to agreement between the manufacturer/supplier and the user. Additionally, one test over the total travel of the axis (once forward and once backward) shall be performed.

Concerning the test conditions, test program and presentation of results, ISO 230-2:2014, Clauses 3, 4 and 7 and 8.2.4 shall be referred to. The starting point of measurement shall be stated.