INTERNATIONAL STANDARD

ISO 10791-1

Second edition
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Test conditions for machining centres —

Part 1: Geometric tests for machines with horizontal spindle (horizontal Z-axis)

Conditions d'essai pour centres d'usinage —

Partie 1: Essais géométriques des machines à broche horizontale (axe Z horizontal)

Reference number
ISO 10791-1:2015(E)

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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 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).

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 39, *Machine tools*, SC 2, *Test conditions for metal cutting machine tools*.

This second edition cancels and replaces the first edition (ISO 10791-1:1998), which has been technically revised.

ISO 10791 consists of the following parts, under the general title *Test conditions for machining centres*:

— *Part 1: Geometric tests for machines with horizontal spindle (horizontal Z-axis)*

— *Part 2: Geometric tests for machines with vertical spindle or universal heads with vertical primary rotary axis (vertical Z-axis)*

— *Part 3: Geometric tests for machines with integral indexable or continuous universal heads (vertical Z-axis)*

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

— *Part 5: Accuracy and repeatability of positioning of work-holding pallets*

— *Part 6: Accuracy of speeds and interpolations*

— *Part 7: Accuracy of finished test pieces*

— *Part 8: Evaluation of contouring performance in the three coordinate planes*

— *Part 9: Evaluation of the operating times of tool change and pallet change*

— *Part 10: Evaluation of the thermal distortions*

Introduction

A machining centre 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 magazine or similar storage unit in accordance with a machining program.

The object of ISO 10791 (all parts) 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 user or manufacturer/supplier. ISO 10791 specifies, with reference to the relevant parts of ISO 230, several families of tests for machining centres with horizontal spindle, standing alone or integrated in flexible manufacturing systems.

This part of ISO 10791 also establishes the tolerances for the test results corresponding to general purpose and normal accuracy machining centres.

This part of ISO 10791 is also applicable, totally or partially, to other numerically controlled machines, when their configuration, components, and movements are compatible with the tests described herein.

Accessory spindle heads, forming the object of Annexes A through C in the first edition of this part of ISO 10791, are now covered by the more general ISO 17543-1, as they are not only used on machining centres.

In this edition of ISO 10791-1, the test of the table flatness (formerly G15) has been deleted for several reasons, among which are the following:

— the table surface is not normally used as a reference for the location of the workpiece;

— sometimes, the machine is supplied with some fixtures already mounted on the table;

— sometimes, the machine is provided with a receiver where several pallets can be mounted;

— for tests made during the working life of the machine, the surface might no longer be suitable for accurate measurements, mostly on large machines.

Test conditions for machining centres —

Part 1: Geometric tests for machines with horizontal spindle (horizontal Z-axis)

1 Scope

This part of ISO 10791 specifies, with reference to ISO 230-1, the geometric tests for machining centres (or other numerically controlled machines, where applicable) with horizontal spindle (i.e. horizontal Z-axis).

This part of ISO 10791 applies to machining centres having three numerically controlled linear axes (X-axis up to 5 000 mm length, Y-axis up to 3 200 mm length, and Z-axis up to 2 000 mm length), but refers also to supplementary movements, such as those of rotary, tilting, and swivelling tables. Movements other than those mentioned are considered as special features and the relevant tests are not included in this part of ISO 10791.

This part of ISO 10791 takes into consideration in Annexes A through D four possible types of tables, fixed and rotary, as hereunder described:

— Annex A: horizontal non-rotating tables;

— Annex B: tables rotating around a vertical B'-axis;

— Annex C: tables rotating around a vertical B'-axis and tilting around a horizontal A'-axis;

— Annex D: tables rotating around a horizontal A'-axis and swivelling around a vertical B'-axis.

This part of ISO 10791 does not consider accessory spindle heads, which are covered by ISO 17543-1:—[1)].

This part of ISO 10791 deals only with the verification of geometric accuracy of the machine and does not apply to the testing of the machine operation, which should generally be checked separately. Tests not concerning the pure geometric accuracy of the machine are dealt with in other parts of ISO 10791, as listed in the Foreword.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. 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:—[1)], *Test code for machine tools — Part 7: Geometric accuracy of axes of rotation*

ISO 841, *Industrial automation systems and integration — Numerical control of machines — Coordinate system and motion nomenclature*

ISO 10791-6:2014, *Test conditions for machining centres — Part 6: Accuracy of speeds and interpolations*

1) To be published.

3 Preliminary remarks

3.1 Measurement units

In this part of ISO 10791, all linear dimensions, deviations, and corresponding tolerances are expressed in millimetres; angular dimensions are expressed in degrees, and angular deviations and the corresponding tolerances are expressed in ratios as the primary method, but in some cases, microradians or arcseconds can be used for clarification purposes. The following expression should be used for conversion of the units of angular deviations or tolerances:

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

3.2 Reference to ISO 230-1

To apply this part of ISO 10791, reference shall be made to ISO 230-1, especially for the installation of the machine before testing, warming up of the spindle and other moving components, description of measuring methods, and recommended uncertainty of testing equipment.

In the "Observations" block of the tests described in Clause 4 and the annexes, the instructions are preceeded by a reference to the corresponding clause in ISO 230-1 in cases where the test concerned is in compliance with the specifications of that International Standard.

3.3 Reference to ISO 10791-6

In ISO 10791-6:2014, Annex A, B, and C, kinematic tests are described for testing circular interpolation motion by simultaneous three-axis control (AK1, AK2, BK1, BK2, CK1, CK2). These are based on using displacement sensor(s) with a sphere-ended test mandrel or using a ball bar.

These kinematic tests can be used for determining the position and orientation of rotary axes with respect to the linear axes.

Kinematic test BK2 c) [CK2 c)] in ISO 10791-6:2014 can be used as an alternative for the following tests if all relevant geometric error compensation functions are identical: BG8, BG9, CG8, CG10, DG9, and DG11.

3.4 Testing sequence

The sequence in which the tests are presented in this part of ISO 10791 in no way defines the practical order of testing. In order to make the mounting of instruments or gauging easier, tests can be performed in any order.

3.5 Tests to be performed

When testing a machine, it is not always necessary, nor possible, to carry out all the tests described in this part of ISO 10791. When the tests are required for acceptance purposes, it is up to the user to choose, in agreement with the manufacturer/supplier, those tests relating to the components and/or the properties of the machine which are of interest. These tests are to be clearly stated when ordering a machine. Mere reference to this part of ISO 10791 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.

3.6 Tolerances

In this part of ISO 10791, all tolerance values (see ISO 230-1:2012, 4.1) are guidelines. 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 are to be clearly stated when ordering the machine.

When establishing the tolerance for a measuring length different from that given in this part of ISO 10791 the tolerance can be determined by means of the law of proportionality (see ISO 230-1:2012, 4.1.2). It shall be taken into consideration that the minimum value of tolerance is 0,005 mm.

3.7 Measuring instruments

Measuring instruments indicated in the tests described in the following sections 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 analogue or digital dial gauges, linear variable differential transformer (LVDTs), linear scale displacement gauges, or non-contact sensors, when applicable to the test concerned (see ISO 230-1:2012, Clause 4).

Similarly, when a "straightedge" is referred to, it can mean any type of straightness reference artefact, such as a granite or ceramic or steel or cast iron straightedge, one arm of a square, one generating line on a cylinder 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 cylinder square, a reference cube, or, again, a special, dedicated artefact.

When "3D probe" is referred to, it means three displacement sensors, housed in a nest, used to measure the changes in the position of the centre of a precision sphere; when the nest and the sphere are moved together along a programmed tool path.

3.8 Diagrams

For reasons of simplicity, diagrams in this part of ISO 10791 illustrate only one type of machine.

3.9 Pallets

For machines working with several pallets, the tests concerning the intrinsic geometric features or their behaviour related to the axes of the machine (tests in Annexes A through D) are to be performed on only one representative pallet clamped in position, unless otherwise specified by an agreement between the user and the manufacturer/supplier. For checking other pallets, see ISO 10791-5.

3.10 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 the 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.

3.11 Machine configurations

Figure 1 and Table 1 show 12 possible configurations of machining centres, with different architectures and different components moving along the linear axes. These configurations are identified by means

of numbers from 01 to 12 for referring Figure 1 and Table 1 to each other. For the axes orientation and nomenclature, reference should be made to ISO 841.

3.12 Designation

A designation is also supplied in Table 1 in order to define the architecture of a machining centre, being a short code; this designation is given by

— the number of this part of ISO 10791,

— the letter H for “horizontal”, and

— a list of the structural and moving components from the workpiece (w) to the tool (t).

Table 1 shows examples of designations referred to the machine configurations shown in Figure 1, where

— the kinematic chain of moving axes is described in square brackets,

— the axis not under NC positioning is represented in brackets [e.g. (C)], and

— “w”, “t”, and “b”, respectively, represent the work holding table, the tool, and the bed.

The sequence can be either from the work holding table to the tool or from the tool to the work holding table.

Table 1 — Designations of configurations shown in Figure 1

01	ISO 10791-1 H [w X’ Z’ b Y (C) t]
02	ISO 10791-1 H [w Z’ b X Y (C) t]
03	ISO 10791-1 H [w X’ Z’ Y’ b (C) t]
04	ISO 10791-1 H [w Z’ X’ b Y (C) t]
05	ISO 10791-1 H [w b Z X Y (C) t]
06	ISO 10791-1 H [w X’ Y’ b Z (C) t]
07	ISO 10791-1 H [w X’ b Z Y (C) t]
08	ISO 10791-1 H [w b X Z Y (C) t]
09	ISO 10791-1 H [w Y’ X’ b Z (C) t]
10	ISO 10791-1 H [w X’ b Y Z (C) t]
11	ISO 10791-1 H [w b X Y Z (C) t]
12	ISO 10791-1 H [w Y’ b X Z (C) t]

3.13 Axes not under test

During the execution of some geometric tests on one axis of motion, the position of the other axes, not under test, can affect the results. Therefore, the positions of these axes, as well as the offsets on the tool side and on the workpiece side, are to be recorded in the test report.

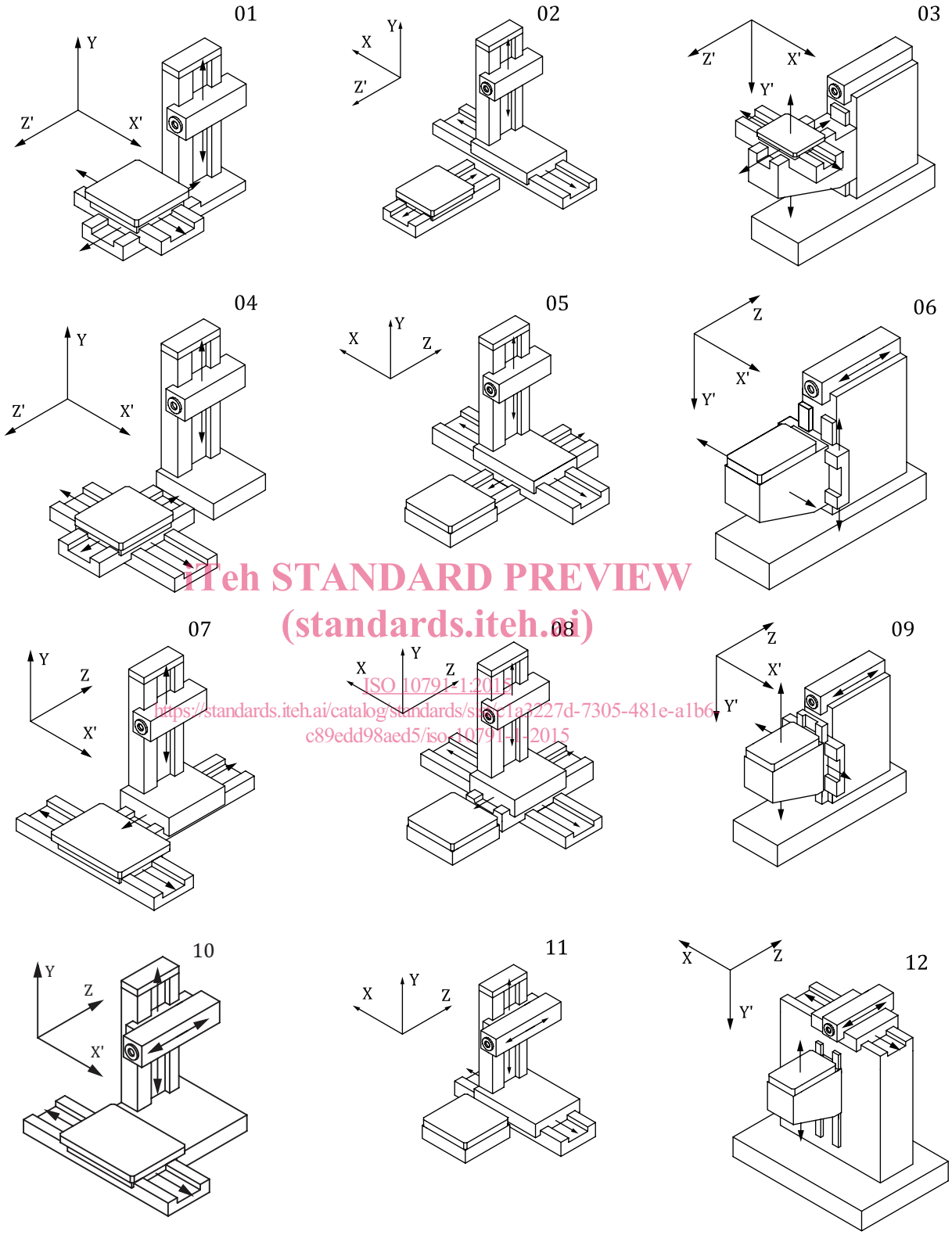


Figure 1 — Possible configurations of linear axes
(Rotary and swivelling axes of the table are shown in Annexes B through D)

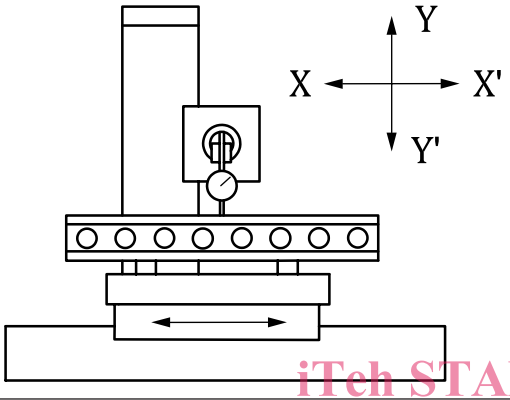
4 Geometric tests

4.1 Straightness errors of linear motions

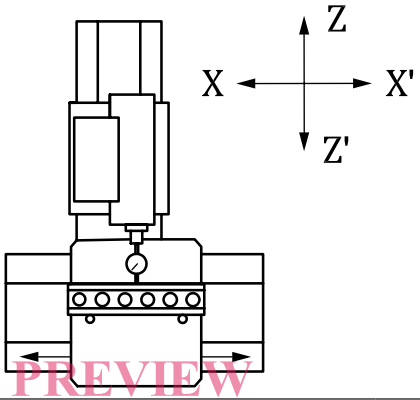
Object	**G1**
Checking of straightness of the X-axis motion: a) in the vertical XY plane (E_{YX}) b) in the horizontal ZX plane (E_{ZX})	

Diagram

a)



b)



Tolerance

		X	≤	500	a) and b)			0,010
500	<	X	≤	800	a) and b)			0,015
800	<	X	≤	1 250	a) and b)			0,020
1 250	<	X	≤	2 000	a) and b)			0,025
2 000	<	X	≤	3 200	a)	0,050	b)	0,032
3 200	<	X	≤	5 000	a)	0,065	b)	0,040

Local tolerance 0,007 for a measuring length of 300

Measured deviation

For X = ...

a) b)

Maximum local deviation:

a) b)

Measuring instruments

a) straightedge and dial gauge or optical methods

b) straightedge and dial gauge or microscope and taut wire or optical methods

Observations and references to ISO 230-1:2012, 8.2 and 8.2.2

For all machine configurations, the straightedge or the taut wire or the straightness reflector shall be placed on the table. If the spindle can be locked, the dial gauge or the microscope or the interferometer can be mounted on it; if the spindle cannot be locked, the instrument shall be placed on the spindle head of the machine.

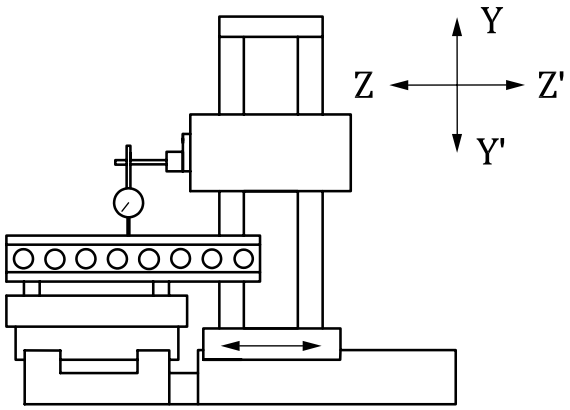
The measuring line should pass as close as possible to the centre of the table. The height of the reference straight line above the table shall be stated in the test report.

Methods based on measurements of angles (ISO 230-1:2012, 12.1.3) shall not be applied as these methods are restricted to measurements of functional surfaces.

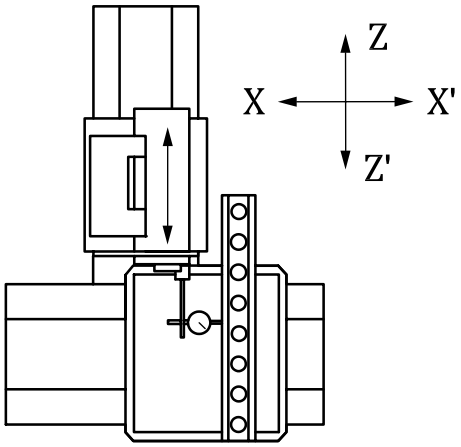
Object	G2
Checking of straightness of the Z-axis motion: a) in the vertical YZ plane (E_{YZ}) b) in the horizontal ZX plane (E_{XZ})	

Diagram

a)



b)



Tolerance

$Z \leq 500$	a) and b)	0,010
$500 < Z \leq 800$	a) and b)	0,015
$800 < Z \leq 1\,250$	a) and b)	0,020
$1\,250 < Z \leq 2\,000$	a) and b)	0,025

Local tolerance 0,007 for a measuring length of 300

Measured deviation

For Z = ...

a) b)

Maximum local deviation:

a) b)

Measuring instruments

a) straightedge and dial gauge or optical methods

b) straightedge and dial gauge or microscope and taut wire or optical methods

Observations and references to ISO 230-1:2012, 8.2 and 8.2.2

For all machine configurations, the straightedge or the taut wire, or the straightness reflector shall be placed on the table. If the spindle can be locked, the dial gauge or the microscope or the interferometer can be mounted on it; if the spindle cannot be locked, the instrument shall be placed on the spindle head of the machine.

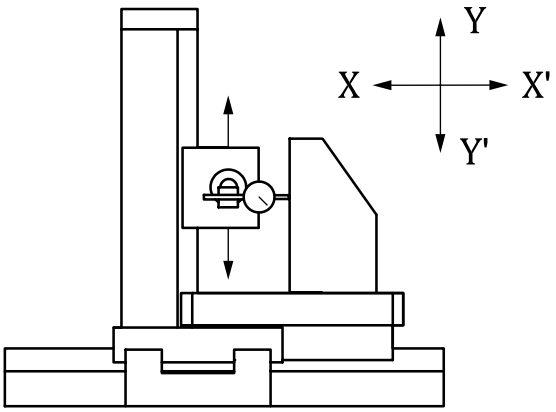
The measuring line should pass as close as possible to the centre of the table. The height of the reference straight line above the table shall be stated in the test report.

Methods based on measurements of angles (ISO 230-1:2012, 12.1.3) shall not be applied as these methods are restricted to measurements of functional surfaces.

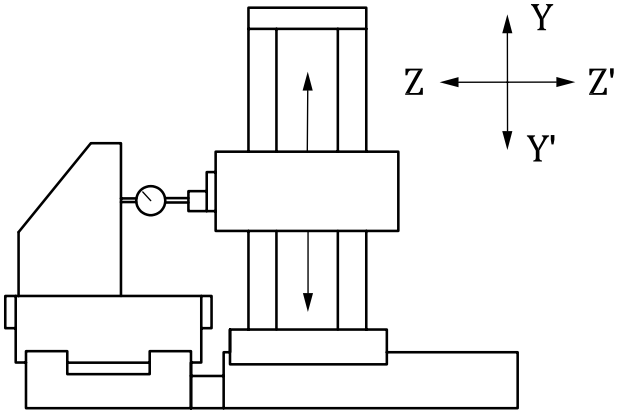
Object	**G3**
Checking of straightness of the Y-axis motion: a) in the XY plane (E_{XY}) b) in the YZ plane (E_{ZY})	

Diagram

a)



b)



Tolerance

For a) and b)

	Y	≤	500	0,010
500	< Y	≤	800	0,015
800	< Y	≤	1 250	0,020
1 250	< Y	≤	2 000	0,025
2 000	< Y	≤	3 200	0,032

Local tolerance 0,007 for a measuring length of 300

Measured deviation

For Y = ...

a) b)

Maximum local deviation:

a) b)

Measuring instruments

For a) and b): square and dial gauge or microscope and taut wire or optical methods

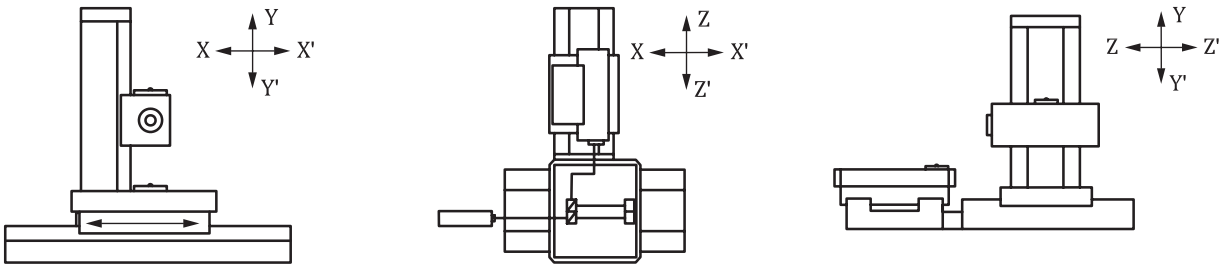
Observations and references to ISO 230-1:2012, 8.2 and 8.2.2

For all machine configurations, the square or the taut wire or the straightness reflector shall be placed in the centre of the table. If the spindle can be locked, the dial gauge or the microscope or the interferometer can be mounted on it; if the spindle cannot be locked, the instrument shall be placed on the spindle head of the machine.

The reference straight line applied shall be stated in the test report.

Methods based on measurements of angles (ISO 230-1:2012, 12.1.3) shall not be applied as these methods are restricted to measurements of functional surfaces.

4.2 Angular errors of linear motions

Object	**G4**
Checking of angular errors of the X-axis motion: a) in the vertical XY plane perpendicular to the spindle axis (pitch E_{CX}) b) in the horizontal ZX plane (yaw E_{BX}) c) in the vertical YZ plane parallel to the spindle axis (roll E_{AX})	
Diagram a) b) c) 	
Tolerance For a), b), and c) X ≤ 2 000 0,060/1 000 or 12 " 2 000 < X ≤ 3 200 0,065/1 000 or 13 " 3 200 < X ≤ 5 000 0,070/1 000 or 14 " Local tolerance: 0,016/1 000 (or 16 µrad or 3,2 ") for a measuring length of 300	
Measured deviation X = ... a) b) c) Maximum local deviation: a) b) c)	
Measuring instruments a) (pitch E_{CX}) precision level or optical angular deviation measuring instruments b) (yaw E_{BX}) optical angular deviation measuring instruments c) (roll E_{AX}) precision level	
Observations and references to ISO 230-1:2012, 8.4 and 8.4.2 The instrument shall be placed on the movable component: a) (pitch E_{CX}) longitudinally b) (yaw E_{BX}) horizontally c) (roll E_{AX}) transversely Measurements shall be taken at least at five positions equally spaced along the travel, in both directions of movement at every position. The difference between the maximum and the minimum reading is the error to be reported. When X-axis motion causes an angular movement of both spindle head and workholding table, differential measurements of the two angular movements shall be made and this shall be stated. In this case, when using precision levels for measurement, the reference level shall be located on the non-moving component (spindle head or workholding table) of the machine.	