INTERNATIONAL STANDARD

**ISO 13041-2**

Second edition
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# Test conditions for numerically controlled turning machines and turning centres —

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

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

*Partie 2: Essais géométriques pour les machines à broche porte-pièce verticale*



Reference number
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ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Fax: +41 22 749 09 47
Email: copyright@iso.org
Website: www.iso.org

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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.

This second edition cancels and replaces the first edition (ISO 13041-2:2008), which has been technically revised. The main changes compared to the previous edition are as follows:

— the categorization of machine size ranges has been abolished;

— the discrimination of tolerances, if any, due to different machine sizes (diameter of chuck or workholding spindle) is expressed in the specific tests G1 to G21;

— the tolerances given in the G-tests have been changed due to the absence of size categories;

— the numbering of tests G1 to G21 has been changed;

— tests for horizontal rams have been removed because these are no longer in existence;

— former G1 test "checking of flatness of the workholding spindle" has been removed;

— terms in Persian and Japanese have been added in Annex B.

In addition to text written in the official ISO languages (English, French or Russian), this document gives text in German, Italian, Japanese and Persian. This text is published under the responsibility of the member body/National Committee for Germany (DIN), Italy (UNI), Japan (JISC) and Iran (ISRI) and is given for information only. Only the text given in the official languages can be considered as ISO text.

A list of all parts in the ISO 13041 series can be found on the ISO website.



# Introduction

A turning centre is a machine tool in which the principal movement is the rotation of the workpiece against the stationary cutting tool(s). It is a numerically controlled machine tool capable of performing multiple machining operations, including milling, turning, boring, drilling and tapping, as well as automatic tool changing from a magazine or similar storage unit in accordance with a machining program.

The objective of the ISO 13041 series is to provide information as wide and comprehensive as possible on geometric, positional, contouring, thermal and machining tests which can be carried out for comparison, acceptance, maintenance or any other purpose.

The ISO 13041 series specifies, with reference to ISO 230-1 and ISO 230-7, tests for turning centres and numerically controlled turning machines with/without tailstocks standing alone or integrated in flexible manufacturing systems. The ISO 13041 series also establishes the tolerances or maximum acceptable values for the test results corresponding to general-purpose and normal-accuracy turning centres and numerically controlled turning machines.

# Test conditions for numerically controlled turning machines and turning centres —

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



## 1 Scope

This document specifies, with reference to ISO 230-1 and ISO 230-7, the geometric tests for general-purpose normal accuracy numerically controlled (NC) turning machines and turning centres with vertical workholding spindles, as well as the corresponding applicable tolerances.

This document explains different concepts or configurations and common features of NC turning machines and turning centres with vertical workholding spindles. It also provides a terminology and designation of controlled axes (see Figures 1, 2 and Table 1).

This document deals only with the verification of the accuracy of the machine. It does not apply to the operational testing of the machine (e.g. vibration, abnormal noise, stick slip motion of components) nor to machine characteristics (e.g. speeds, feeds). Tests not concerning the geometric accuracy of the machine are dealt with in other parts of ISO 13041.

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

## 3 Terms and definitions

For the purposes of this document, the following terms and definitions 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**
**turning machine**
machine tool in which the principal movement is the rotation of the workpiece against the stationary cutting tool(s)

**3.2**
**numerical control**
**NC**
automatic control of a process performed by a device that makes use of numerical data introduced while the operation is in progress

[SOURCE: ISO 2806:1994, 2.1.1]

**3.3**
**numerically controlled turning machine**
**NC turning machine**
*turning machine* (3.1) that operates under *numerical control* (3.2) or computerized numerical control

**3.4**
**turning centre**
*NC turning machine* (3.3) equipped with power driven tool(s) and the capacity to orientate the workholding spindle around its axis

Note 1 to entry: This machine may include additional features such as automatic tool changing from a magazine.

**3.5**
**tool turret**
multiple tool holding system capable of positioning the cutting tool to execute machining operation

## 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 tolerance are expressed in ratios; but in some cases, micro-radians or arc seconds may be used for clarification purposes. The equivalence of Formula (1) should always be kept in mind.

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

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

To apply this document, reference shall be made to ISO 230-1:2012 and ISO 230-7:2015, when required, especially for installation of the machine before testing, warming up of the spindle and moving components, description of measuring methods and recommended measuring instrument uncertainty.

Where the test concerned is in compliance with the specifications of ISO 230-1 or ISO 230-7, a reference to the corresponding clause of ISO 230-1 or ISO 230-7 is shown before the instructions in the "Observations" block of the tests described in Clause 5. Tolerances are given for each test (see G1 to G21, AR1 and AR2).

### 4.3 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, 6.1.1 and 6.1.2.).

### 4.4 Testing sequence

The sequence in which 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.

## 4.5 Test to be performed

When testing a machine, it is not always necessary or 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 components and/or the properties of the machine. These tests are to be clearly stated when ordering a machine. 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.

## 4.6 Measuring instruments

Measuring instruments indicated in the tests described below 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, that 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 analogue 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, ceramic, steel or cast iron square, a cylindrical square, a reference cube, or, again, a special, dedicated artefact.

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

## 4.7 Diagrams

In this document, for reasons of simplicity, the diagrams associated with geometric tests generally illustrate only one type of turning machine.

## 4.8 Software compensation

When built-in software facilities are available for compensating certain geometric deviations, their use during these tests for acceptance purposes shall be based on an agreement between the user and the manufacturer/supplier, with due consideration of the machine tool intended use. When software compensation is used, this shall be stated in the test report. It shall be noted that when software compensation is used, axes shall not be locked for test purposes (see ISO/TR 16907).

## 4.9 Gravity influence for two rail head machines

For machine tools provided with two slides on the cross rail [see Figure 2 and Table 1, Type B, a) and b)], the rail head not under test shall be in a defined park position according to the manufacturer's recommendations. If both rail heads are used, the deviations can change due to gravity.

## 4.10 Tolerances

In this document, all tolerance values are recommendations. When they are used for acceptance purposes, other values can be agreed upon between the user and the manufacturer/supplier. The required/agreed tolerance values shall be clearly stated when ordering the machine.

When the tolerance for a geometric test is established for a measuring length different from that given in this document, it shall be taken into consideration that the minimum value of tolerance is 0,005.

In principles, angular tolerances are given as a distance over 1 000 mm. The angle converted for a typical measuring length is presented in parentheses. For example: 0,060/1 000 (0,015/250).

### 4.11 Linear motions

For simplicity, all the machine examples shown in Figures 1 and 2 use the axis designation of a letter and a number (e.g. X, X1, X2,…) as defined in ISO 841:2001, 6.1. In all examples, the use of the letters U, V, or W can be substituted.

### 4.12 Tool turrets or toolholding components (element)

Depending on the machine configuration, cutting tools (stationary or power driven) can be clamped in a tool holder or in a tool turret located on the tool holder slide (rail head ram) and/or the side head ram. An automatic tool change device can also be used. However, this document does not provide any test methods for automatic tool change operations.

### 4.13 Machine configurations and designation of axes

A designation of the kinematic chain for the particular machine tool is supplied along with its respective diagrams (see Figures 1, 2 and Table 1). The designation illustrates the architecture of the machine tool by giving a list of structural and moving components starting from the workpiece (w) towards the tool (t). It describes the kinematic chain of moving axes in square brackets, where "w", "t", and "b" represent the workholding table or spindle, the tool, and the bed. The letter in front of the designation represents the type of machine tool. "V" stands for vertical workholding spindle/table.

### 4.14 Machine classifications

The machines considered in this document are divided into the following basic configurations (see Figures 1, 2 and Table 1).

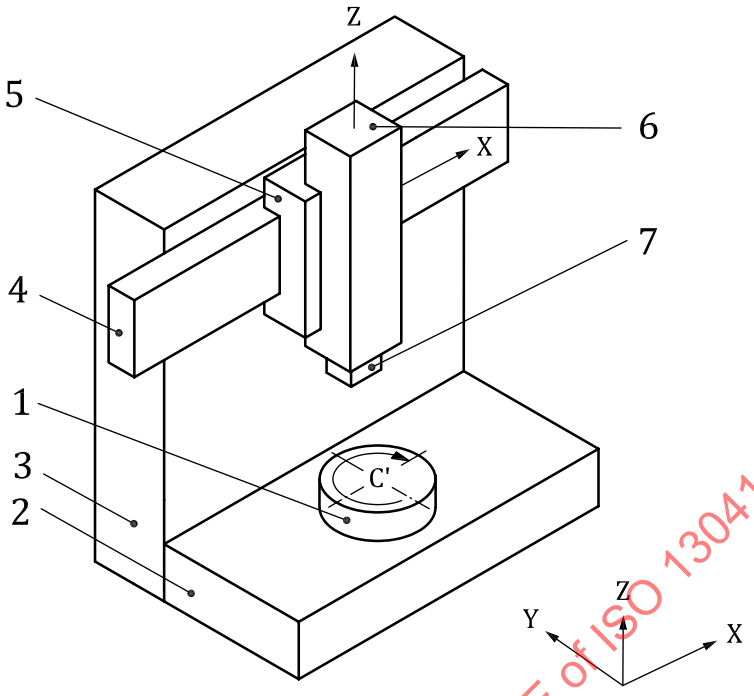
— Type A: single-column machines;

— Type B: double-column machines.

Type B machine configurations are further classified into the following types:

— fixed columns — portal type;

— moving columns — gantry type.

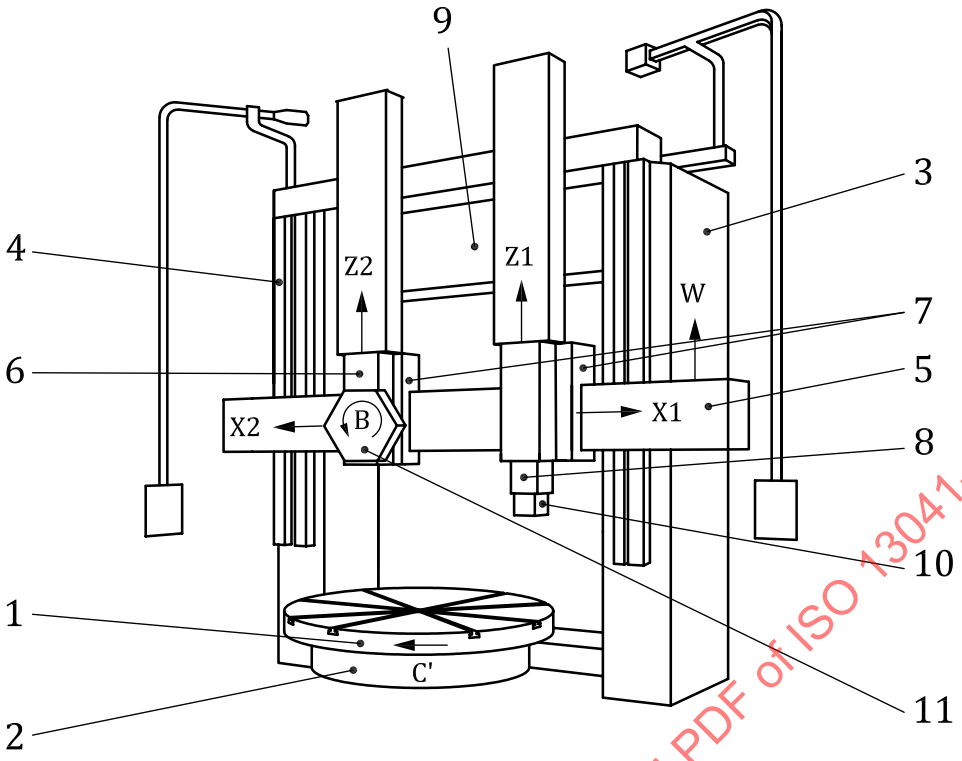



**Key**

| | English | French |
|---|---|---|
| 1 | workholding spindle (workholding table), C’ | broche porte-pièce (plateau tournant), C’ |
| 2 | base | base |
| 3 | column | montant |
| 4 | cross-rail | traverse porte-chariot |
| 5 | rail head (saddle), X | chariot de traverse (traînard), X |
| 6 | tool holder slide (rail head ram), Z | chariot de tourelle, Z |
| 7 | tool holder | porte-outil |

NOTE For languages other than official ISO languages, see Table B.1.

**Figure 1 — Example of a single-column machines (Type A) V [w C' b X Z t]**




**Key**

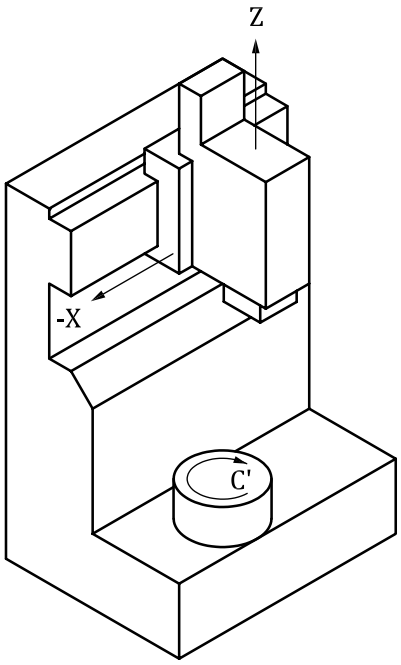
| | English | French |
|---|---|---|
| 1 | workholding spindle (workholding table), C’ | broche porte-pièce (plateau tournant), C’ |
| 2 | base | base |
| 3 | right-hand column | montant droit |
| 4 | left-hand column | montant gauche |
| 5 | cross-rail, W | traverse porte-chariot, W |
| 6 | tool holder slide (rail head ram), Z2 | coulant du chariot de traverse, Z2 |
| 7 | rail head (saddle), X1, X2 | chariot de traverse (traînard), X1, X2 |
| 8 | tool holder slide (rail head ram), Z1 | coulant du chariot de traverse, Z1 |
| 9 | bridge | traverse |
| 10 | tool holder | porte-outil |
| 11 | tool turret, B | tourelle, B |

NOTE For languages other than official ISO languages, see Table B.2.

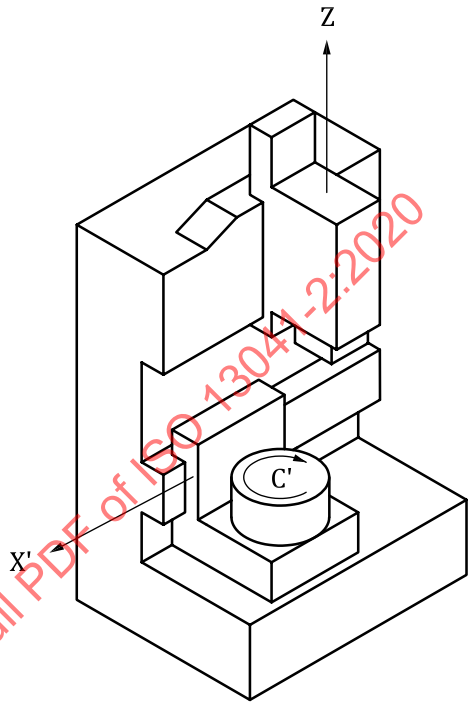
**Figure 2 — Example of a double-column machines (Type B) V [w C' b W X1 Z1 t1] [w C' b W X2 Z2 B t*n*]**

**Table 1 — Examples of machine configurations**

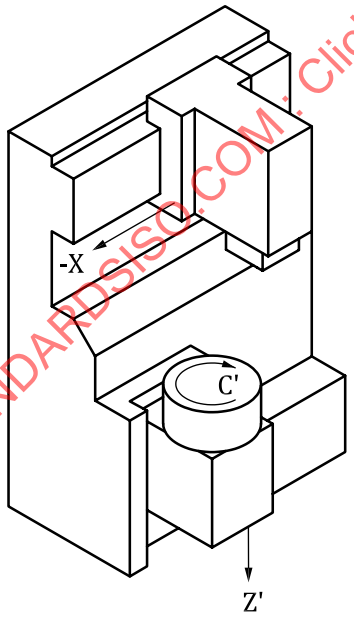
**Type A - Single-column machines**



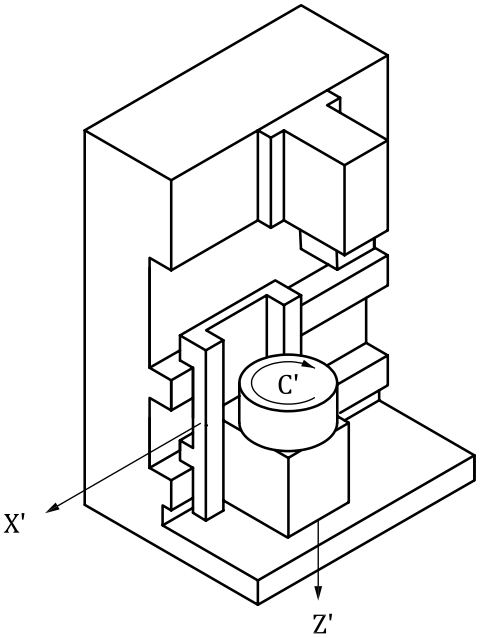

**a) Compound head type**
**V [w C' b X Z t]**




**b) Shared motion**
**(moving workholding spindle) type**
**V [w C' X' b Z t]**



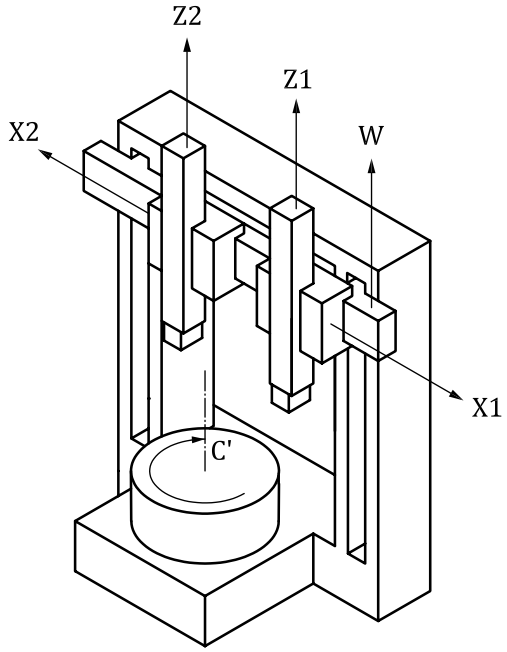

**c) Shared motion**
**(moving head/saddle) type**
**V [w C' Z' b X t]**



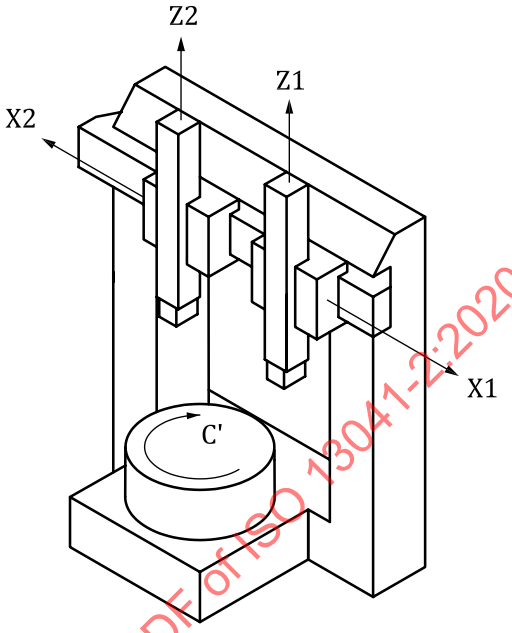

**d) Compound workholding**
**spindle type**
**V [w C' Z' X' b t]**

**Table 1** *(continued)*

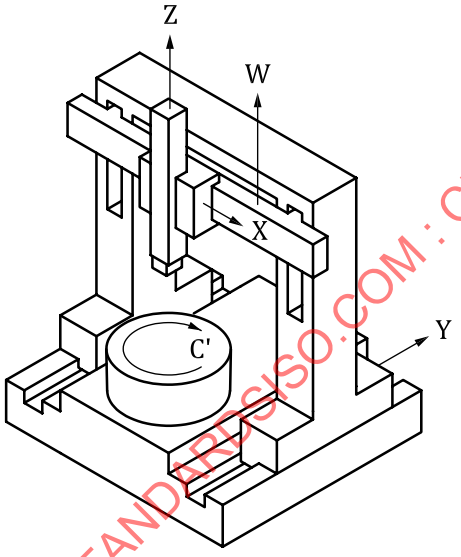
**Type B - Double-column machines**



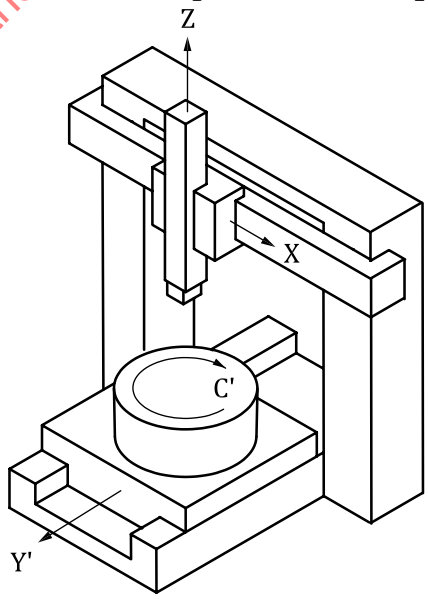

**a) Fixed column (portal type), moving cross-rail**
**V [w C' b W X1 Z1 $t_1$] V [w C' b W X2 Z2 $t_2$]**




**b) Fixed column (portal type), fixed cross-rail**
**V [w C' b X1 Z1 $t_1$] V [w C' b X2 Z2 $t_2$]**



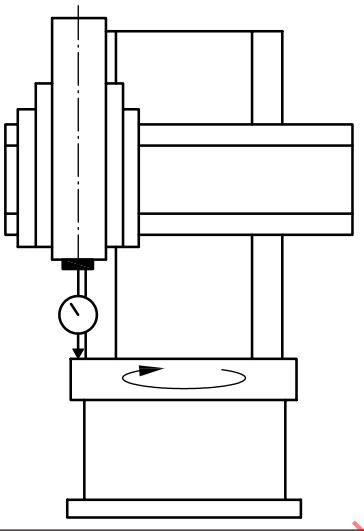
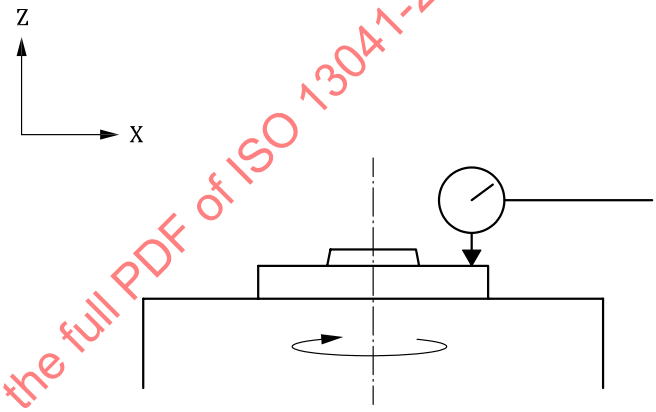

**c) Moving column (gantry type), moving cross-rail**
**V [w C' b Y W X Z t]**




**d) Fixed column (portal type), moving workholding spindle (Y-axis)**
**V [w C' Y' b X Z t]**

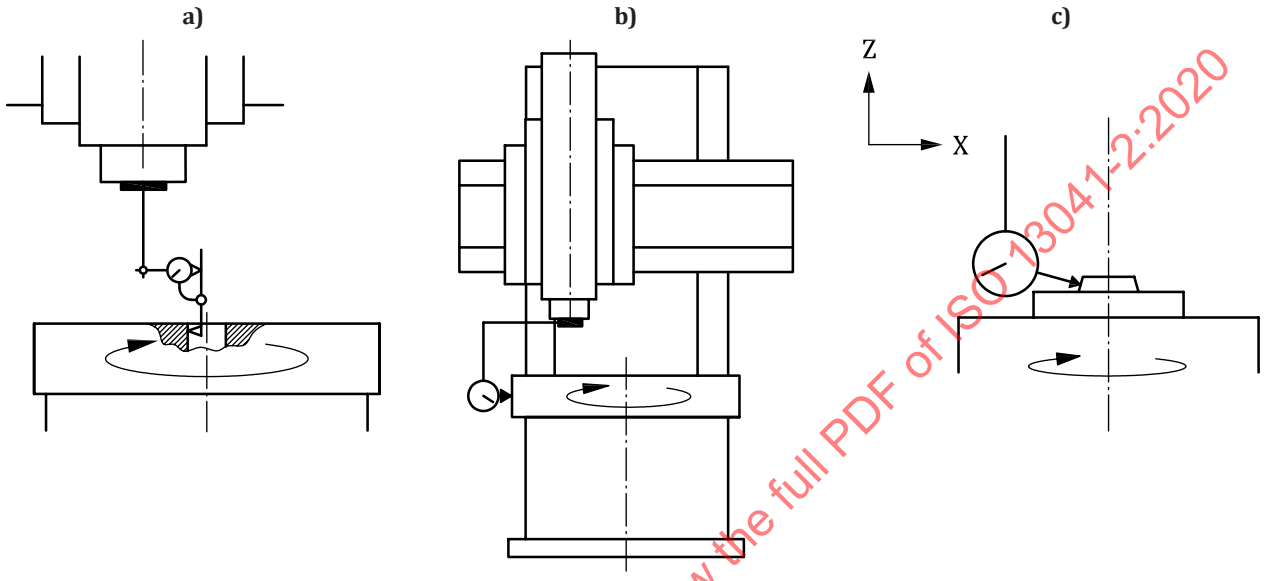
# 5 Geometric tests

## 5.1 Workholding spindle or table

| **Object** | | | **G1** |
|---|---|---|---|
| Checking of the face run-out of workholding table or spindle:<br>a) face run-out of the workholding table surface;<br>b) face run-out of the spindle face. | | | |
| **Diagram**<br>**a)**  **b)**   | | | |
| **Tolerance** | | | **Measured error** |
| a) | For diameters up to 1 000: | 0,010 | a) |
| | For every further diameter increase of up to 1 000: | +0,010 | |
| b) | For all diameters: | 0,010 | b) |
| Measuring instruments<br>a) and b) Dial gauge | | | |
| **Observations and references to ISO 230-1:2012, 12.5.2**<br>a) The dial gauge shall be placed on a component of the machine tool carrying the tool and shall be placed as near as possible to the workholding table periphery and approximately 180° from the position occupied by the tool if the workholding table was machined in situ (see also Test AR1).<br>Cross-rail and rail head locked in position, where possible.<br>b) The dial gauge measurements shall be taken on the maximum diameter of the spindle face. | | | |

| **Object** | **G2** |
|---|---|
| Checking of the run-out of:<br>a) the workholding table bore;<br>b) the external cylindrical surface of the workholding table (in the case of a workholding table not having a central bore);<br>c) centring diameter of the workholding spindle. | |

**Diagram**




| **Tolerance** | | | **Measured error** |
|---|---|---|---|
| a) | For workholding table diameter up to 1 000: | 0,010 | a) |
| | For workholding table diameter greater than 1 000: | 0,020 | |
| b) | For diameter up to 1 000: | 0,010 | b) |
| | For every further increase of up to 1 000 diameter: | +0,010 | |
| c) | For all centering diameter sizes: | 0,010 | c) |

**Measuring instruments**

a), b) and c) Dial gauge

**Observations and references to ISO 230-1:2012, 12.5**

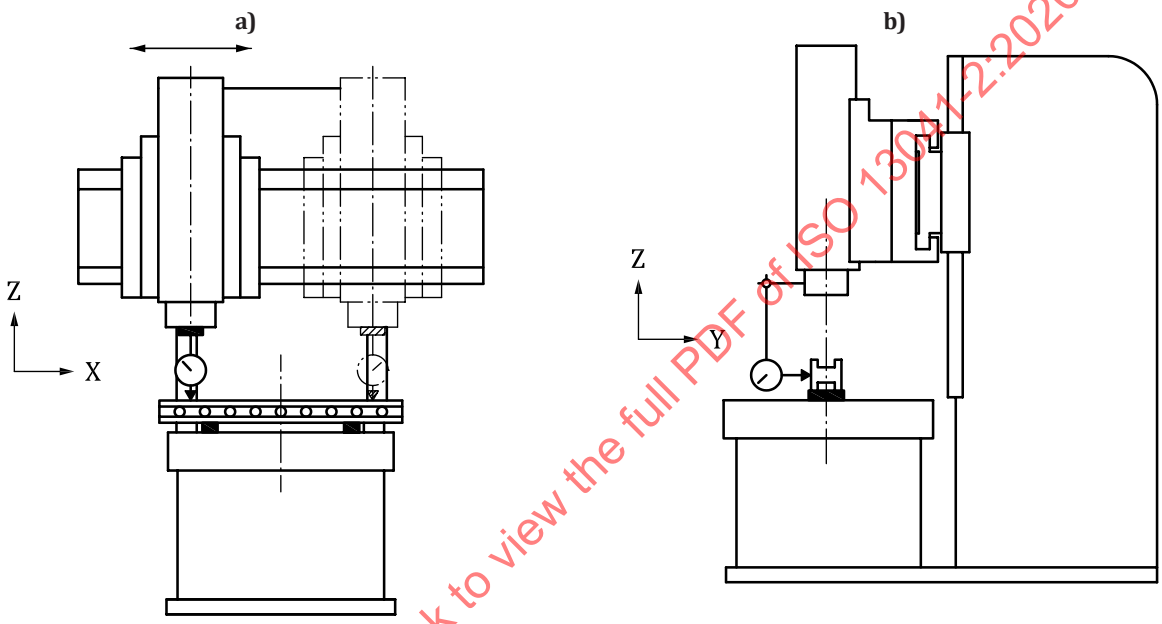
a) and b) The dial gauge shall be placed approximately 180° from the position occupied by the tool if the workholding table was machined in situ.

Cross-rail, rail head and slide locked in position, where possible.

The dial gauge should be placed on the tool holder close to the tool position.

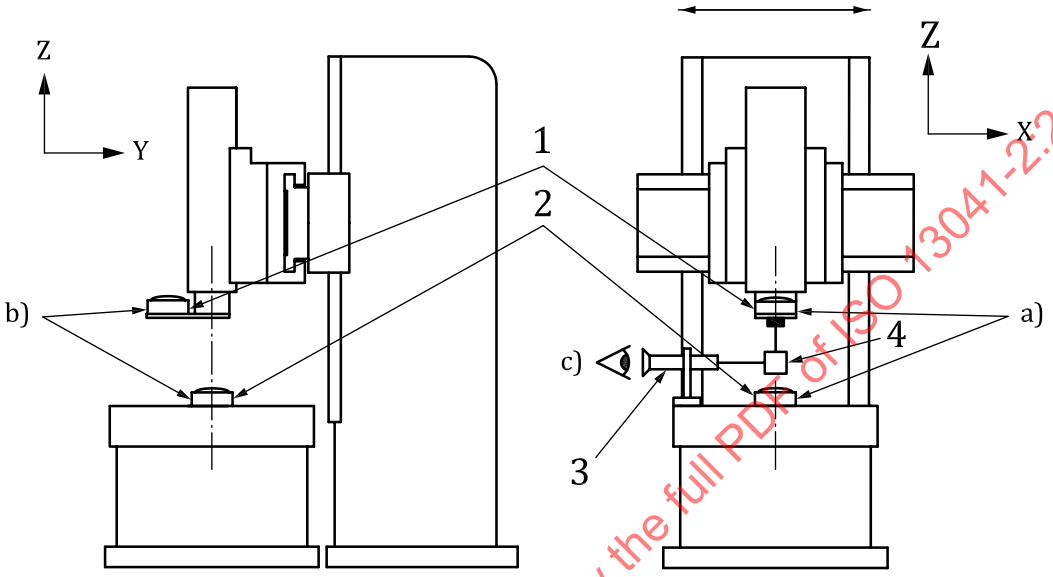
c) See ISO 230-1:2012, 12.5.2. When the surface is conical, the stylus of the dial gauge shall be normal to the contacting surface.

## 5.2 Linear axes X and Z

| **Object** | **G3** |
|---|---|
| Checking of the straightness of the rail head (X-axis) motion on the cross-rail:<br>a) in the vertical ZX plane ($E_{ZX}$);<br>b) in the horizontal XY plane ($E_{YX}$).<br>NOTE Test setup shown in b) is for turning centres only. | |
| **Diagram**<br>  <br> | |
| **Tolerance**<br>For a) and b)<br>0,020 for measuring length of 1 000<br>Add 0,010 for each additional length of 500<br>Local tolerance: 0,010 for any measuring length of 500 | **Measured error**<br>a)<br>b) |
| **Measuring instruments**<br>a) Straightedge, adjustable blocks and dial gauge or optical instrument<br>b) Straightedge, adjustable blocks and dial gauge or optical instrument or taut wire and microscope | |
| **Observations and references to ISO 230-1:2012, 8.2**<br>If the gantry or workholding spindle (table) is movable in the Y-axis direction, it shall be positioned such that the measuring line should be close to the workholding spindle axis of rotation.<br>Position the tool holder slide in the middle position of its travel. The straightedge shall be placed on the workholding spindle or table approximately perpendicular to the C-axis.<br>The dial gauge, the interferometer, the target or the microscope shall be mounted on the rail head near the position of a tool.<br>If the straightedge is not aligned mechanically, the results can be evaluated according to ISO 230-1:2012, 3.4.8. | |

| **Object** | **G4** |
|---|---|
| Checking of the angular error of the rail head motion (X-axis) on the cross-rail:<br>a) in the ZX plane $E_{BX}$ (pitch);<br>b) in the YZ plane $E_{AX}$ (roll);<br>c) in the XY plane $E_{CX}$ (yaw). | |

**Diagram**




**Key**

| | |
|---|---|
| 1 measuring level | 3 autocollimator |
| 2 reference level | 4 mirror |

| **Tolerance** | **Measured error** |
|---|---|
| For a), b), and c) | a) |
| For measuring length up to 1 600: 0,040/1 000 | b) |
| For measuring length over 1 600: 0,060/1 000 | c) |

**Measuring instruments**

a) Precision level, or optical angular measuring instrument

b) Precision level

c) Optical angular measuring instrument, e.g. autocollimator

**Observations and references to ISO 230-1:2012, 3.4.16 and 8.4**

The measuring level or instrument shall be placed on the tool holder:

a) ($E_{BX}$: pitch) level, or optical instrument oriented in the ZX plane (set vertically);

b) ($E_{AX}$: roll) level oriented in the YZ plane;

c) ($E_{CX}$: yaw) optical instrument (e.g. autocollimator) oriented in the XY plane (set horizontally).

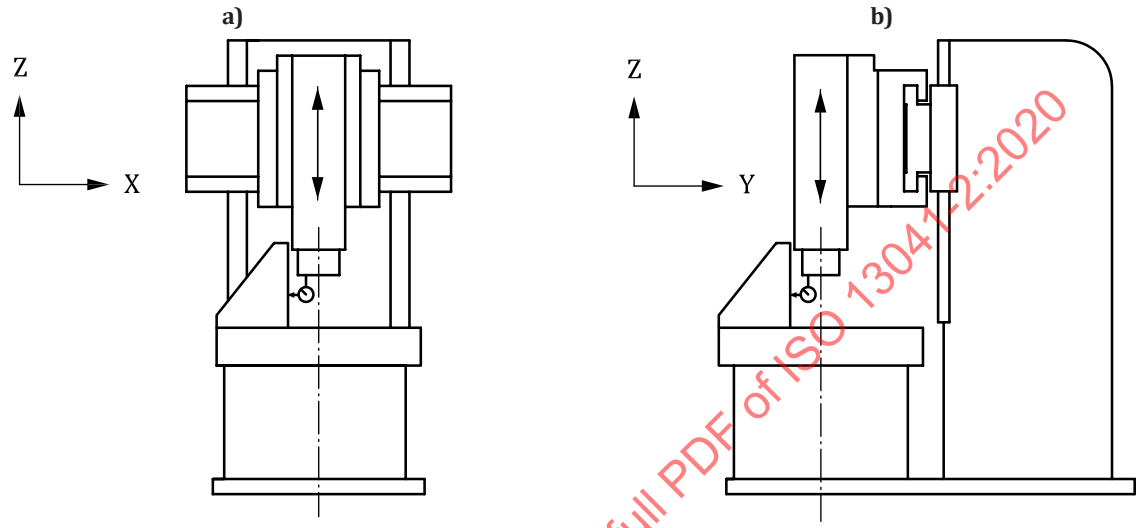
When rail head motion causes an angular error of both tool holder and workholding spindle or table, differential measurements of the two angular errors shall be made and this shall be stated.

The reference level shall be placed on the workholding spindle or table.

Measurements shall be carried out at a minimum of five positions equally spaced along the path of travel in both directions of the movement.

| **Object** | **G5** |
|---|---|
| Checking of the straightness of motion of the tool holder slide (ram) in the Z-axis direction:<br>a) in the ZX plane ($E_{XZ}$);<br>b) in the YZ plane ($E_{YZ}$). | |

**Diagram**




| **Tolerance** | **Measured error** |
|---|---|
| For a) and b)<br>0,050 over a measuring length of 1 000<br>Local tolerance: 0,020 over 300 | a)<br>b) |

**Measuring instruments**

a) and b) Square and dial gauge

Alternative: Optical instrument, e.g. sweeping laser

**Observations and references to ISO 230-1:2012, 8.2**

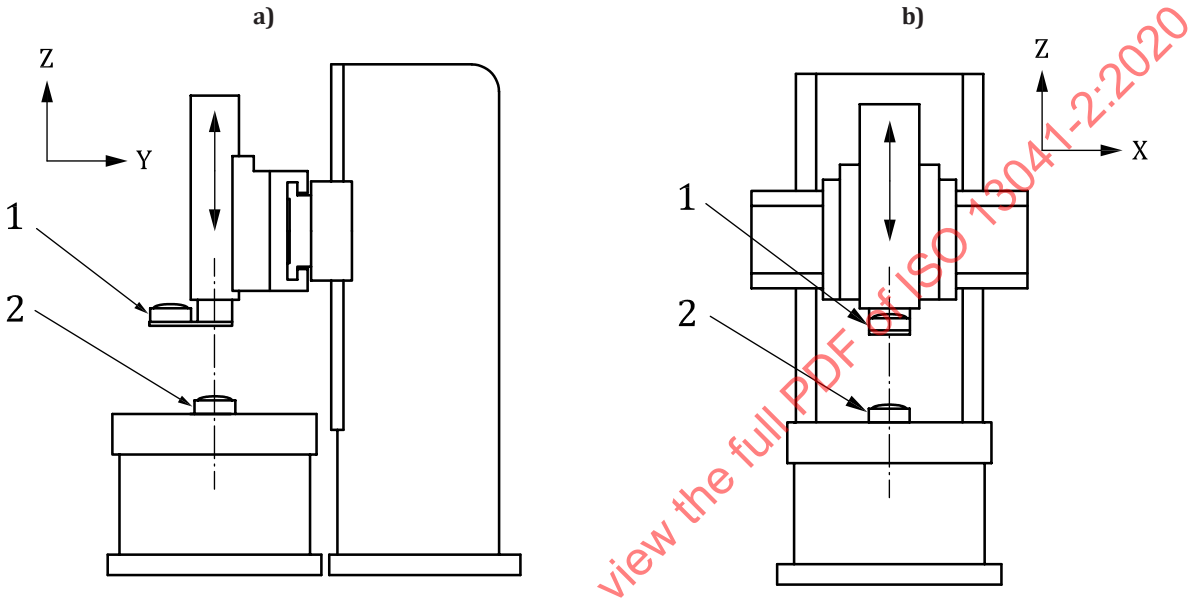
Move tool holder slide over the centre of the table. Place a square (not a cylindrical square) in radial direction on the table, with the horizontal arm parallel to the X-axis, on one side of the tool holder slide, in such a way that the table can rotate 90° to bring the square from the ZX plane to the YZ plane without interference with the tool holder slide. The square does not need to be aligned with the C-axis. Take readings from the dial gauge at several positions along the Z-axis.

If this test is to be combined with test G8, place the square in such a position as to allow the table to be rotated to four positions at 90° from each other.

This test setup is also applicable to the tests G8, G9 and G11.

| **Object** | **G6** |
|---|---|
| Checking of the angular error of the tool holder slide (ram) motion (Z-axis).<br>Optional, checking of rotation of the ram around Z-axis (if roll is relevant):<br>a) in the YZ plane $E_{AZ}$ (tilt around X);<br>b) in the ZX plane $E_{BZ}$ (tilt around Y);<br>c) optional: $E_{CZ}$ (roll). | |

**Diagram**




**Key**

1 measuring level 2 reference level

| **Tolerance** | | **Measured error** |
|---|---|---|
| For measuring length up to 1 600: | 0,030/1 000 | a) |
| For measuring length over 1 600: | 0,060/1 000 | b) |
| For optional measuring of roll the tolerance is 0,040/1 000 | | c) |

**Measuring instruments**

a) and b) Precision level, autocollimator or laser interferometer with angular optics

**Observations and references to ISO 230-1:2012, 3.4.16 and 8.4**

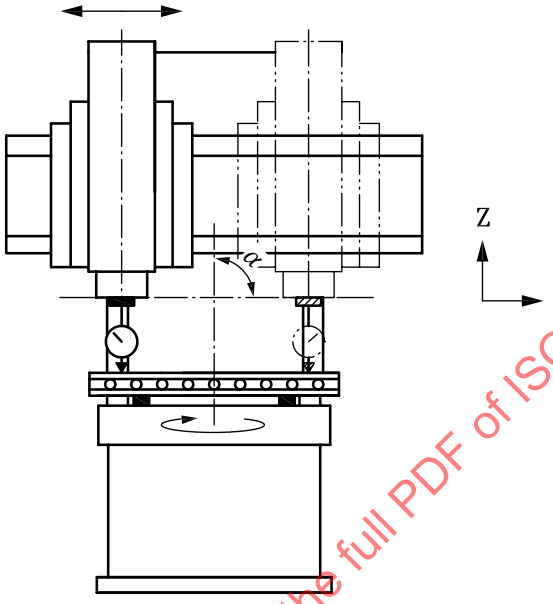
Measurements shall be carried out at a minimum of five positions equally spaced along the travel in both directions of the movement.

The reference level shall be placed on the workholding spindle or table.

For optional measuring roll of Z, see ISO 230-1:2012, 8.4.2.4.

| **Object** | **G7** |
|---|---|
| Checking of the squareness of rail head motion (X-axis) to workholding spindle axis of rotation (C-axis) [$E_{B(0(C))X}$].<br>NOTE Also applicable for a second tool holder slide on the column. | |

**Diagram**




| **Tolerance** | | **Measured error** |
|---|---|---|
| 0,070/1 000 (≈0,020/300) | | |
| For every further increase of 300 measuring length: | +0,010/300 | |
| Direction of deviation: | $\alpha \leq 90°$ | |
| The trajectory of X-axis shall be concave unless by special arrangement between the user and supplier/manufacturer. | | |

**Measuring instruments**

Straightedge, adjustable blocks and dial gauge

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

A dial gauge is fixed to the tool turret or tool holder close to the tool position.

The straightedge shall be placed on the workholding spindle or table perpendicular to the C-axis, or the lack of squareness shall be considered in the measurement; or

If the straightedge is not perfectly perpendicular to the C-axis, measurements should be taken at several positions of the X-axis motion, then rotate the spindle through 180° and take a second set of measurements at the same X locations. The squareness deviation is the range of the mean of these two sets of measurements.

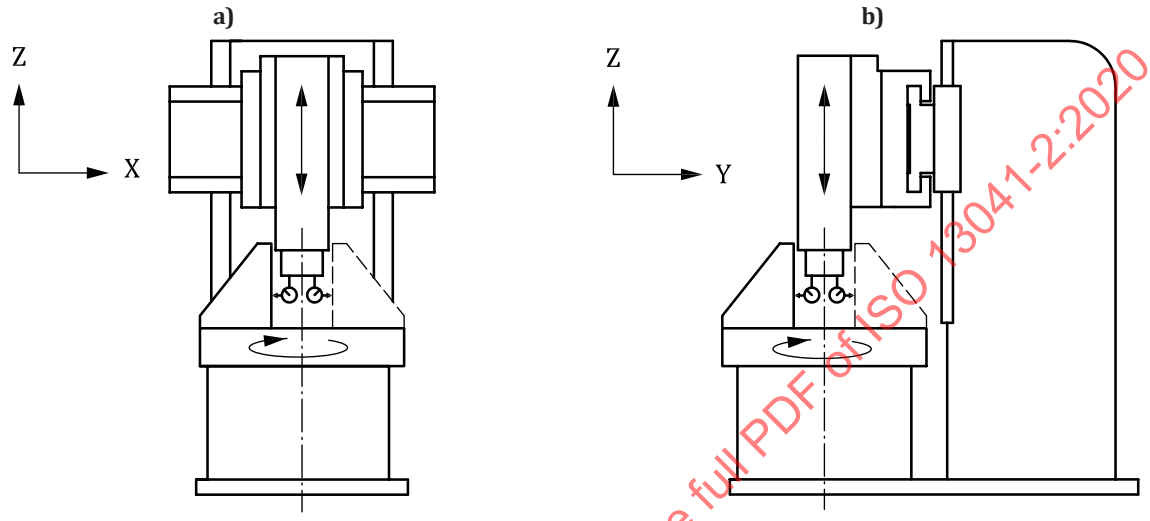
This test applies to all rail heads.

The X-axis orientation should be identified either through its least square line or through reading in two extreme measuring points, if possible symmetrical. But some X-axes cannot move too far beyond the table centre. In this case, whichever option is chosen, it can apply approximately to one radius.

NOTE For milling application, squareness of X to Z can be an important consideration. In this case, it can be measured by G21 test or derived from the results of G7 and G8 tests.

| **Object** | **G8** |
|---|---|
| Checking of the parallelism of Z-axis motion (tool holder slide) to the workholding spindle axis of rotation:<br>a) in the ZX plane [$E_{B(0(C))Z}$];<br>b) in the YZ plane [$E_{A(0(C))Z}$].<br>NOTE Also applicable for a second tool holder slide on the column. | |

**Diagram**




| **Tolerance** | **Measured error** |
|---|---|
| a) 0,030/1 000 (0,010/300) | a) |
| b) 0,050/1 000 (0,015/300) | b) |

**Measuring instruments**

a) and b) Square and dial gauges

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

Move tool holder slide over the centre of the table. Place a square (not a cylindrical square) in radial direction on the table, with one arm parallel to the X-axis, on one side of the tool holder slide, in such a way that the table can rotate 180° to bring the square on the opposite side of the tool holder slide without interference. The square does not need to be aligned with the C-axis.

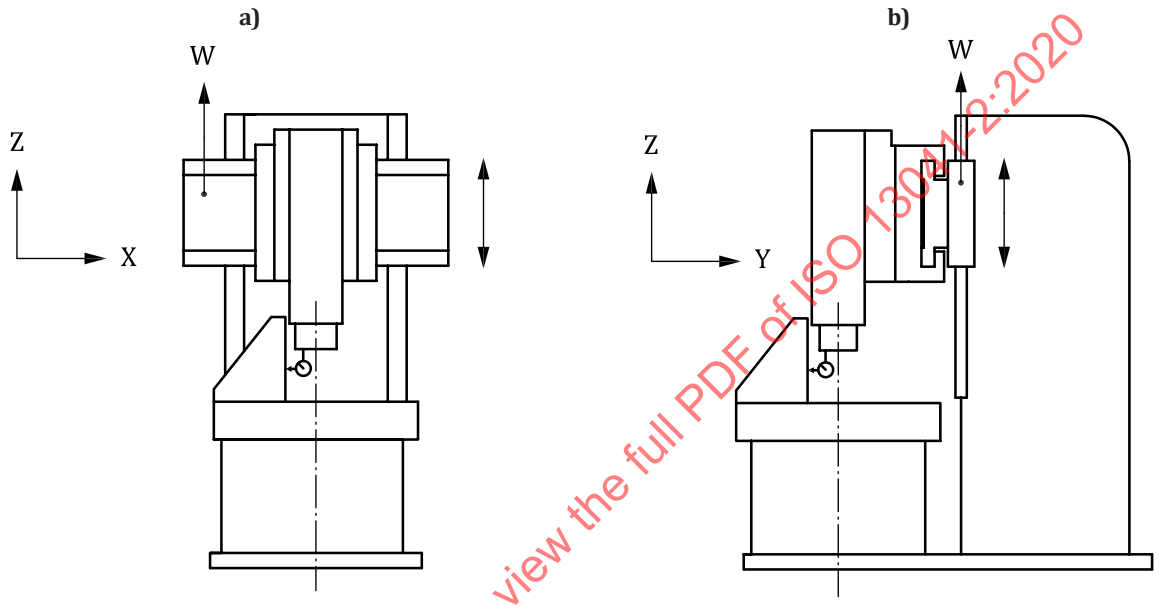
Take readings from the dial gauge at several positions along the Z-axis. If test G5 has been performed before test G8, use the readings taken for test G5. For both a) and b), without moving the X-axis, rotate the table by 180° to bring the square to the opposite side of the tool holder slide. Take the readings from the dial gauge at the same heights on the square. Half the difference between the least square line slopes of the two measurements (at 0° and 180°) provides the parallelism deviation of Z-axis to C-axis.

This test setup is also applicable to the tests G5, G9 and G11.

NOTE 1 For machines with two rail head rams, this test can be performed with a cylindrical square placed in the centre of the table.

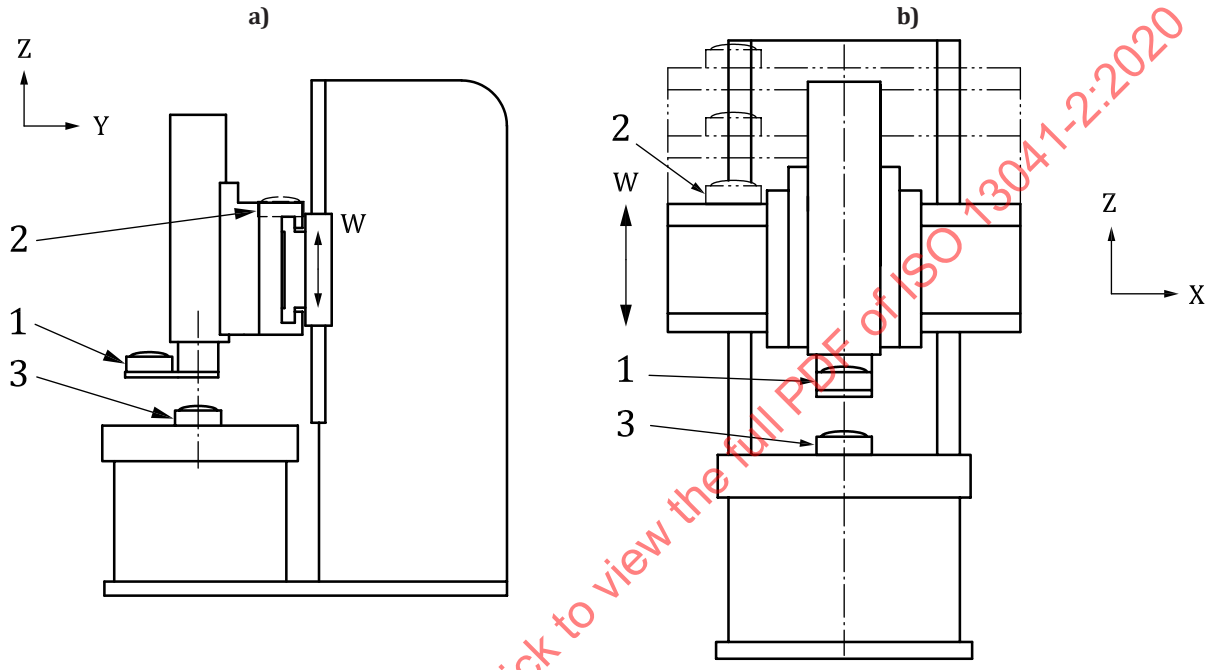
NOTE 2 For machines with two tool holder slides, difference of G8 tests for two tool holder slides gives information about the parallelism of tool holder slides. Tolerance for this parallelism is subject to agreement between the supplier/manufacturer and the user.

## 5.3 Cross-rail movement

| **Object** | **G9** |
|---|---|
| Checking of the straightness of motion of the cross-rail W-axis:<br>a) in the ZX plane ($E_{XW}$);<br>b) in the YZ plane ($E_{YW}$). | |
| **Diagram**<br>  <br> | |
| **Tolerance**<br>For a) 0,050 over a measuring length of 1 000<br>For b) 0,080 over a measuring length of 1 000 | **Measured error**<br>a)<br>b) |
| **Measuring instruments**<br>a) and b) Square and dial gauge<br>Alternative: Optical instrument, e.g. sweeping laser | |
| **Observations and references to ISO 230-1:2012, 8.2**<br>The rail head(s) shall be placed in suitable parking position(s) according to the manufacturer's specification and the position(s) shall be reported. Vertical slide over the centre of the table, if there is only one rail head. Place a dial gauge on the tool holder. Place a square (not a cylindrical square) in radial direction on the table, with one arm parallel to the X-axis, on one side of the tool holder slide. The square does not need to be aligned with the C-axis. Readings along the W-axis shall be taken in several positions with the cross-rail clamped on the columns without moving the X-axis.<br>If this test is to be combined with test G11, place the square in such a position as to allow the table to be rotated to four positions at 90° from each other.<br>This test setup is also applicable to the tests G5, G8 and G11. | |

| **Object** | **G10** |
|---|---|
| Checking of the angular error of the cross-rail in its W-axis motion.<br>Optional, checking of rotation of the cross-rail around W-axis (if roll is relevant):<br>a) in the vertical YZ plane ($E_{AW}$);<br>b) in the vertical ZX plane ($E_{BW}$);<br>c) in the XY plane $E_{CW}$ (roll). | |

**Diagram**




**Key**

1 measuring level (preferred position)

2 measuring level (alternative position)

3 reference level

| **Tolerance** | **Measured error** |
|---|---|
| For a) and b) | a) |
| For any measuring length 0,030/1 000 | b) |
| For optional measuring of roll the tolerance is 0,040/1 000 | c) |

**Measuring instruments**

a) and b) Precision levels, autocollimator or laser interferometer with angular optics

**Observations and references to ISO 230-1:2012, 8.4**

Place the measuring level at possibly mid-position of the cross-rail (tool holder) on an appropriate surface and read the indication in the quoted positions.

The rail head shall be placed in suitable parking position according to the manufacturer's specification and shall be reported.

When W-axis motion causes angular error of both the tool holder and the workholding spindle or table, differential measurements of the two angular movements shall be taken and this shall be stated.

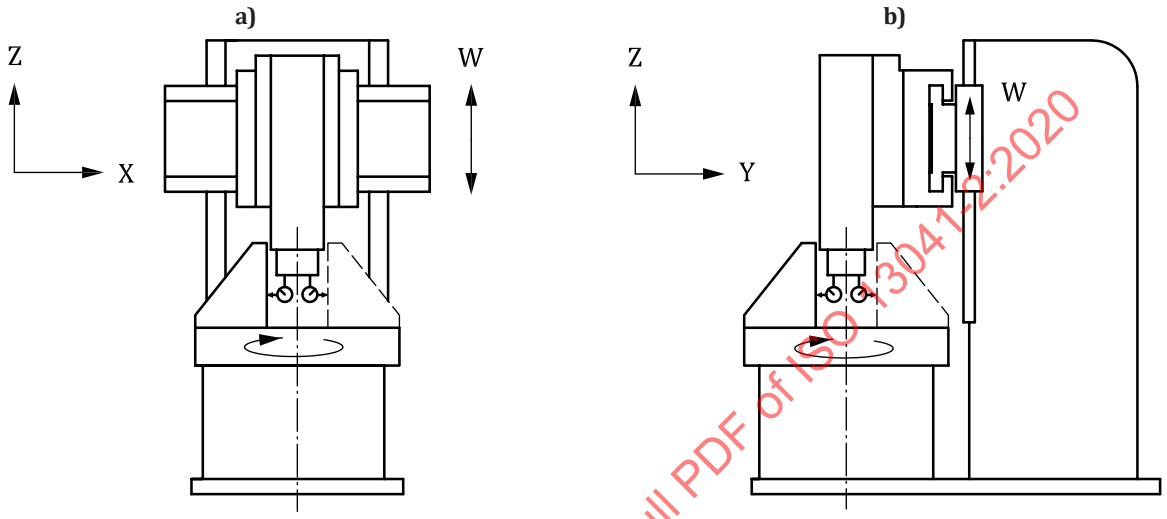
When differential measurement is applied, the reference level shall be placed on the workholding table.

Lock the cross-rail at each position, where possible.

For measuring roll of W-axis, see ISO 230-1:2012, 8.4.2.4.

| **Object** | **G11** |
|---|---|
| Checking of the parallelism of cross-rail W-axis motion to workholding spindle or table axis of rotation:<br>a) in the ZX plane [$E_{B(0C)W}$];<br>b) in the YZ plane [$E_{A(0C)W}$]. | |

**Diagram**




| **Tolerance** | **Measured error** |
|---|---|
| a) 0,050/1 000 (0,015/300) | a) |
| b) 0,067/1 000 (0,020/300) | b) |

**Measuring instruments**

a) and b) Dial gauge and square or optical instrument, e.g. sweeping laser

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

The rail head(s) shall be placed in suitable parking position according to the manufacturer's specification and the positions shall be reported.

Vertical slide over the centre of the table, if possible. Place a dial gauge on the tool holder.

Place a square (not a cylindrical square) in radial direction on the table, with one arm parallel to the X-axis, on one side of the tool holder slide, in such a way that the table can rotate 180° to bring the square on the opposite side of the tool holder slide without interference. The square does not need to be aligned with the C-axis.

Take readings from the dial gauge at several positions along the W-axis with the cross-rail clamped on the columns before each reading.

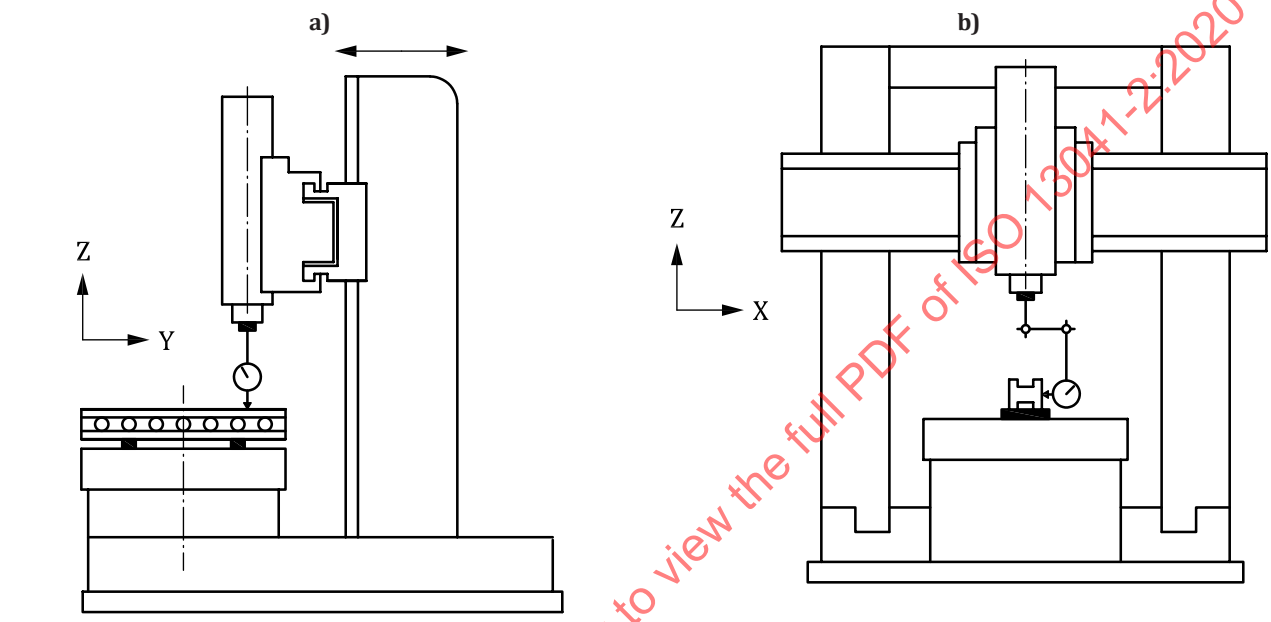
If test G9 has been performed before test G11, use the readings taken for test G9. For both a) and b), without moving the X-axis, rotate the table by 180° to bring the square to the opposite side of the tool holder slide.

Take the readings from the dial gauge at the same heights on the square. Half algebraic differences of all pairs of readings at the same heights provide the straightness deviations of the W-axis (already checked by G9).

Half the difference between the two results obtained at the ends of the travel, divided by the travel length (or better the least square line slope of the plot) provides parallelism deviation of W-axis to C-axis.

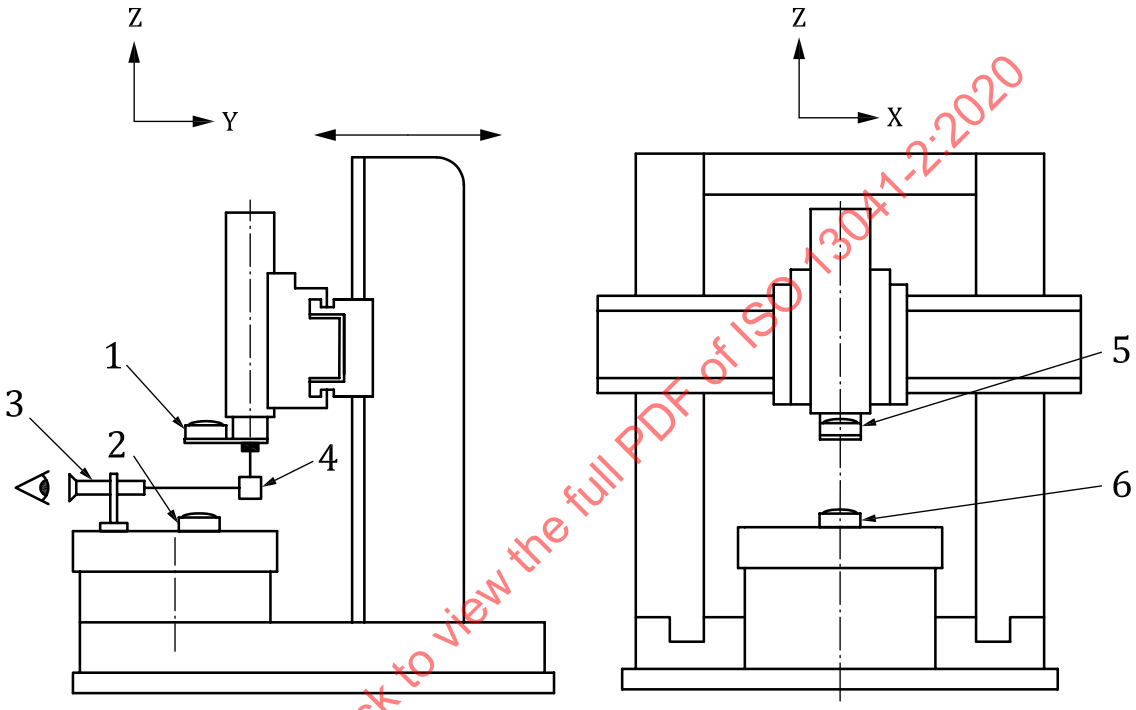
This test setup is also applicable to the tests G5, G8 and G9.

## 5.4 Tests related to Y-axis

| **Object** | **G12** |
|---|---|
| Checking of the straightness of motion of gantry (gantry type) or moving workholding table (portal type) in the Y-axis direction:<br>a) in the vertical YZ plane ($E_{ZY}$);<br>b) in the horizontal XY plane ($E_{XY}$). | |
| **Diagram**<br>  <br> | |
| **Tolerance**<br>a) 0,030 over a measuring length of 1 000<br>b) 0,040 over a measuring length of 1 000 | **Measured error**<br>a)<br>b) |
| **Measuring instruments**<br>a) Straightedge, adjustable blocks and dial gauge or optical instrument.<br>b) Straightedge, adjustable blocks and dial gauge or optical instrument or microscope and taut wire. | |
| **Observations and references to ISO 230-1:2012, 8.2 and 12.1.2.2**<br>For gantry type machines cross-rail locked in the middle position, tool holder slide in the measuring position.<br>The straightedge should be placed on the workholding table parallel to the Y-axis.<br>The dial gauge, the interferometer, the target or the microscope for taut wire shall be mounted on the rail head near to the position of a tool. The measuring line should be close to the workholding table axis of rotation.<br>Alternatively, when the straightedge is not aligned mechanically, the results can be evaluated according to ISO 230-1:2012, 3.4.8. | |

| **Object** | **G13** |
|---|---|
| Checking of the angular error of moving gantry (gantry type) or moving workholding table (portal type) in the Y direction:<br>a) in the YZ plane $E_{AY}$ (pitch);<br>b) in the ZX plane $E_{BY}$ (roll);<br>c) in the XY plane $E_{CY}$ (yaw). | |

**Diagram** **a) and c)** **b)**




**Key**

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

| **Tolerance** | **Measured error** |
|---|---|
| For a), b), and c)<br>For any measuring length 0,050/1 000 | a)<br>b)<br>c) |

**Measuring instruments**

a) Precision level, or optical angular measuring instrument

b) Precision level

c) Optical angular measuring instrument

**Observations and references to ISO 230-1:2012, 3.4.16 and 8.4**

The measuring level or instrument shall be placed on the rail head which is fixed in position:

a) ($E_{AY}$: pitch) level, or optical instrument oriented in the YZ plane;

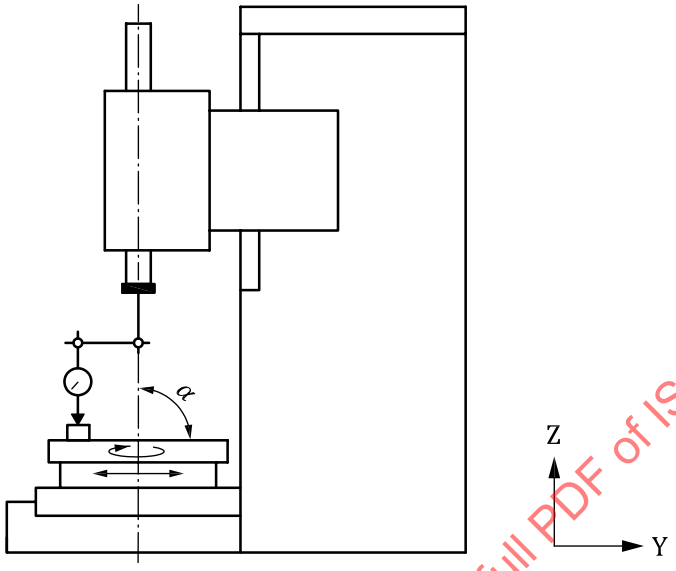
b) ($E_{BY}$: roll) level oriented in the ZX plane;

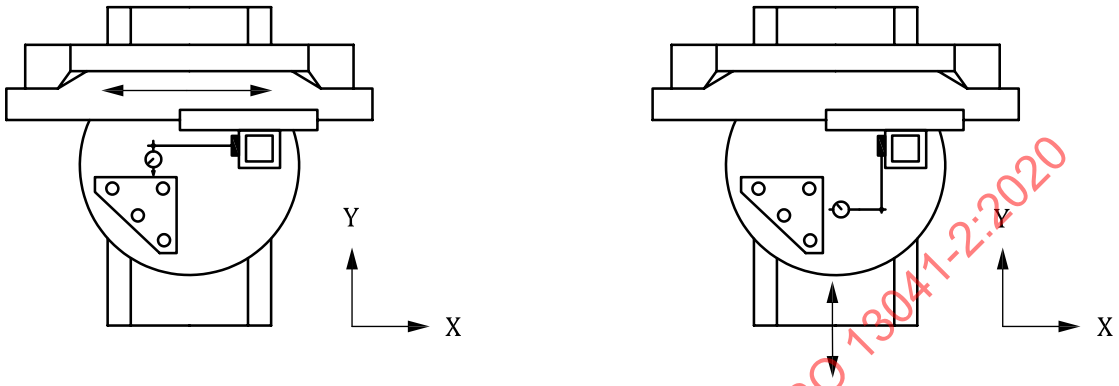
c) ($E_{CY}$: yaw) optical instrument oriented in the XY plane.

When the motion of the moving element (gantry or table slide) causes angular errors of both workholding table and tool holder, differential measurements of the two angular errors shall be made and this shall be stated.

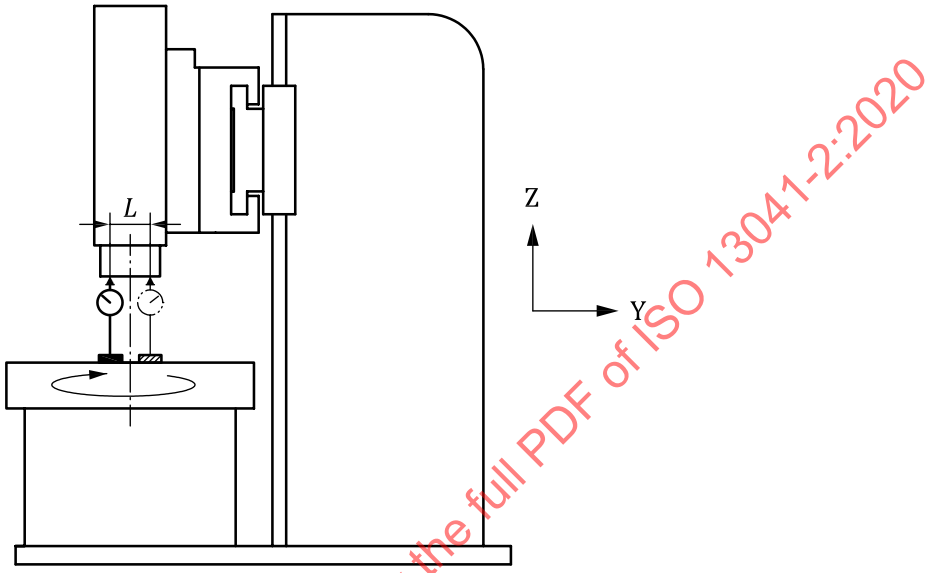
The reference level shall be placed on the non-moving element (table or tool holder).

Measurements shall be carried out at a minimum of five positions equally spaced along the path of travel in both directions of the movement.

| **Object** | **G14** |
|---|---|
| Checking of the squareness of Y-axis motion (gantry or workholding table) to C-axis [$E_{A(0C)Y}$].<br>NOTE This test applies to machines shown in Table 1, Type B c) and Type B d). | |
| **Diagram**<br>  <br> | |
| **Tolerance**<br>0,040/1 000 | **Measured error** |
| **Measuring instruments**<br>Gauge block and dial gauge | |
| **Observations and references to ISO 230-1:2012, 10.3.3**<br>Place a gauge block on one edge of the table, in the Y direction apart from the axis of rotation; fix the dial gauge on the tool holder; bring the stylus into contact with the gauge block and zero the dial gauge. Rotate the table by 180° and move the Y-axis until the stylus touches the gauge block again. The dial gauge reading, divided by the Y displacement, is the error to be reported.<br>The value of angle, $\alpha$, being less than, equal to or greater than 90°, shall be noted. | |

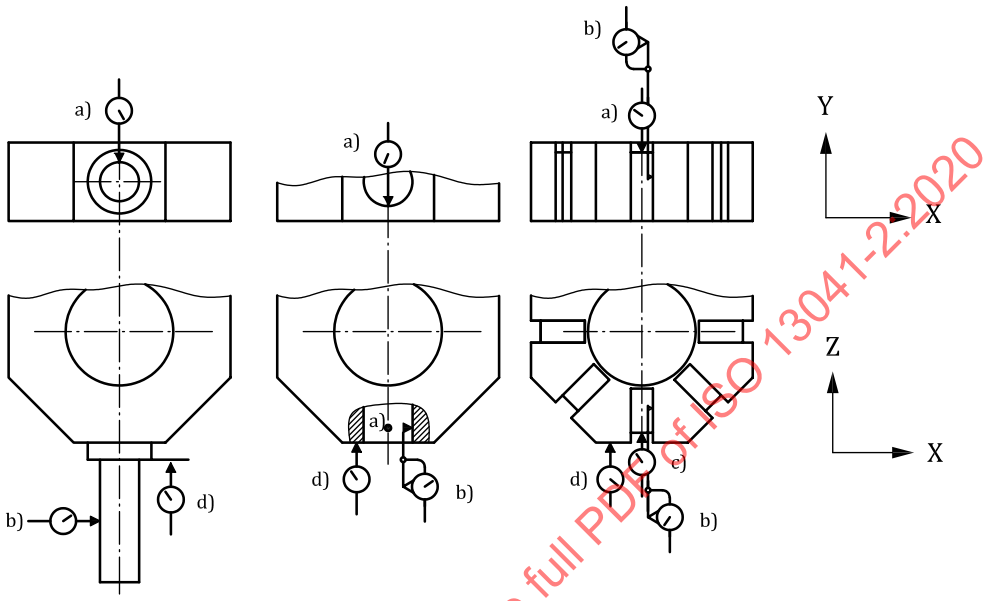
| **Object** | **G15** |
|---|---|
| Checking of the squareness of Y-axis motion (gantry or workholding table) to X-axis motion (rail head) $E_{C(0X)Y}$.<br>NOTE This test applies to machines shown in Table 1, Type B c) and Type B d). | |
| **Diagram**<br>  | |
| **Tolerance**<br>0,040/1 000 | **Measured error** |
| **Measuring instruments**<br>Square and dial gauge or laser interferometer with squareness and straightness optics | |
| **Observations and references to ISO 230-1:2012, 10.3.2**<br>Mount the dial gauge on the tool holder. Place the square on the workholding table (workholding spindle) and adjust it parallel to rail head movement using the dial gauge.<br>Adjust the stylus of the dial gauge perpendicular to the other side of the square.<br>For gantry type machines:<br>Move the portal with the displacement sensor along the square and take the reading at the end points (2 records).<br>For machines with moving workholding table:<br>Move the workholding table with the square along the stationary displacement sensor and take the reading at the end points (2 records).<br>Squareness error is the difference of those two records divided by their distance travelled between those two measurement points. | |

## 5.5 Tool holders and tool turrets

| **Object** | **G16** |
|---|---|
| Checking of the perpendicularity of tool-fixing faces of the tool holder to workholding spindle axis of rotation.<br>NOTE The test applies to tool-fixing faces of tool turrets that are square to the workholding spindle axis. | |
| **Diagram**<br>  | |
| **Tolerance**<br>0,020 over the measuring length of $L$<br>where $L$ is the diameter of measurement | **Measured error** |
| **Measuring instruments**<br>Dial gauge | |
| **Observations and references to ISO 230-1:2012, 12.4.1**<br>A dial gauge shall be fixed on the workholding spindle and shall touch the bottom face of the tool holder.<br>The workholding spindle shall be rotated and the dial gauge shall be moved to touch the face of the tool holder on the largest possible diameter.<br>If the machine is equipped with a tool turret, the test shall be repeated for each of the tool-fixing faces of the tool turret. | |

| **Object** | **G17** |
|---|---|
| Checking of the accuracy of the tool turret indexing.<br>NOTE This test applies only for machines equipped with a tool turret. | |

**Diagram**




| **Tolerance** | **Measured error** |
|---|---|
| 0,030 | |

**Measuring instruments**

Dial gauge and test mandrel

**Observations and references to ISO 230-1:2012**

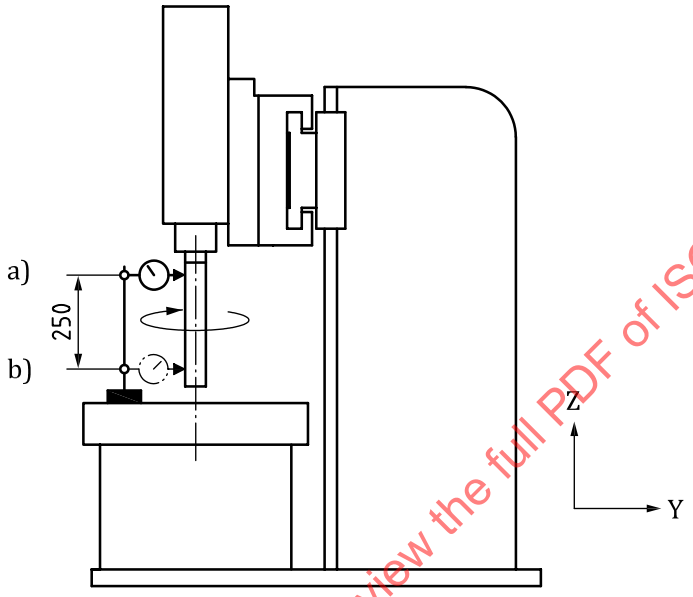
Position the dial gauge styli a), b) and c) so that they contact the tool turret reference holes or grooves. Record the tool turret axis position. Record the dial gauge readings. Withdraw the tool turret position to clear off the dial gauge, index the tool turret to the next orientation, and reposition the tool turret axis. Record the dial gauge readings.

If the tool turret reference face is used, the dial gauge should be used at position d).

Repeat the test three times for each tool turret orientation; the readings at each orientation are then averaged to minimize the effect of tool turret repeatability. The maximum difference of all averaged dial gauge readings is the accuracy of tool turret indexing.

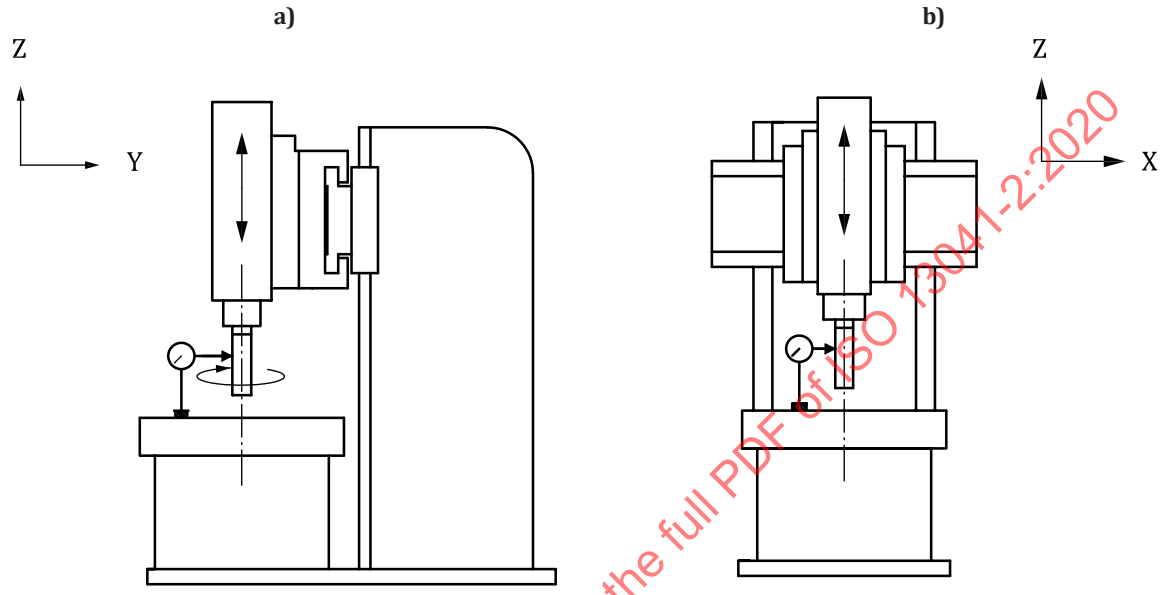
The repeatability of the tool turret indexing and the repeatability of mounting test mandrel (if applied) can influence the readings.

## 5.6 Power driven toolholding spindles

| **Object** | **G18** |
|---|---|
| Checking of the run-out of the internal taper of the toolholding spindle(s):<br>a) at the toolholding spindle nose;<br>b) at a distance of 250 from the toolholding spindle nose. | |
| **Diagram**<br>  <br> | |
| **Tolerance**<br>a) 0,010<br>b) 0,020 | **Measured error**<br>a)<br>b) |
| **Measuring instruments**<br>a) and b) Dial gauge and test mandrel | |
| **Observations and references to ISO 230-1:2012, 12.5.3**<br>Attach a dial gauge to the table (workholding spindle) and insert the test mandrel in the power driven toolholding spindle.<br>Place the displacement sensor as close as possible to position a), rotate the toolholding spindle and record the reading.<br>Repeat the same operation at position b).<br>If the machine has multiple toolholding spindles, carry out these tests for each of them (see also AR2 test). | |

| **Object** | **G19** |
|---|---|
| Checking of the parallelism of toolholding spindle axis of rotation C1 to the tool holder slide motion (Z-axis):<br>a) in the YZ plane [$E_{A(0Z)(C1)}$];<br>b) in the ZX plane [$E_{B(0Z)(C1)}$]. | |

**Diagram**




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

**Measuring instruments**

a) and b) Dial gauge and test mandrel

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

A test mandrel is mounted on the tool holding spindle.

If possible, the workholding spindle should be clamped.

a) Dial gauge is attached to the workholding spindle indicating against the mandrel in the Y direction. Mean orientation of the mandrel is determined by rotating the tool holding spindle between the two extreme readings of the displacement sensor. Displacement sensor is set to zero at this mean orientation. Then the tool holder slide is moved to the other end of the measuring stroke and the displacement sensor reading is recorded.

b) Dial gauge is attached to the workholding spindle indicating against the mandrel in the X direction. Mean orientation of the mandrel is determined by rotating the tool holding spindle between the two extreme readings of the displacement sensor. Displacement sensor is set to zero at this mean orientation. Then the tool holder slide is moved to the other end of the measuring stroke and the displacement sensor reading is recorded.

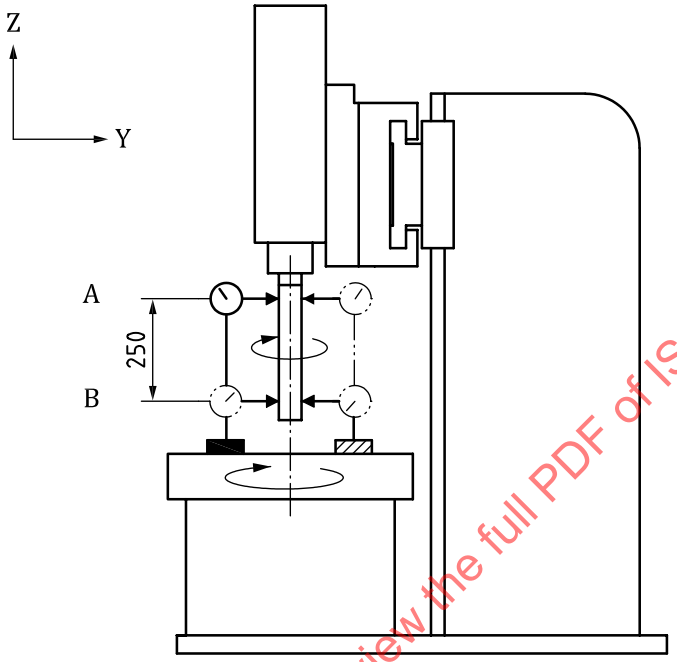
Parallelism deviation is the difference of the mean of the two measurements, taken at the end points only (at 0° and 180°) and divided by the travelled distance.

Alternatively, apply the slope of the reference straight line of the mean of the two measurements (at 0° and 180°).

NOTE Further tests for checking the accuracy of axes of rotation are outlined in Annex A.

| **Object** | **G20** |
|---|---|
| Checking of the coaxiality of the axis of the tool holding spindle to the workholding spindle axis of rotation:<br>a) in the YZ plane [$E_{Y(0C)(C1)}$ and $E_{A(0C)(C1)}$];<br>b) in the ZX plane [$E_{X(0C)(C1)}$ and $E_{B(0C)(C1)}$]. | |

**Diagram**




| **Tolerance** | **Measured error** |
|---|---|
| offset | offset |
| a) 0,025 | a) |
| b) 0,025 | b) |
| parallelism | parallelism |
| a) 0,080/1 000 (0,020/250) | a) |
| b) 0,080/1 000 (0,020/250) | b) |

**Measuring instruments**

Test mandrel, dial gauge and alignment laser

**Observations and references to ISO 230-1:2012, 10.2**

Fix the dial gauges/support to the workholding spindle and a test mandrel to the tool spindle.

Rotate the workholding spindle so that the dial gauge is in the ZX plane and touch the stylus with the test mandrel at position A and take the first reading. Rotate both spindles 90° increments and take the readings at each increment. Repeat the measurement for the position B. The difference of the two readings taken at 0° and 180° divided by 2, represents the offsets between the two axes of rotation in the position A and B in ZX-plane.

The difference of the two readings taken at 90° and 270° divided by 2, represents the offsets between the two axes of rotation in the position A and B in YZ-plane.

When alignment laser is used, rotate both spindles and record readings at the number of rotational positions that the laser alignment system requires (e.g. 0°, 90°, 180° and 270°).

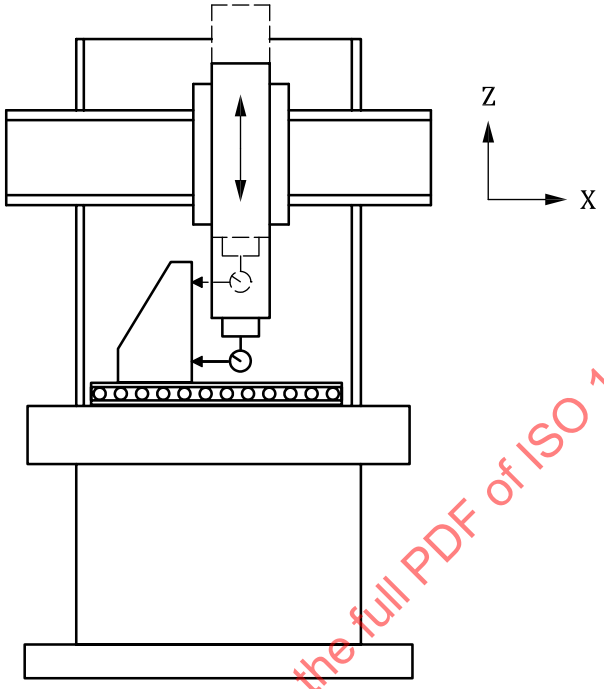
The coaxiality error contains both offset and parallelism error. The offset error is the offset at position B.

The parallelism error is the difference between offsets at point A and B, divided by the distance between points A and B (250 mm).

NOTE Further tests for checking the accuracy of axes of rotation are outlined in Annex A.

| **Object** | **G21** |
|---|---|
| Checking of the squareness of tool holder slide motion (Z-axis) to rail head motion (X-axis) [$E_{B(0X)Z}$]. | |

**Diagram**




| **Tolerance** | **Measured error** |
|---|---|
| 0,050/1 000 (0,015/300) | |

**Measuring instruments**

Dial gauge, straightedge and square

**Observations and references to ISO 230-1:2012, 10.3 and 10.3.2**

A dial gauge shall be fixed to the tool holder close to the tool position.

Set the straightedge parallel to the rail head motion (X-axis).

Place a square onto the straightedge.

Afterwards, move the dial gauge to a position so that it touches the vertical plane of the square.

Measurements shall be taken along the Z-axis on the vertical plane of the square.

NOTE Squareness of tool holder slide motion (Z-axis) to rail head motion (X-axis) can be derived from the result of G7 and G8 tests.