BS ISO 10791-1:2015

BSI Standards Publication

Test conditions for machining centres

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

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National foreword

This British Standard is the UK implementation of ISO 10791-1:2015. It supersedes BS ISO 10791-1:1998 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee MTE/1/2, Machine tools - Accuracy.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

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INTERNATIONAL STANDARD

ISO 10791-1

Second edition
2015-02-01

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

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 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.

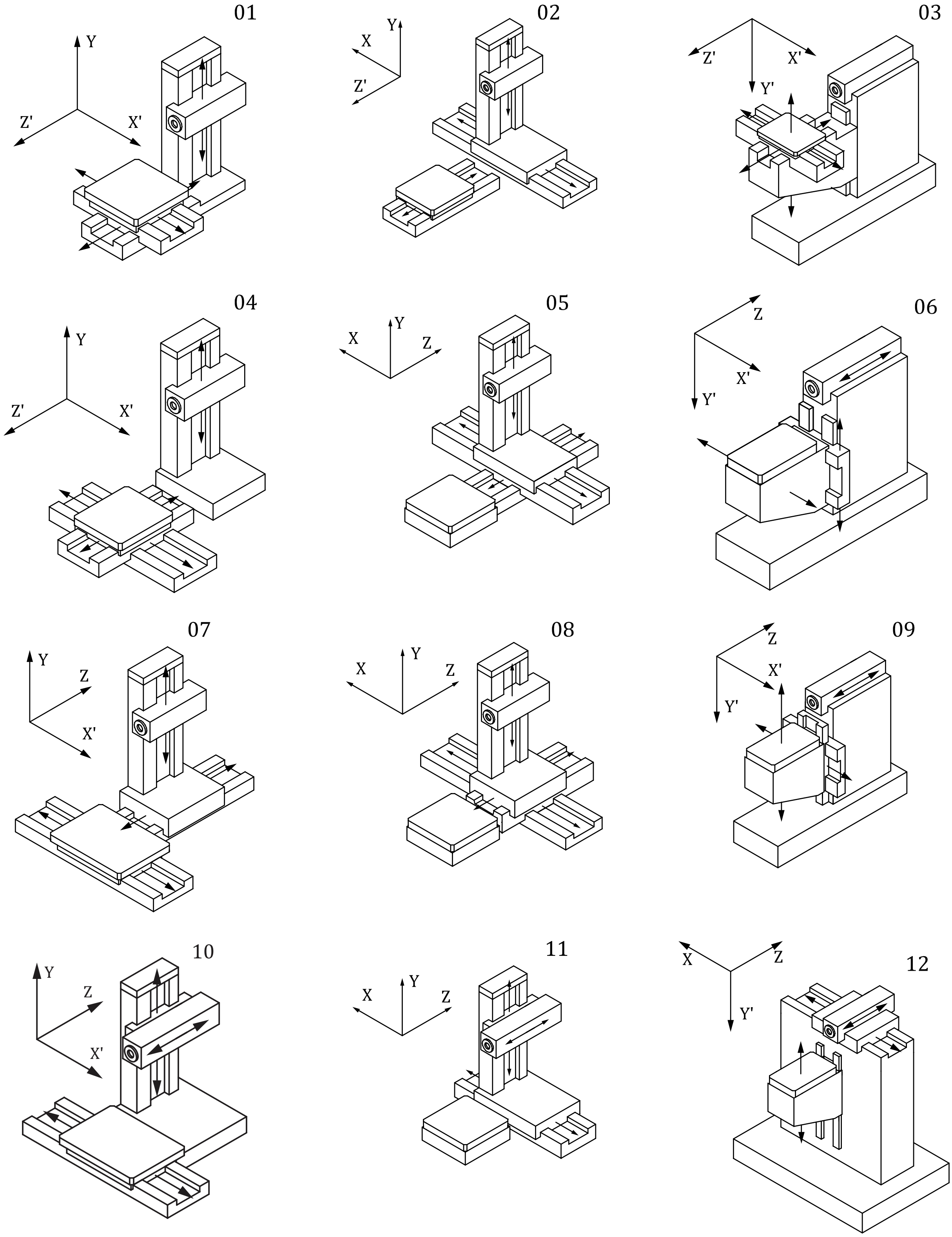


Figure 1 — Possible configurations of linear axes
(Rotary and swivelling axes of the table are shown in Annexes B through D)

4 Geometric tests

4.1 Straightness errors of linear motions

Object	**G1**

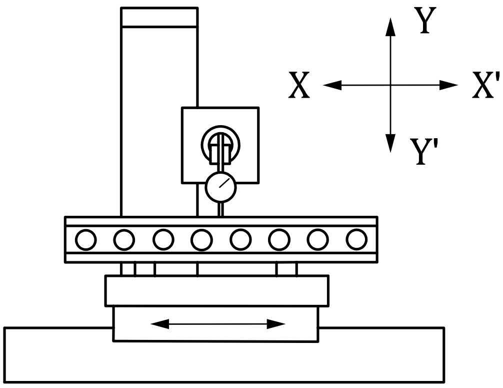
Checking of straightness of the X-axis motion:

a) in the vertical XY plane (E_{YX})

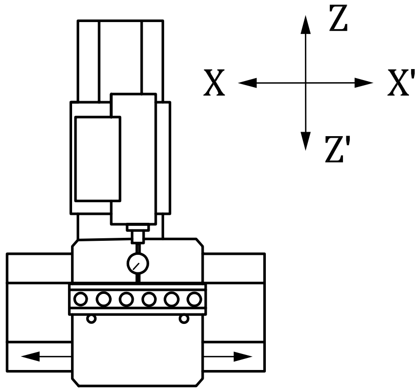
b) in the horizontal ZX plane (E_{ZX})

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**

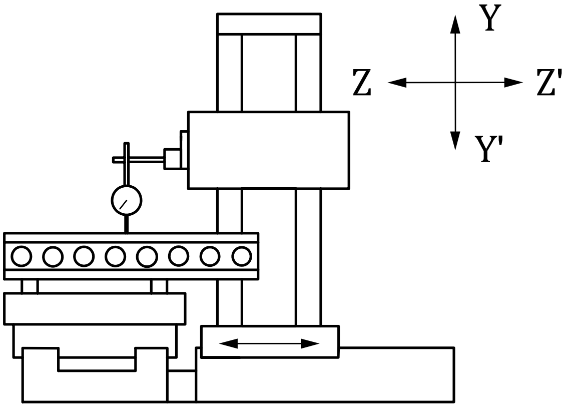
Checking of straightness of the Z-axis motion:

a) in the vertical YZ plane (E_{YZ})

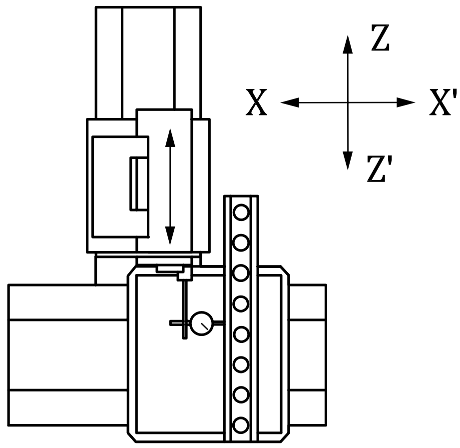
b) in the horizontal ZX plane (E_{XZ})

Diagram

a)



b)



Tolerance

Z ≤ 500	a) and b)	0,010
500 < Z ≤ 800	a) and b)	0,015
800 < Z ≤ 1 250	a) and b)	0,020
1 250 < Z ≤ 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

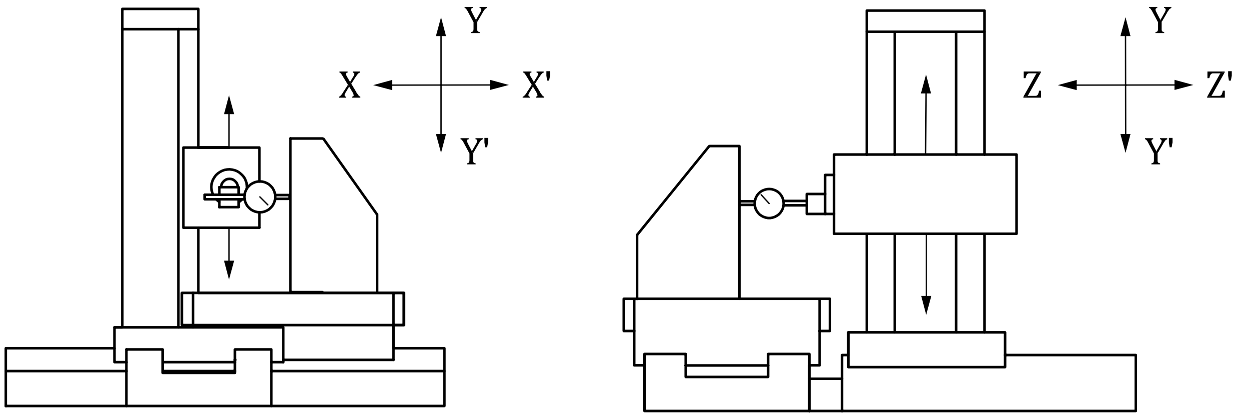
Observations and references to ISO 230-1:2012, 8.2 and 8.2.2

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:

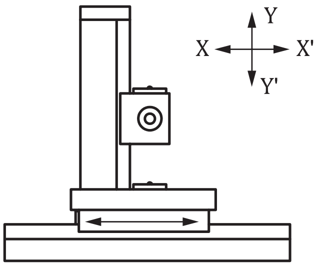
a) in the vertical XY plane perpendicular to the spindle axis (pitch E_{CX})

b) in the horizontal ZX plane (yaw E_{BX})

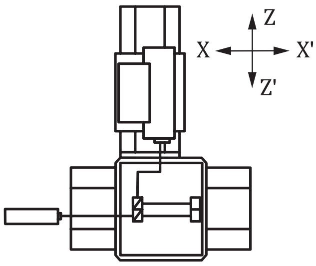
c) in the vertical YZ plane parallel to the spindle axis (roll E_{AX})

Diagram

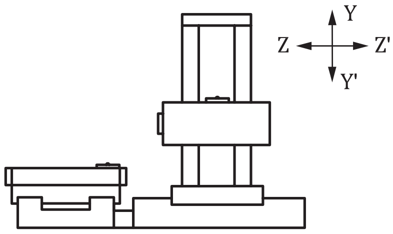
a)



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.

Object	**G5**

Checking of angular errors of the Z-axis motion:

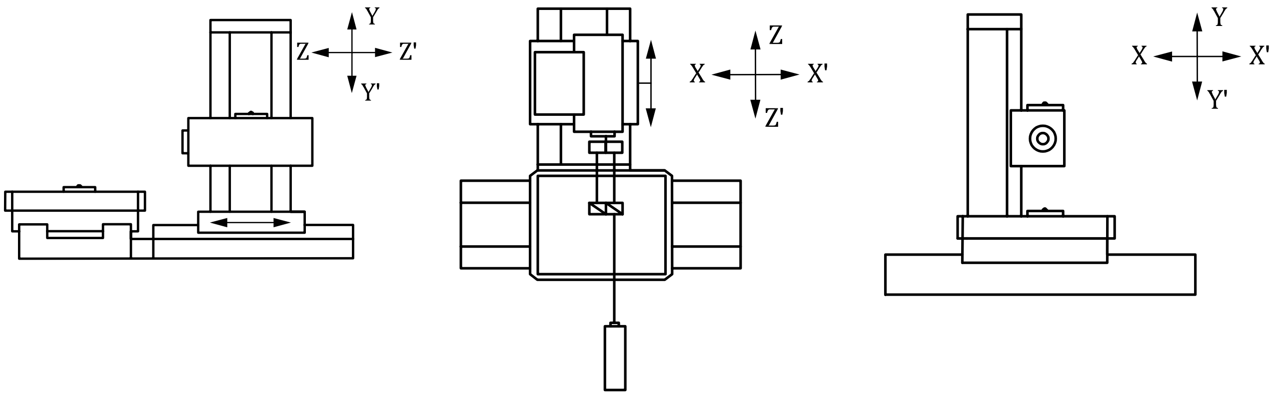
a) in the vertical YZ plane perpendicular to the spindle axis (pitch E_{AZ})

b) in the horizontal ZX plane (yaw E_{BZ})

c) in the vertical XY plane parallel to the spindle axis (roll E_{CZ})

Diagram

a) b) c)



Tolerance

For a), b), and c) Z ≤ 2 000 0,060/1 000 or 12 “

Local tolerance: 0,016/1 000 (or 16 µrad or 3,2 “) for a measuring length of 300

Measured deviation

Z = …………

a) b) c)

Maximum local deviation:

a) b) c)

Measuring instruments

a) (pitch E_{AZ}) precision level or optical angular deviation measuring instruments

b) (yaw E_{BZ}) optical angular deviation measuring instruments

c) (roll E_{CZ}) 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_{AZ}) longitudinally

b) (yaw E_{BZ}) horizontally

c) (roll E_{CZ}) 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 Z-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.

Object	**G6**

Checking of angular errors of the Y-axis motion:

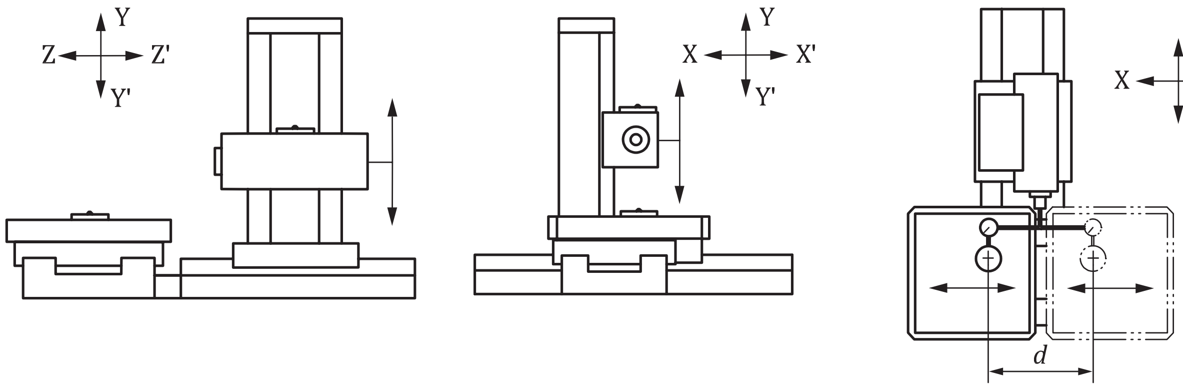
a) in the vertical YZ plane parallel to the spindle axis (E_{AY})

b) in the vertical XY plane perpendicular to the spindle axis (E_{CY})

c) in the horizontal ZX plane (roll E_{BY})

Diagram

a) b) c)



Tolerance

For a), b), and c)	Y ≤ 500	0,040/1 000 or 8 “
	500 < Y ≤ 1 250	0,050/1 000 or 10 “
	1 250 < Y ≤ 3 200	0,060/1 000 or 12 “
Local tolerance:	0,016/1 000 (or 16 µrad or 3,2 “) for a measuring length of 300	

Measured deviation

Y = …………

a) b) c)

Maximum local deviation:

a) b) c)

Measuring instruments

a) and b):	Precision level or optical angular deviation measuring instruments
c) (roll E_{BY}):	Cylindrical square, precision level and dial gauge, or precision cube and dial gauges, or sweeping alignment laser

Observations and references to ISO 230-1:2012, 8.4 and 8.4.2

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.

For a) (E_{AY}) and b) (E_{CY}), when Y-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.

For c) (roll E_{BY}), when a sweeping alignment laser is not used, place a cylindrical square (or a precision cube) on the table, approximately parallel to the Y-axis, and set the stylus of a dial gauge mounted on a special arm against the square. Note the readings and mark the corresponding heights on the square. Move the X-axis and move the dial gauge to the other side of the spindle head so that the stylus can touch the square again along the same line. The possible roll deviation of the X-axis motion shall be measured and taken into account (if a precision cube is used, no X-axis motion is required). The dial gauge shall be zeroed again and the new measurements shall be taken at the same heights of the previous ones, then noted. For each measurement height, calculate the difference Δ of the two readings. The algebraic maximum and minimum of these differences shall be selected and the result of

$$\frac{\Delta\max - \Delta\min}{d}$$

is the error to be reported, “*d*” being the distance between the two positions of the dial gauge.

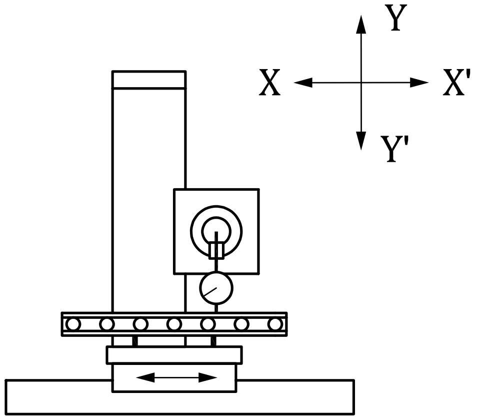
If a sweeping alignment laser is used, the sweeping plane is to be aligned approximately parallel to the machine XY plane. The measurement procedure is the same as above, where the dial gauge is to be replaced by the laser target and no X-axis motion is required.

4.3 Squareness errors between linear motions

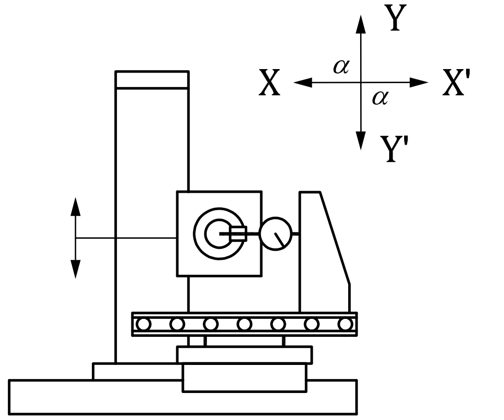
Object	**G7**
Checking of $E_{C(0X)Y}$ squareness error of the Y-axis motion to the X-axis motion.	

Diagram

Step 1)



Step 2)



Tolerance

Y ≤ 2 000 0,040/1 000 or 8 “

2 000 < Y ≤ 3 200 0,050/1 000 or 10 “

Measured deviation

Y = …………

Measuring instruments

Straightedge or surface plate, square, and dial gauge

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

In step 1), the straightedge or the surface plate shall be set parallel to the X-axis, or the lack of parallelism shall be considered in the measurement.

In step 2), the Y-axis shall then be checked by means of a square standing on the straightedge or on the surface plate.

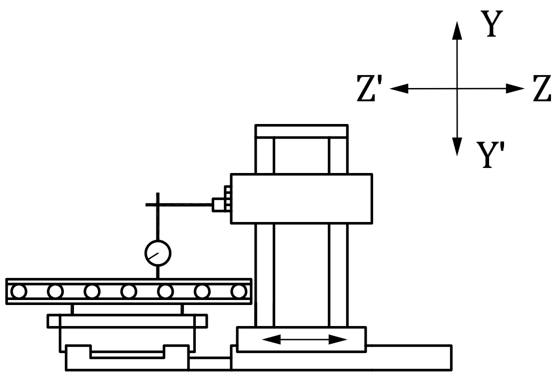
If the spindle can be locked, the dial gauge can be mounted on it; if the spindle cannot be locked, the dial gauge shall be placed on the spindle head of the machine.

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

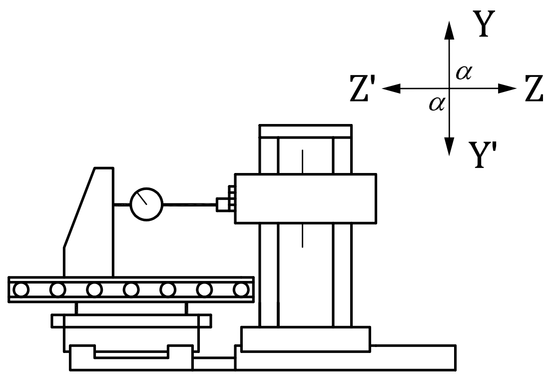
Object	**G8**
Checking of $E_{A(0Z)Y}$ squareness error of the Y-axis motion to the Z-axis motion	

Diagram

Step 1)



Step 2)



Tolerance

Y ≤ 2 000 0,040/1 000 or 8 “

2 000 < Y ≤ 3 200 0,050/1 000 or 10 “

Measured deviation

Y = …………

Measuring instruments

Straightedge or surface plate, square, and dial gauge

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

In step 1), the straightedge or the surface plate shall be set parallel to the Z-axis, or the lack of parallelism shall be considered in the measurement.

In step 2), the Y-axis shall then be checked by means of a square standing on the straightedge or on the surface plate.

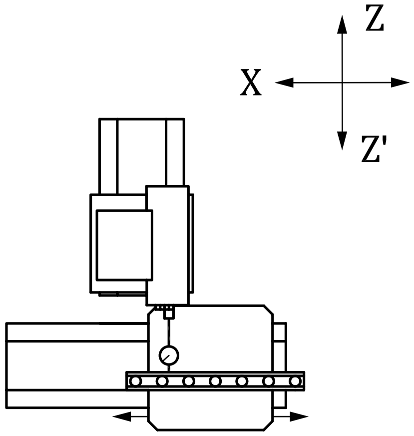
If the spindle can be locked, the dial gauge can be mounted on it; if the spindle cannot be locked, the dial gauge shall be placed on the spindle head of the machine.

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

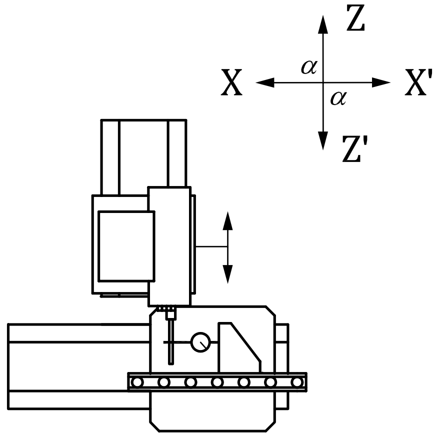
Object	**G9**
Checking of $E_{B(0X)Z}$ or $E_{B(0Z)X}$ squareness error of the Z-axis motion to the X-axis motion	

Diagram

Step 1)



Step 2)



Tolerance

0,040/1 000

Measured deviation

Measuring instruments

Straightedge, square, and dial gauge

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

In step 1), the straightedge shall be set parallel to the X-axis for $E_{B(0X)Z}$ or parallel to the Z-axis for $E_{B(0Z)X}$, or the lack of parallelism shall be considered in the measurement.

In step 2), the Z (or X)-axis shall then be checked by means of a square placed on the table with one side against the straightedge.

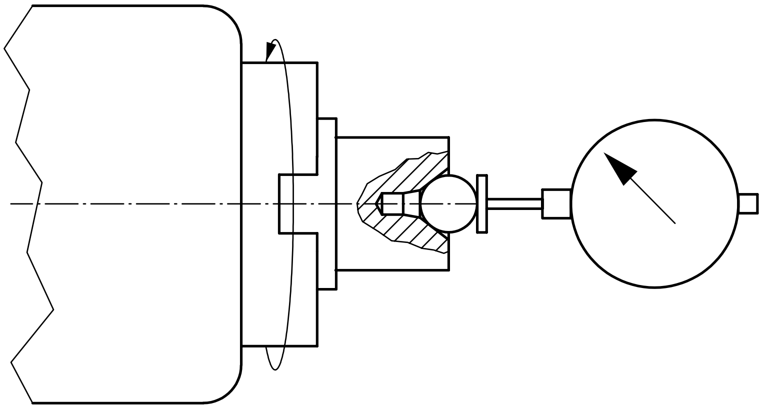
This test can be performed as well without the straightedge, aligning one arm of the square along one axis and checking the second axis on the other arm of the square.

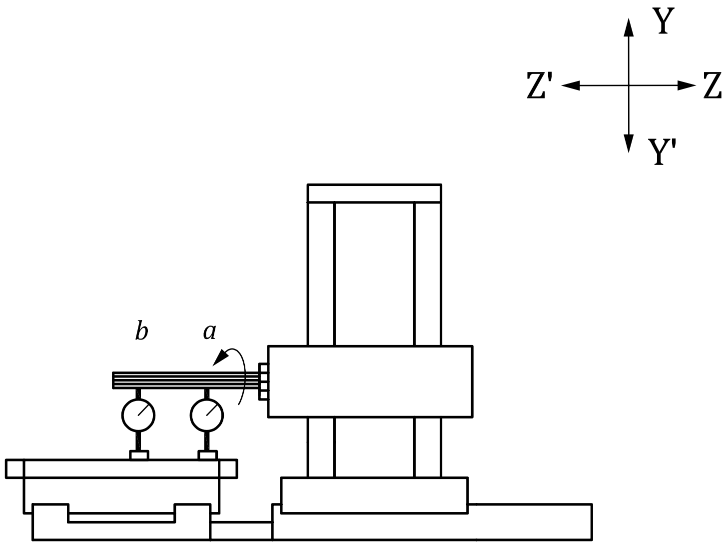
If the spindle can be locked, the dial gauge can be mounted on it; if the spindle cannot be locked, the dial gauge shall be placed on the spindle head of the machine.

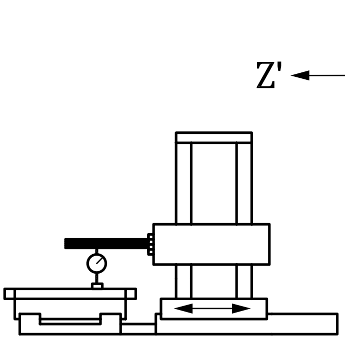
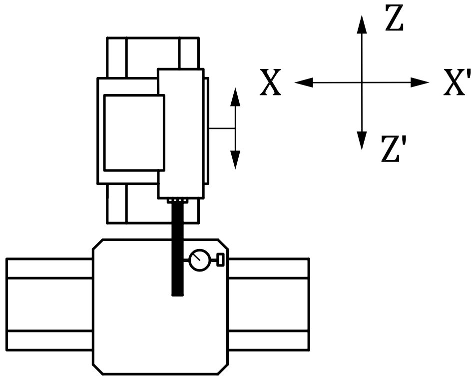
The height above the table shall be stated in the test report.

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

4.4 Spindle

Object	**G10**
Checking of axial error motion of the spindle.	
Diagram 	
Tolerance 0,005	
Measured deviation	
Measuring instruments Dial gauge with flat ended stylus tip	
Observations and references to ISO 230-1:2012, 9.1 (see also ISO 230-7) See also test ER1 in Annex E.	

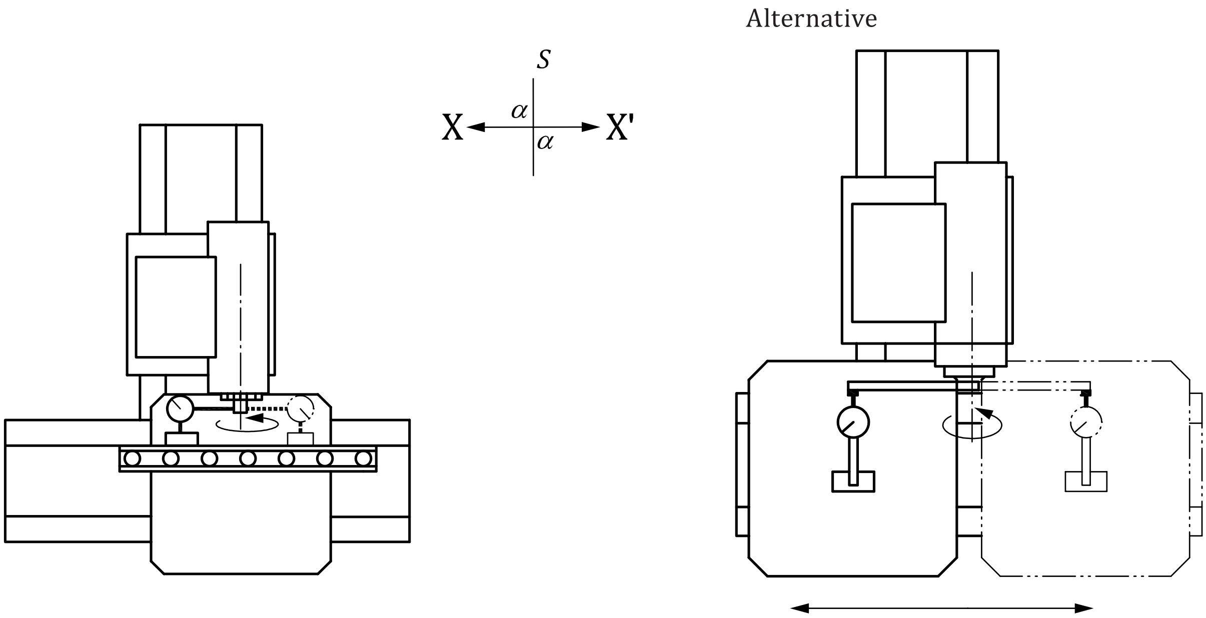
Object	**G11**
Checking of run-out of internal taper of the spindle: a) as close as possible to the spindle nose b) at a distance of 250 mm from the first measuring position in a)	
Diagram  	
Tolerance a) 0,010 b) 0,015	
Measured deviation a) b)	
Measuring instruments Test mandrel and dial gauge	
Observations and references to ISO 230-1:2012, 12.5.3 (see also ISO 230-7) See also test ER1 in Annex E. In order to make the reading easier, the spindle should rotate slowly at a speed not exceeding 100 min^{-1} (rpm). The test report shall state whether the rotation is achieved by spindle motor or manually.	

Object	**G12**
Checking of parallelism error of the spindle axis to the Z-axis motion: a) $E_{A(0Z)(C)}$ in the vertical YZ plane b) $E_{B(0Z)(C)}$ in the horizontal ZX plane	
Diagram a)  b) 	
Tolerance for a) and b) 0,050/1 000 (0,015/300) (or 0,050 µrad or 10")	
Measured deviation a) b)	
Measuring instruments Test mandrel and dial gauge	
Observations and references to ISO 230-1:2012, 3.6.2, 10.1.4, and 10.1.4.3 Z-axis in centre of the travel. The signs of the parallelism errors in both planes shall be reported.	

Object	**G13**

Checking of $E_{B(0X)(C)}$ squareness error of the spindle axis to the X-axis motion.

Diagram



Tolerance

0,050/1 000 (0,015/300)

(or 0,050 µrad or 10”)

Measured deviation

Measuring instruments

Straightedge, special arm, and dial gauge

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

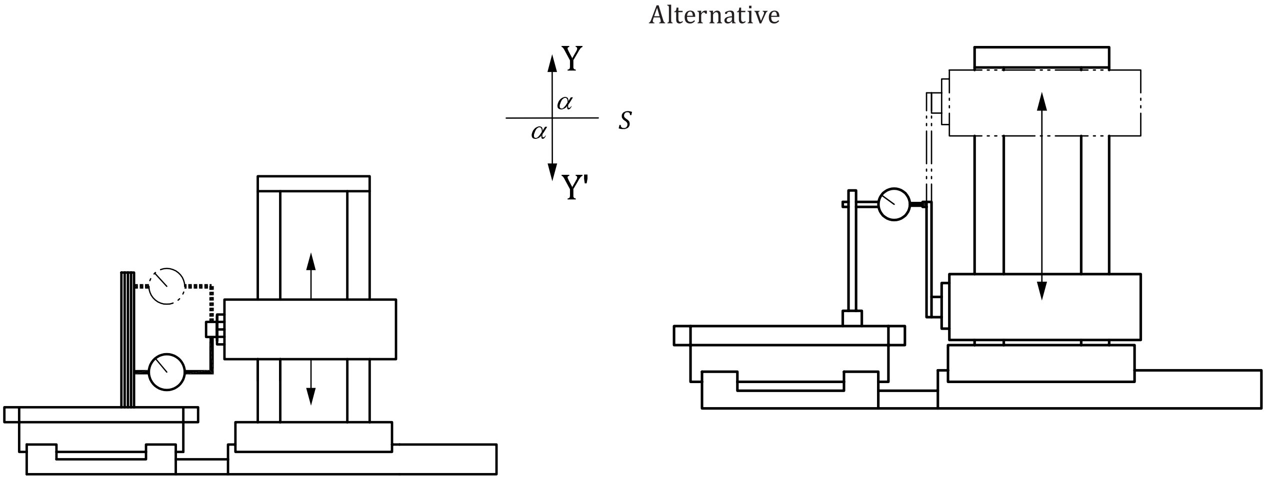
Z-axis to be locked, if possible (see 3.9).

The straightedge shall be set parallel to the X-axis, or the lack of parallelism shall be considered in the measurement.

This test can also be performed without the straightedge, by mounting the dial gauge on the table and touching with the stylus a point on a special arm fixed on the spindle, thus making the reading easier. The spindle axis shall be rotated 180° and the X-axis shall be moved in order to make the stylus touch the special arm in the same point. In this case, the measurement is influenced by the E_{ZX} horizontal straightness error of the X-axis.

The squareness error obtained with this test can be cross checked with the results of tests G9 and G12 b).

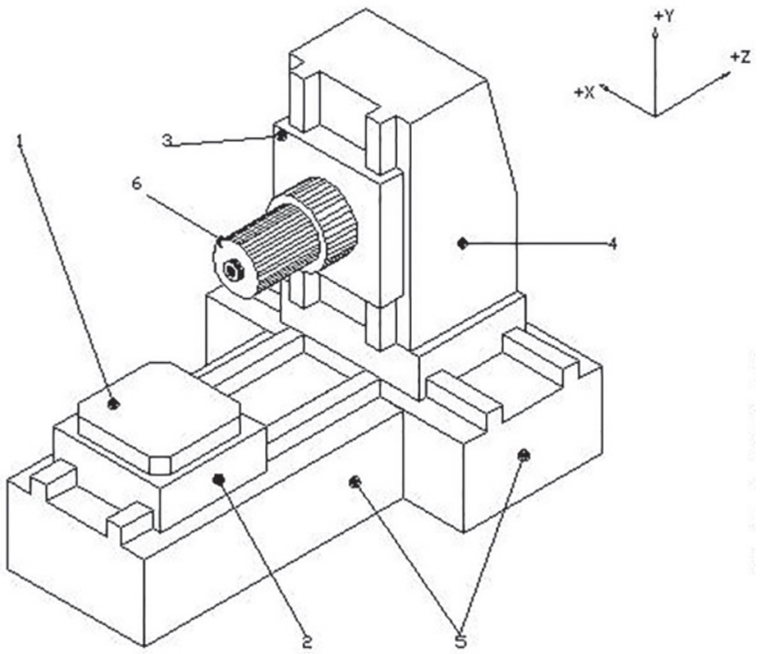
The value of angle α, being less than, equal to or greater than 90°, shall be reported.

Object	**G14**
Checking of $E_{A(0Y)(C)}$ squareness error of the spindle axis to the Y-axis motion.	
Diagram	
	
Tolerance 0,050/1 000 (0,015/300) (or 0,050 µrad or 10”)	
Measured deviation	
Measuring instruments Square, special arm, and dial gauge	
Observations and references to ISO 230-1:2012, 10.3 and 10.3.3 Z-axis to be locked, if possible (see 3.9). The measurement side of the square should be set parallel to the Y-axis, or the lack of parallelism shall be considered in the measurement. The special arm shall be stiff enough so as to prevent any possible reading errors due to its opposite deflections in the two measurement positions. This test can also be performed without the square by placing the dial gauge support on the table and touching with the stylus a point on a special arm fixed on the spindle, thus, avoiding any possible deflection of the dial gauge arm and making the reading easier. The spindle axis shall be rotated 180° and the Y-axis shall be moved in order to make the stylus touch the special arm in the same point. In this, case the measurement is influenced by the E_{ZY} straightness error of the Y-axis. The squareness error obtained with this test can be cross checked with the results of tests G8 and G12 a). The value of angle α, being less than, equal to or greater than 90°, shall be reported.	

Annex A
(normative)

Horizontal non-rotating tables

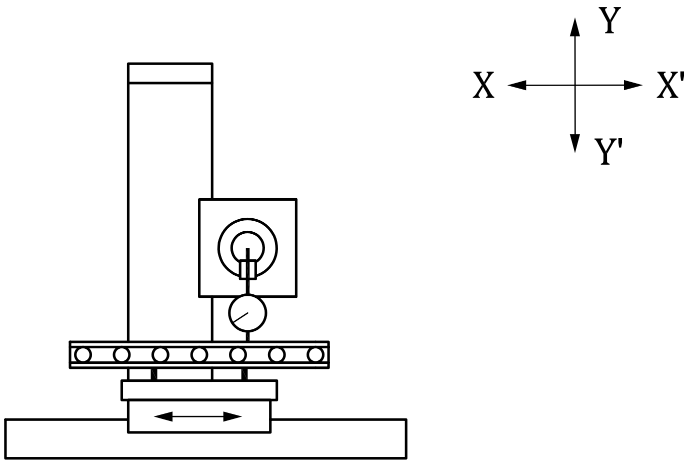
Figure A.1 hereunder shows a typical example of a machining centre with horizontal spindle and a horizontal non-rotating table.

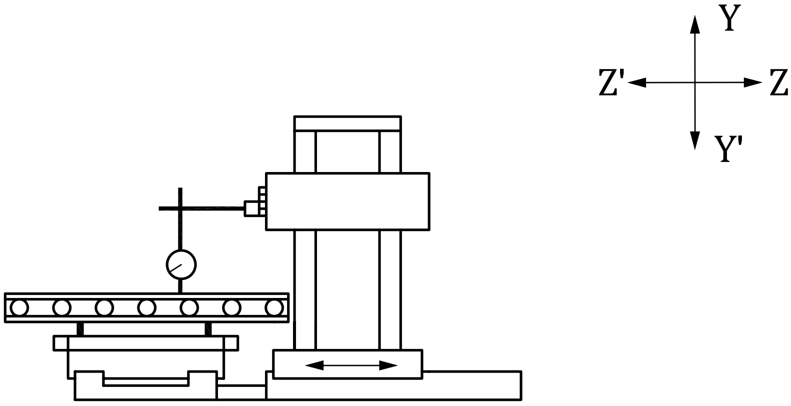


Key

1 table
2 table saddle (Z’-axis)
3 spindle head (Y-axis)
4 column (X-axis)
5 bed (b)
6 spindle [(C)]

Figure A.1 — Typical example of horizontal machining centre with a non-rotating Table Machining centre ISO 10791-1 H [w Z’ b X Y (C) t] (see 3.12)

Object	**AG1**
Checking of $E_{C(0X)T}$ parallelism error of the table[1)] surface to the X-axis motion 1) Built-in table or one representative non-rotary pallet clamped in position	
Diagram 	
Tolerance $L \le 500$ 0,020 $500 < L \le 800$ 0,025 $800 < L \le 1\,250$ 0,030 $1\,250 < L \le 2\,000$ 0,040 $2\,000 < L \le 3\,200$ 0,060 Where L is the table length in the X direction	
Measured deviation For L = …………	
Measuring instruments Straightedge, equal height spacer blocks, and dial gauge	
Observations and references to ISO 230-1:2012, 12.3.2.5 The stylus of the dial gauge is to be placed approximately at the working position of the tool. The measurement can be made on a straightedge laid parallel to the table surface. If the table is ground and new, or freshly re-conditioned, the dial gauge stylus can directly touch the table surface. If the spindle can be locked, the dial gauge can be mounted on it. If the spindle cannot be locked, the dial gauge shall be placed on the spindle head of the machine. For this test, the difference between the maximum and the minimum reading of the dial gauge is the error to be reported.	

Object	**AG2**
Checking of $E_{A(0Z)T}$ parallelism error of the table[1] surface to the Z-axis motion. [1] Built-in table or one representative non-rotary pallet clamped in position.	
Diagram 	
Tolerance W ≤ 500 — 0,020 500 < W ≤ 800 — 0,025 800 < W ≤ 1 250 — 0,030 1 250 < W ≤ 2 000 — 0,040 Where W is the table width in the Z direction	
Measured deviation For W = …………	
Measuring instruments Straightedge, equal height spacer blocks, and dial gauge	
Observations and references to ISO 230-1:2012, 10.3, 10,3.3, and 12.3.2.5 Y-axis to be locked, if possible. The stylus of the dial gauge is to be placed approximately at the working position of the tool. The measurement can be made on a straightedge laid parallel to the table surface. If the table is ground and new or freshly re-conditioned, the dial gauge stylus can directly touch the table surface. If the spindle can be locked, the dial gauge can be mounted on it. If the spindle cannot be locked, the dial gauge shall be placed on the spindle head of the machine. For this test, the difference between the maximum and the minimum reading of the dial gauge is the error to be reported.	

Object	**AG3**

Checking of squareness error of the table[1] surface to the Y-axis motion:

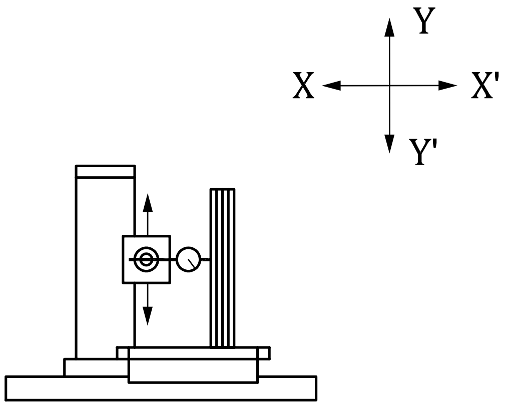
a) $E_{C(0Y)T}$ in the vertical XY plane perpendicular to the spindle axis

b) $E_{A(0Y)T}$ in the vertical YZ plane parallel to the spindle axis

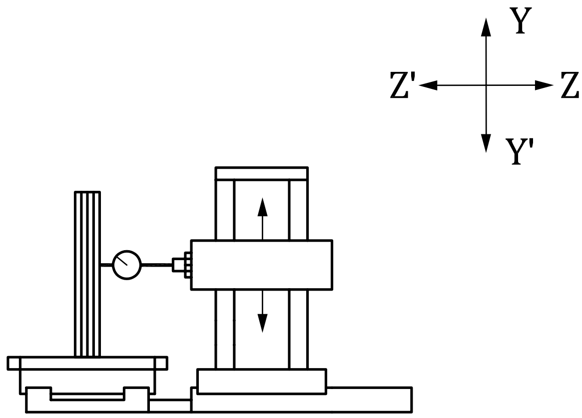
[1] Built-in table or one representative non-rotary pallet clamped in position.

Diagram

a)



b)



Tolerance

for a) and b)

0,050/1 000 (= 0,015/300)

Measured deviation

a)

b)

Measuring instruments

Surface plate, square or cylindrical square, and dial gauge

Observations and references to ISO 230-1:2012, 12.4.5

a) X-axis to be locked, if possible.

b) Z-axis to be locked, if possible.

The surface plate shall be located on the centre of the table and a square or cylindrical square shall be placed on it. If a surface plate is not used, the squareness error can be heavily affected by any small imperfection of the table surface under the narrow base of a square or cylindrical square. In this case, this test is to be carried out only on ground and new or freshly re-conditioned tables.

If the spindle can be locked, the dial gauge can be mounted on it. If the spindle cannot be locked, the dial gauge shall be placed on the spindle head of the machine.

The squareness errors measured with this test can be cross checked with the results of the following tests:

for a), tests G7 and AG1;

for b), tests G8 and AG2.

Object	**AG4**

Checking of $E_{\mathrm{B(0X)T}}$ parallelism error of:

a) the longitudinal median or reference T-slot, or

b) the centre line of the alignment holes (if longitudinal), or

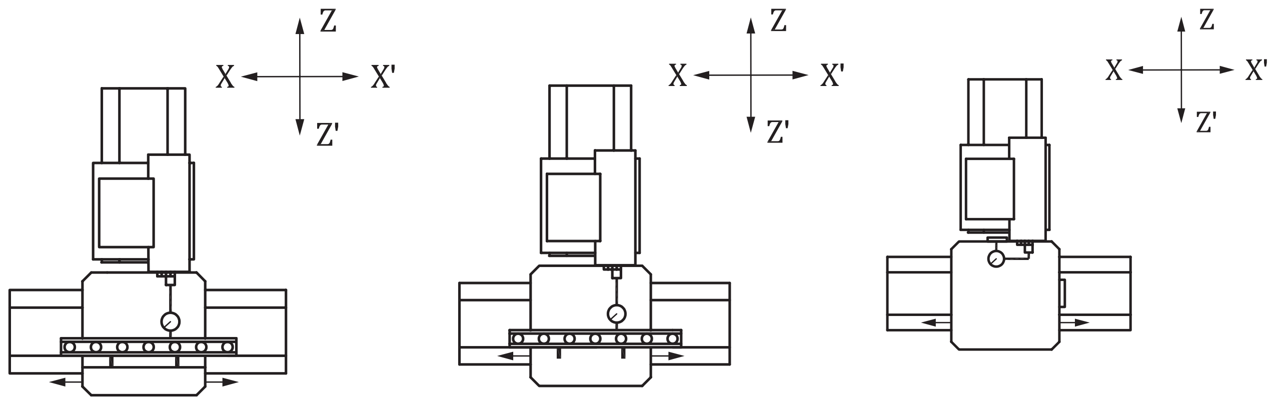
c) the longitudinal edge locator

of the table[1)] to the X-axis motion.

[1)] Built-in table or one representative non-rotary pallet clamped in position.

Diagram

a) b) c)



Tolerance

for a), b), and c)

0,025 over a measuring length of 500

Measured deviation

Measuring instruments

Gauge blocks or master pins and dial gauge.

Observations and references to ISO 230-1:2012, 12.3.2.5

Z-axis to be locked, if possible.

If the spindle can be locked, the dial gauge can be mounted on it. If the spindle cannot be locked, the dial gauge shall be placed on the spindle head of the machine.

When a reference T-slot or a tenon slot is provided, insert two gauge blocks in the slot, at the same distance from the centre of the table. Zero the dial gauge against one of the gauge blocks. The dial gauge reading on the second gauge block, divided by the distance between the gauge blocks, is the error to be reported. Note the direction of the error.

When the alignment holes exist, two master pins which fit in the holes and have protruding parts of the same diameter shall be used.

Object	**AG5**

Checking of $E_{B(0Z)T}$ parallelism error of

a) the centre line of the alignment holes (if transverse), or

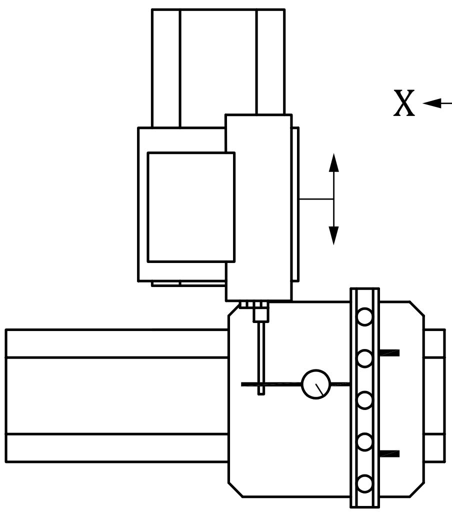
b) the transverse edge locator

of the table[1)] to the Z-axis motion.

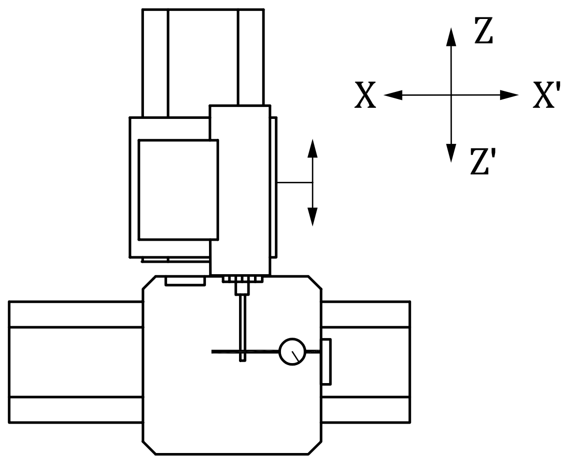
1) Built-in table or one representative non-rotary pallet clamped in position.

Diagram

a)



b)



Tolerance

for a) and b)

0,025 over a measuring length of 500

Measured deviation

Measuring instruments

Gauge blocks or master pins and dial gauge

Observations and references to ISO 230-1:2012, 12.3.2.5

X-axis to be locked, if possible.

If the spindle can be locked, the dial gauge can be mounted on it. If the spindle cannot be locked, the dial gauge shall be placed on the spindle head of the machine.

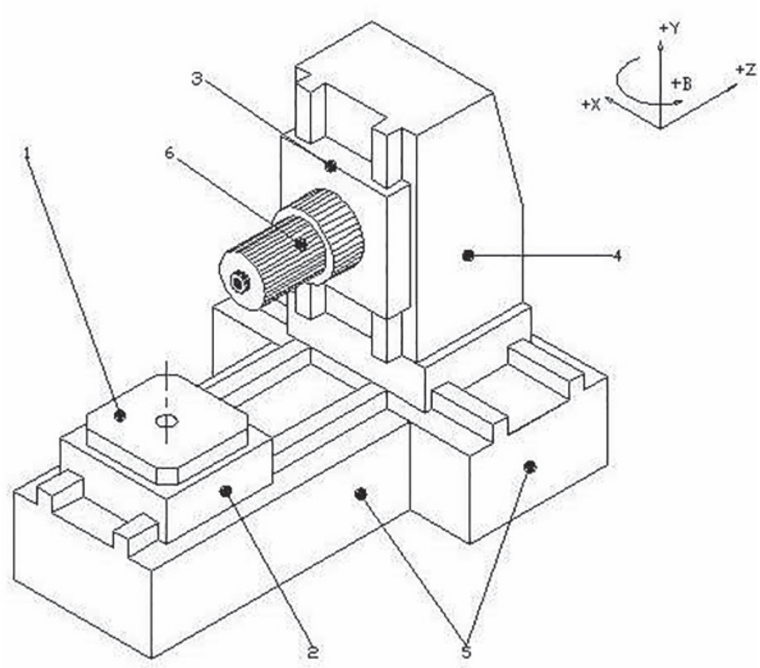
When a reference T-slot or a cross tenon slot is provided, insert two gauge blocks in the slot, at the same distance from the centre of the table. Zero the dial gauge against one of the gauge blocks. The dial gauge reading on the second gauge block, divided by the distance between the gauge blocks, is the error to be reported. Note the direction of the error.

When the alignment holes exist, two master pins which fit in the holes and have protruding parts of the same diameter shall be used.

Annex B
(normative)

Tables rotating around a vertical B’ axis

Figure B.1 hereunder shows a typical example of a machining centre with horizontal spindle and a horizontal table rotating around a vertical B’ axis.



Key

1 table

2 table saddle (Z’-axis)

3 spindle head (Y-axis)

4 column (X-axis)

5 bed (b)

6 spindle [(C)]

Figure B.1 — Typical example of horizontal machining centre with a non-rotating Table Machining centre ISO 10791-1 H [w B’ Z’ b X Y (C) t] (see 3.12)

Object	**BG1**

Checking of:

a) run-out of the centre hole of the table[1)] (when the centre hole is used for locating purposes);

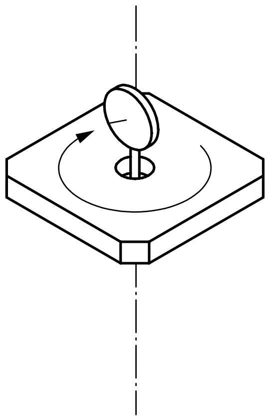
b) face error motion of the table[1)] surface[2)].

[1)] Built-in rotary table or one representative pallet clamped in position

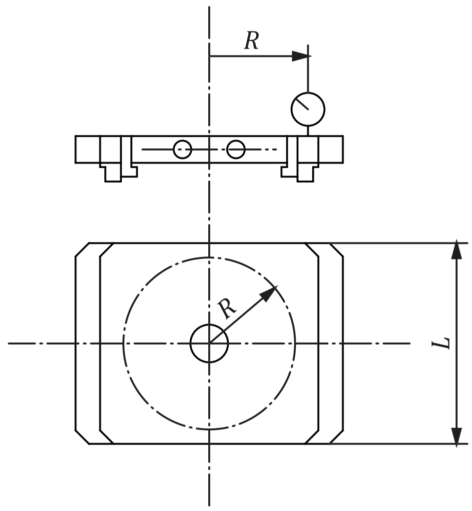
[2)] For indexing tables, check at least four positions at 90° from each other

Diagram

a)



b)



Tolerance

a) 0,025

b)

$L \leq 500$	0,030
$500 < L \leq 800$	0,040
$800 < L \leq 1\,250$	0,050
$1\,250 < L \leq 2\,000$	0,060

where L is the length of the shorter side of the table or pallet.

Measured deviation

For L =

a) b)

Measuring instruments

a) dial gauge

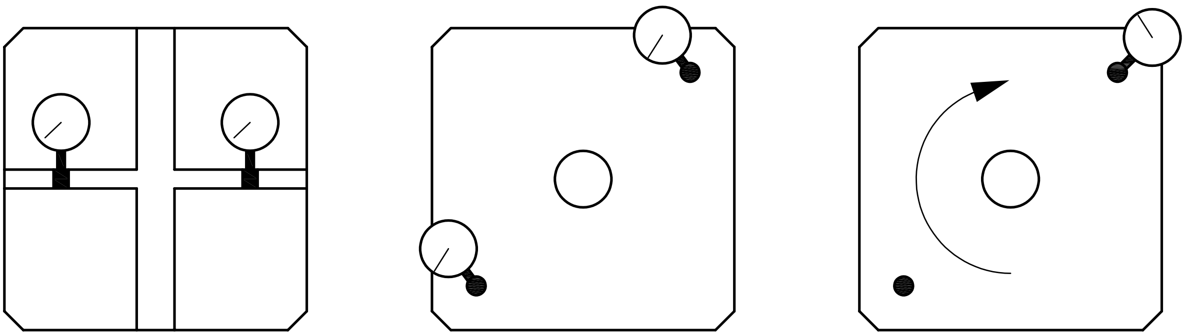
b) gauge blocks and dial gauge

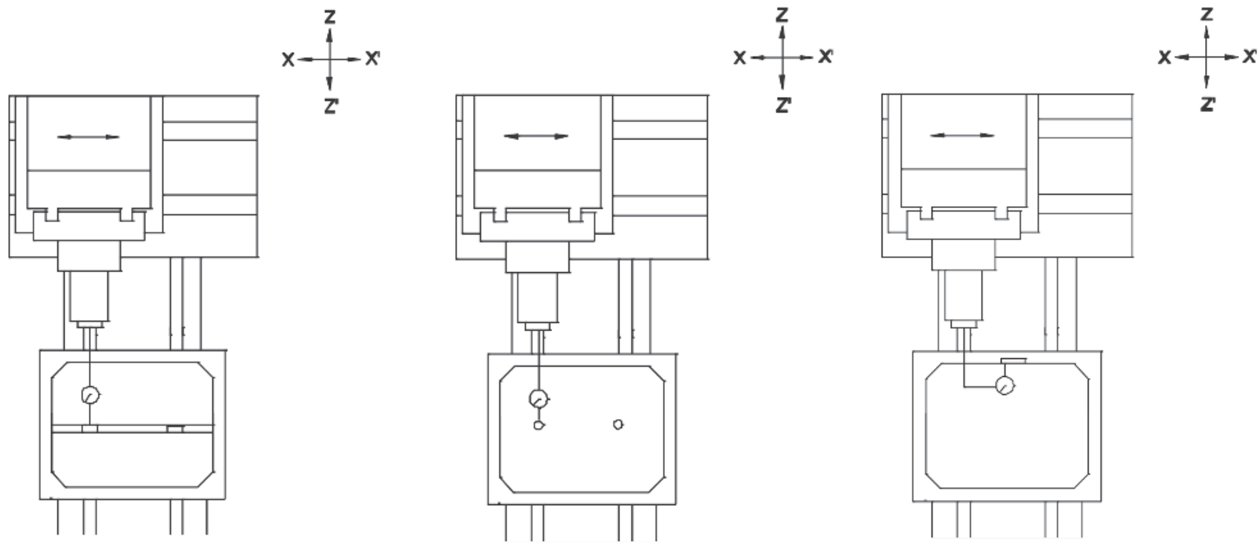
Observations and references to ISO 230-1:2012, 12.5.2 and 12.5.2.3

a) 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 the spindle head of the machine.

b) The radius R shall be as large as possible. Test b) can also be carried out without continuous contact between stylus and table surface, by using an intermediate gauge block and measuring in discrete positions (e.g. 8 points at 45° steps).

See also test ER2 in Annex E, especially if the rotary table is foreseen for turning operations.

Object	**BG2**
Checking of: a) intersection of the centre line of the longitudinal median T-slot, or of the cross tenon slot (when existing) or the line between the alignment holes, with the B'-axis of rotation of the table. b) equidistance of the alignment holes with the B'-axis of rotation of the table[1]. [1] Built-in rotary table or one representative pallet clamped in position.	
Diagram	
a) b) 	
Tolerance	
For a) and b) 0,030	
Measured deviation	
a) b)	
Measuring instruments	
a) gauge blocks or master pins and dial gauge b) master pins and dial gauge	
Observations and references to ISO 230-1	
a) When a reference T-slot or a tenon slot is provided, insert two gauge blocks in the slot, at the same distance from the axis of rotation. Adjust the B'-axis in order to have the T-slot parallel to the X-axis (or Z-axis). Parallel means that the two readings on the gauge blocks are the same. The dial gauge, placed on a fixed part of the spindle head, is then zeroed. Turn the table by 180° and again adjust the B'-axis in order to have the same readings on both gauge blocks, without resetting the dial gauge. Half of the new reading on the dial gauge is the error to be reported. When the alignment holes are provided, two master pins which fit in the holes and have protruding parts of the same diameter shall be used instead of the gauge blocks. The same procedure as above is then to be followed. b) The readings to be compared are the maximum radial readings on each master pin, which can also not precisely correspond to readings at 180° from each other, because of the deviation read in a).	

Object	**BG3**
Checking of $E_{B(0X)T}$ parallelism error of: a) the longitudinal median or reference T-slot, or b) the centre line of the alignment holes (if longitudinal), or c) the longitudinal edge locator of the table[1], with B' = 0°, to the X-axis motion. [1] Built-in rotary table or one representative pallet clamped in position.	
Diagram a) b) c) 	
Tolerance for a), b), and c) 0,025 over a measuring length of 500	
Measured deviation	
Measuring instruments a) gauge block and dial gauge b) master pins and dial gauge c) dial gauge	
Observations and references to ISO 230-1:2012, 12.3.2.5 Z-axis to be locked, if possible. If the spindle can be locked, the dial gauge can be mounted on it. If the spindle cannot be locked, the dial gauge shall be placed on the spindle head of the machine. When a reference T-slot or a tenon slot is provided, insert two gauge blocks in the slot, at the same distance from the B'-axis of rotation. Zero the dial gauge against one of the gauge blocks. The dial gauge reading on the second gauge block, divided by the distance between the gauge blocks, is the error to be reported. Note the direction of the error. When the alignment holes exist, two master pins which fit in the holes and have protruding parts of the same diameter shall be used. NOTE The result of this tests includes the possible E_{BB} positioning deviation of the B'-axis at 0°.	

Object	**BG4**

Checking of $E_{B(0Z)T}$ parallelism error of

a) the centre line of the alignment holes (if transverse), or

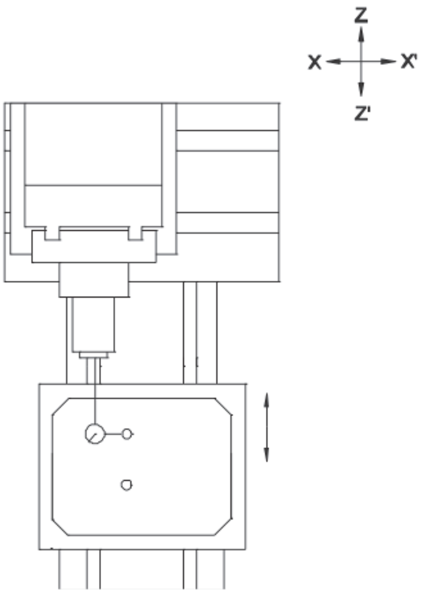
b) the transverse edge locator

of the table[1)] with B’ = 0° to the Z-axis motion.

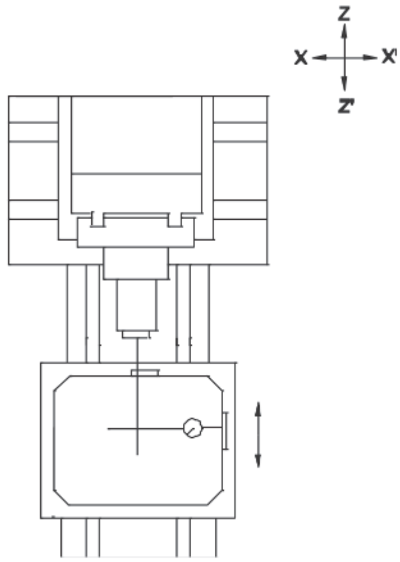
[1)] Built-in rotary table or one representative pallet clamped in position.

Diagram

a)



b)



Tolerance

for a) and b)

0,025 over a measuring length of 500

Measured deviation

Measuring instruments

a) master pins and dial gauge

b) dial gauge

Observations and references to ISO 230-1:2012, 12.3.2.5

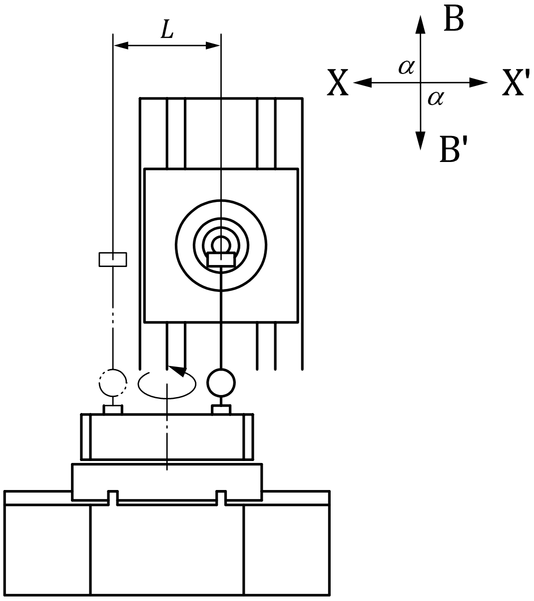
X-axis to be locked, if possible.

If the spindle can be locked, the dial gauge can be mounted on it. If the spindle cannot be locked, the dial gauge shall be placed on the spindle head of the machine.

When a reference T-slot or a cross tenon slot is provided, insert two gauge blocks in the slot, at the same distance from the centre of the table. Zero the dial gauge against one of the gauge blocks. The dial gauge reading on the second gauge block, divided by the distance between the gauge blocks, is the error to be reported. Note the direction of the error.

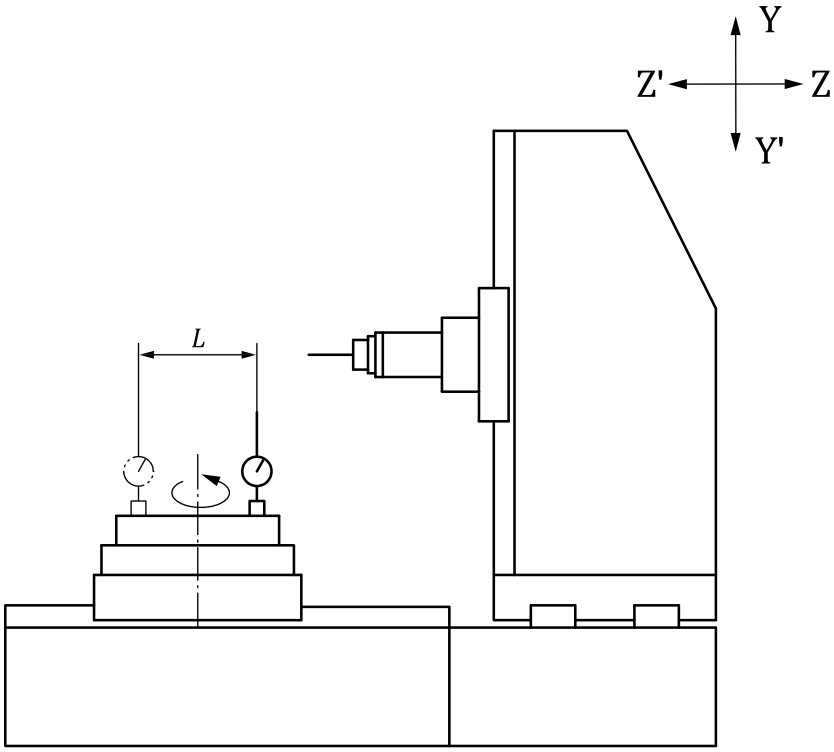
When the alignment holes exist, two master pins which fit in the holes and have protruding parts of the same diameter shall be used.

NOTE The result of this tests includes the possible E_{BB} positioning deviation of the B'-axis at 0°.

Object	**BG5**
Checking of $E_{C(0X)B}$ squareness error of the B' axis of rotation of the table[1], or receiver, to the X-axis motion [1] Built-in rotary table or any pallet clamped in position	
Diagram 	
Tolerance 0,030/1 000 (= 0,015/500)	
Measured deviation	
Measuring instruments Gauge block and dial gauge	
Observations and references to ISO 230-1 Y-axis to be locked, if possible. Place a gauge block on one edge of the table, in the X direction apart from the axis of rotation; fix the dial gauge on the spindle, if it can be locked, or on the spindle head; bring the stylus into contact with the gauge block and zero the dial gauge. Rotate the table by 180° and move the X-axis until the stylus again touches the gauge block in the same point. The dial gauge reading, divided by the X displacement, is the error to be reported. Note the direction of the error. The sign convention of the error shall correspond to the squareness sign between B' and X-axes according to ISO 230-1:2012, 3.6.7, Note 2. This test might be influenced by the E_{YX} vertical straightness error of the X-axis. The value of angle α, being less than, equal to or greater than 90°, shall be noted. The squareness error obtained with this test can be cross checked with the results of tests G7 and BG10 b).	

Object	**BG6**
Checking of $E_{A(0Z)B}$ squareness error of the B’-axis of rotation of the table, or receiver, to the Z-axis motion	

Diagram



Tolerance

0,030/1 000 (= 0,015/500)

Measured deviation

Measuring instruments

Gauge block and dial gauge

Observations and references to ISO 230-1

Y-axis to be locked, if possible.

Place a gauge block on one edge of the table, in the Z direction apart from the axis of rotation; fix the dial gauge on the spindle, if it can be locked, or on the spindle head; bring the stylus into contact with the gauge block and zero the dial gauge. Rotate the table by 180° and move the Z-axis until the stylus again touches the gauge block. The dial gauge reading, divided by the Z displacement, is the error to be reported.

The value of angle α, being less than, equal to or greater than 90°, shall be noted. The sign convention of the error shall correspond to the squareness sign between B’ and Z-axes according to ISO 230-1:2012, 3.6.7, Note 2.

This test might be influenced by the E_{YZ} vertical straightness error of the Z-axis.

The squareness error obtained with this test can be cross checked with the results of tests G8 and BG10 a).

Object	**BG7**

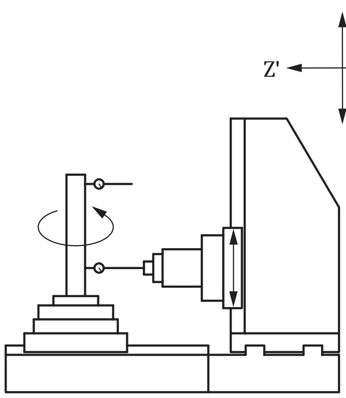
Checking of parallelism error of the B'-axis of rotation of the table, or receiver, to the Y-axis motion:

a) $E_{A(0Y)B}$ in the vertical YZ plane

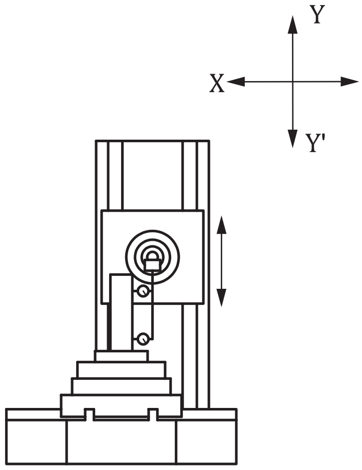
b) $E_{C(0Y)B}$ in the vertical XY plane

Diagram

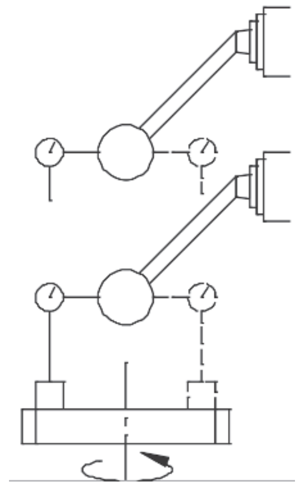
a)



b)



Alternative method



Tolerance

For a) and b) 0,040/1 000 (= 0,020/500)

Measured deviation

a)

b)

Measuring instruments

Cylinder square with flange base, or test sphere as an alternative, and dial gauge

Observations and references to ISO 230-1:2012, 3.6.3, 10.1.4, 10.1.4.3, or 10.1.4.4 as alternative

a) Z-axis to be locked, if possible.

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

If the spindle can be locked, the dial gauge can be mounted on it. If the spindle cannot be locked, the dial gauge shall be placed on the spindle head of the machine.

1) Fix a cylinder square with a flange base on the table, and centre it on approximately on the axis of rotation.

2) Fix the dial gauge on the spindle head with the stylus oriented in the Z-axis direction for a) and X-axis direction for b).

3) Touch the cylinder square by the stylus, close to the cylinder bottom, and find the maximum reading by small movements along the X-axis for a) and along Z-axis for b). Zero the dial gauge.

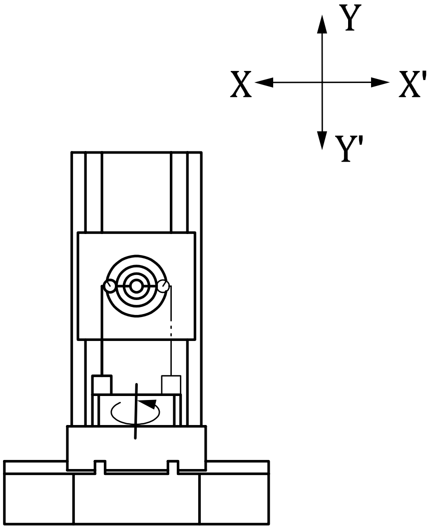
4) Move the head apart from the table along the Y-axis, and touch again the cylinder close to its top. Note the Y travel length. Find the maximum dial gauge reading by small movements along the X-axis for a) and along Z-axis for b) and note the new dial gauge reading.

5) Turn the table by 180°, and repeat steps 3) and 4).

6) For both measurements a) and b), the average value (half the algebraic sum) of the two dial gauge readings on top of the cylinder, divided by the Y travel length, is the error to be reported. The sign convention of the error shall correspond to the parallelism sign between B' and Y-axis according to ISO 230-1:2012, 3.6.3 Note 2.

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 B'-axis average line by moving X and Z-axes, while rotating the B'-axis. The Y-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.

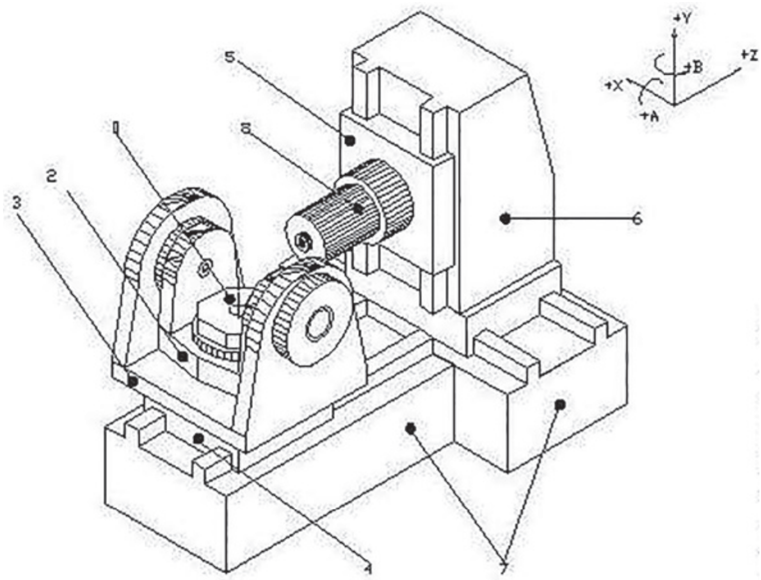
See also test ER2 in Annex E, especially if the rotary table is foreseen for turning operations.

Object	**BG8**
Checking that the B'-axis of rotation of the table and the spindle axis lie in the same YZ plane at a predefined position (i.e. measuring the $E_{X(0(C))B}$ deviation in the X direction)	
Diagram 	
Tolerance 0,010	
Measured deviation	
Measuring instruments Test mandrel and dial gauge	
Observations and references to ISO 230-1 1) Move the X-axis by numerical control to the central position where the B'-axis of rotation of the table and the spindle axis should lie in the same YZ plane. 2) Fix the test mandrel in the spindle, and the dial gauge on the table with the stylus parallel to the table surface in radial direction. 3) With the dial gauge stylus oriented in the X-axis direction touch the test mandrel, close to the spindle nose, and find the maximum reading by small movements along the Y-axis. Zero the dial gauge. 4) Move up the head along the Y direction, in order to take the test mandrel off the dial gauge. Turn both the table and the spindle by 180°, and again bring the test mandrel into contact with the dial gauge by means of Y-axis movements. 5) Find the maximum reading by small movements along the Y-axis. 6) Half of the new reading on the dial gauge is the error to be reported. NOTE 1 If this test is carried out in different positions of the Z-axis it is affected by the $E_{B(0Z)(C)}$ parallelism error between the spindle axis and the Z-axis and by the E_{XZ} horizontal straightness error of the Z-axis. NOTE 2 If this test is carried out in different positions of the Y-axis it is affected by the $E_{C(0Y)B}$ parallelism error between the B' axis of rotation of the table and the Y-axis and by the E_{XY} straightness error of the Y-axis .	

Annex C
(normative)

Tables rotating around a vertical B' axis and tilting around a horizontal A'axis

Figure C.1 hereunder shows a typical example of a machining centre with horizontal spindle and a table rotating around a B' axis and tilting around a horizontal A' axis.



Key

1 rotary table (B'-axis)
2 cradle (A'-axis)
3 trunnion
4 table saddle (Z'-axis)
5 spindle head (Y-axis)
6 column (X-axis)
7 bed (b)
8 spindle [(C)]

Figure C.1 — Typical example of horizontal five-axis machining centre with a table rotating around a vertical B' axis and tilting around a horizontal A' axis
Machining centre ISO 10791-1 H [w B' A' Z' b X Y (C) t](see 3.12)

Object	**CG1**

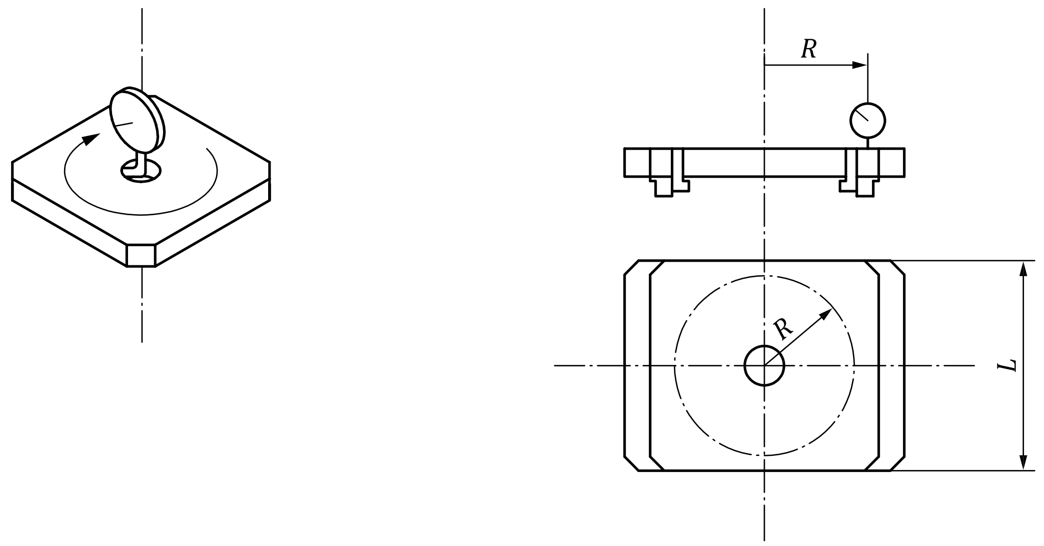
Checking of

a) run-out of the centre hole of the table (when the centre hole is used for locating purposes)

b) face error motion of the table1) surface

1) Built-in rotary table or one representative pallet clamped in position

Diagram



a) b)

Tolerance

a)		0,025
b)	$L \leq$ 500	0,030
	500 < $L \leq$ 800	0,040
	800 < $L \leq$ 1 250	0,050
	1 250 < $L \leq$ 2 000	0,060

where L is the length of the shorter side of the table or pallet.

Measured deviation

For L =........

a) b)

Measuring instruments

a) Dial gauge b) Gauge blocks and dial gauge

Observations and references to ISO 230-1:2012, 9.1 (see also ISO 230-7)

If the spindle can be locked, the dial gauge can be mounted on it. If the spindle cannot be locked, the dial gauge shall be placed on the spindle head of the machine.

b) The radius R shall be as large as possible. Test b) can also be carried out without continuous contact between stylus and table surface, by using an intermediate gauge block and measuring in discrete positions (e.g. 8 points at 45° steps).

See also test FR1 in Annex F.

Object	**CG2**

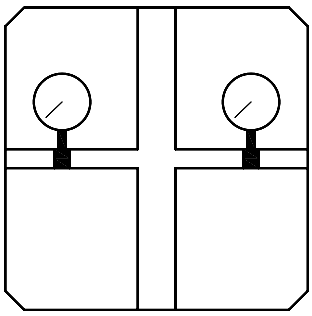
Checking of

a) intersection of the centre line of the longitudinal median T-slot, or of the cross tenon slot (when existing) or the line between the alignment holes, with the B’-axis of rotation of the table.

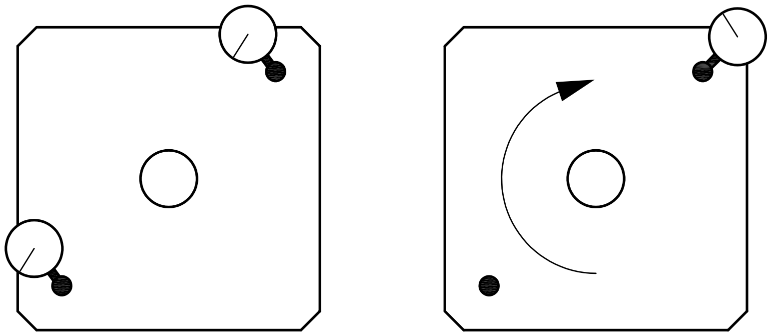
b) equidistance of the alignment holes with the B’-axis of rotation of the table.

Diagram

a)



b)



Tolerance

For a) and b) 0,030

Measured deviation

a)

b)

Measuring instruments

a) Straightedge, gauge blocks or master pins, and dial gauge

b) Master pins and dial gauge

Observations and references to ISO 230-1

a) When a reference T-slot or a tenon slot is provided, insert two gauge blocks in the slot, at the same distance from the axis of rotation. Adjust the B’-axis in order to have the T-slot parallel to the X-axis (or Z-axis). Parallel means that the two readings on the gauge blocks are the same. The dial gauge, placed on a fixed part of the spindle head, is then zeroed. Turn the table by 180° and again adjust the B’-axis in order to have the same readings on both gauge blocks, without resetting the dial gauge. Half of the new reading on the dial gauge is the error to be reported.

When the alignment holes are provided, two master pins which fit in the holes and have protruding parts of the same diameter shall be used instead of the gauge blocks. The same procedure as above is then to be followed.

b) The readings to be compared are the maximum radial readings on each master pin, which might also not precisely correspond to readings at 180° from each other, because of the deviation read in a).

Object	**CG3**

Checking of parallelism error of

— the longitudinal median or reference T-slot, or

— the centre line of the alignment holes (if longitudinal), or

— the longitudinal edge locator of the table[1)], with B’ = 0°,

to the X-axis motion:

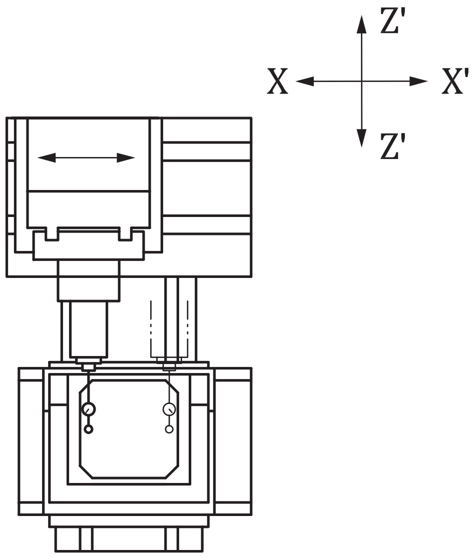
a) $E_{B(0X)T}$ with the table in the horizontal position (A’ = 0°)

b) $E_{C(0X)T}$ with the table in the vertical position (A’ = −90°)

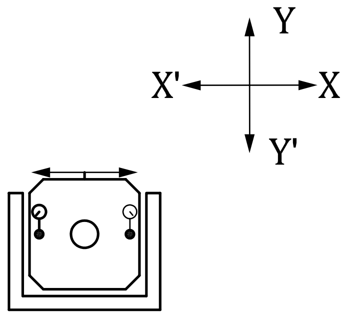
1) Built-in rotary table or one representative pallet clamped in position

Diagram

a)



b)



Tolerance

for all types

0,025 over a measuring length of 500

Measured deviation

a)

b)

Measuring instruments

Gauge blocks or master pins and dial gauge

Observations and references to ISO 230-1:2012, 12.3.2.5

a) Z-axis to be locked, if possible.

b) Y-axis to be locked, if possible.

If the spindle can be locked, the dial gauge can be mounted on it. If the spindle cannot be locked, the dial gauge shall be placed on the spindle head of the machine.

When a reference T-slot or a tenon slot is provided, insert two gauge blocks in the slot, at the same distance from the A’-axis of rotation. Zero the dial gauge against one of the gauge blocks. The dial guage reading on the second gauge block, divided by the distance between the gauge blocks, is the error to be reported. Note the direction of the error.

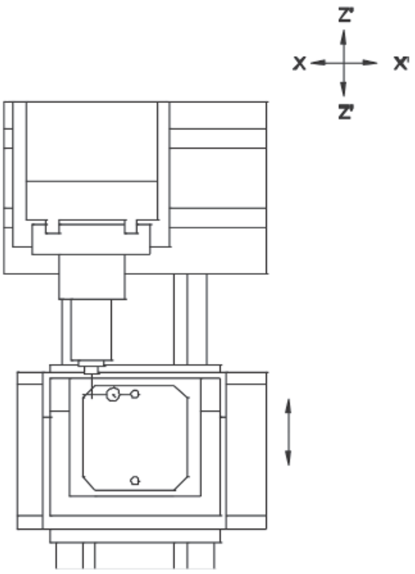
When the alignment holes exist, two master pins which fit in the holes and have protruding parts of the same diameter shall be used.

NOTE The result of this test includes the possible E_{BB} positioning error of the B’-axis at 0°.

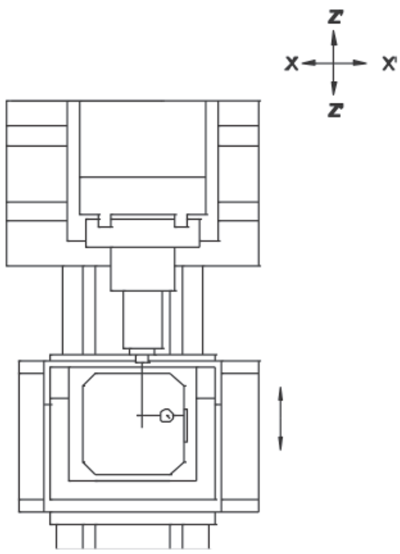
Object	**CG4**
Checking of $E_{B(0Z)T}$ parallelism error of — the centre line of the alignment holes (if transverse), or — the transverse edge locator of the table[1)] in horizontal position (A' = 0°), with B' = 0°, to the Z-axis motion [1)] Built-in rotary table or one representative pallet clamped in position	

Diagram

a)



b)



Measured deviation

Measuring instruments

Gauge blocks or master pins and dial gauge

Observations and references to ISO 230-1:2012, 12.3.2.5

X-axis to be locked, if possible.

If the spindle can be locked, the dial gauge can be mounted on it. If the spindle cannot be locked, the dial gauge shall be placed on the spindle head of the machine.

When a reference T-slot or a cross tenon slot is provided, insert two gauge blocks in the slot, at the same distance from the centre of the table. Zero the dial gauge against one of the gauge blocks. The dial gauge reading on the second gauge block, divided by the distance between the gauge blocks, is the error to be reported. Note the direction of the error.

When the alignment holes exist, two master pins which fit in the holes and have protruding parts of the same diameter shall be used.

The result of this test includes the possible E_{BB} positioning error of the *B'*-axis at 0°.

Object	**CG5**

Checking of $E_{C(0Y)T}$ parallelism error of

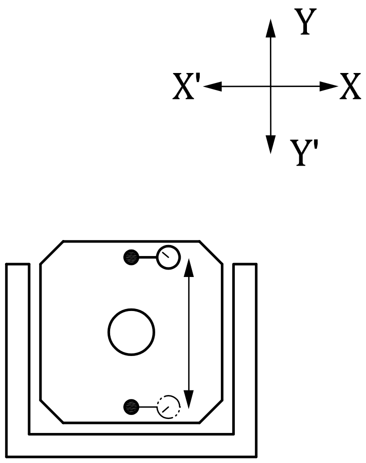
— the centre line of the alignment holes (if transverse), or

— the transverse edge locator of the table[1] in vertical position (A’ = - 90°), with B’ = 0°,

to the Y-axis motion

[1] Built-in rotary table or one representative pallet clamped in position

Diagram



Tolerance

0,025 over a measuring length of 500

Measured deviation

Measuring instruments

Gauge blocks or master pins and dial gauge

Observations and references to ISO 230-1:2012, 12.3.2.5

X-axis locked, if possible.

If the spindle can be locked, the dial gauge can be mounted on it. If the spindle cannot be locked, the dial gauge shall be placed on the spindle head of the machine.

When a reference T-slot or a cross tenon slot is provided, insert two gauge blocks in the slot, at the same distance from the centre of the table. Zero the dial gauge against one of the gauge blocks. The dial gauge reading on the second gauge block, divided by the distance between the gauge blocks, is the error to be reported. Note the direction of the error.

When the alignment holes exist, two master pins which fit in the holes and have protruding parts of the same diameter shall be used.

The result of this test includes the possible E_{BB} positioning error of the *B’*-axis at 0°.

Object — **CG6**

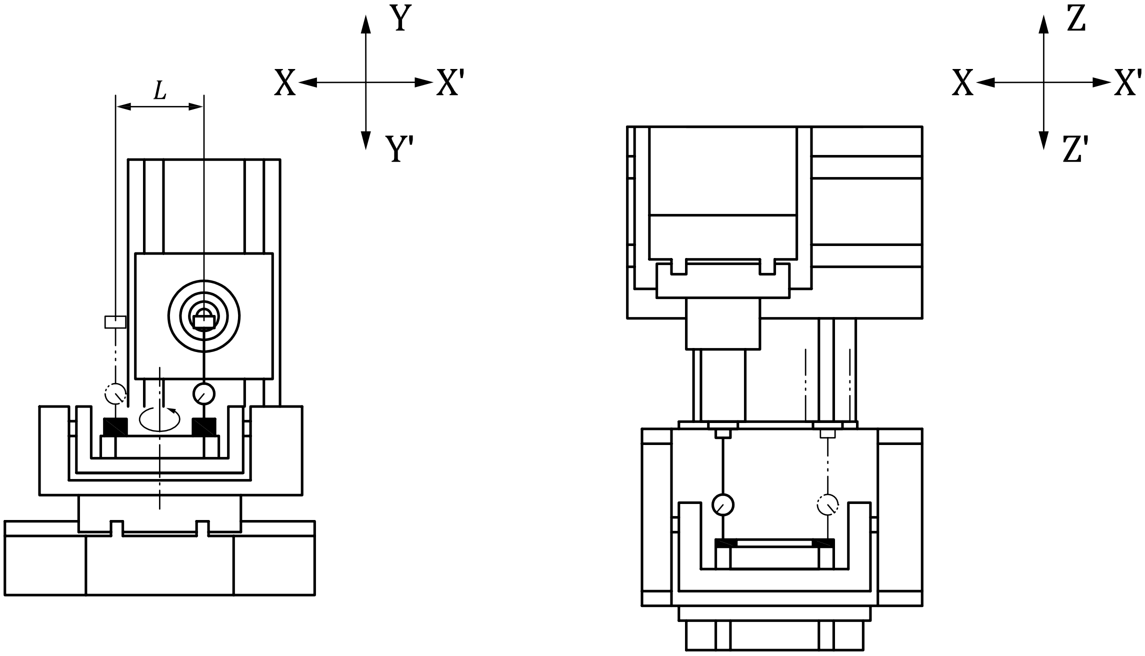
Checking of squareness error of the *B'*-axis of rotation of the table, or receiver, to the X-axis motion:

a) $E_{C(0X)B}$ table in the horizontal position (*A'* = 0°)

b) $E_{B(0Y)B,\ A'=-90}$ with the table in the vertical position (*A'* = - 90°)

Diagram

a) b)



Tolerance

For a) and b)

0,040/1 000

Measured deviation

a) b)

Measuring instruments

Gauge block and dial gauge

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

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

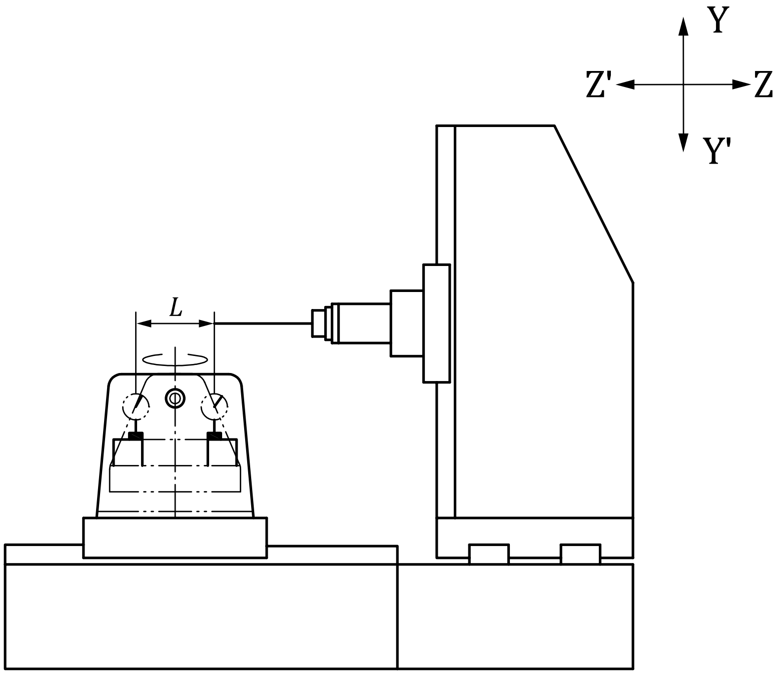
b) Z-axis to be locked, if possible.

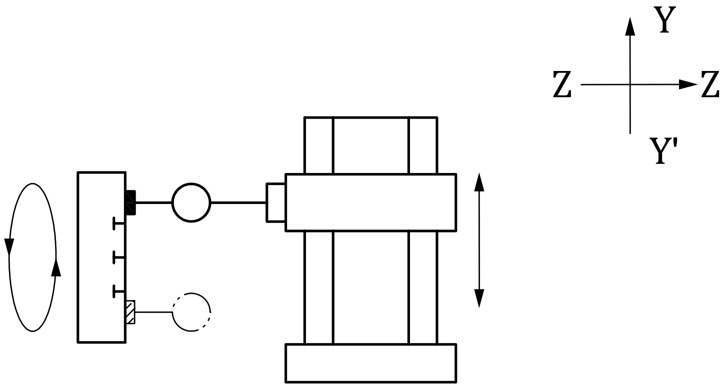
Place a gauge block on one edge of the table, in the X direction apart from the axis of rotation; fix the dial gauge on the spindle, if it can be locked, or on the spindle head; bring the stylus into contact with the gauge block and zero the dial gauge. Rotate the table by 180° and move the X-axis until the stylus again touches the gauge block in the same point. The dial gauge reading, divided by the X displacement, is the error to be reported.

Note the direction of the error. The sign convention of the error shall correspond to the squareness sign according to ISO 230-1:2012, 3.6.7, Note 2.

Test a) might be influenced by the E_{YX} vertical straightness error of the X-axis, and test b) by the E_{ZX} horizontal straightness error of the X-axis.

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

Object	**CG7**
Checking of $E_{A(0Z)B}$ squareness error of the B'-axis of rotation of the table, or receiver, in the horizontal position (A' = 0°), to the Z-axis motion	
Diagram 	
Tolerance 0,040/1 000	
Measured deviation	
Measuring instruments Gauge block and dial gauge	
Observations and references to ISO 230-1:2012, 10.3 and 10.3.3 Y-axis locked, if possible. Place a gauge block on one edge of the table, in the Z-direction apart from the axis of rotation; fix the dial gauge on the spindle, if it can be locked, or on the spindle head; bring the stylus into contact with the gauge block and zero the dial gauge. Rotate the table by 180° and move the Z-axis until the stylus again touches the gauge block in the same point. The dial gauge reading, divided by the Z displacement, is the error to be reported. Note the direction of the error. The sign convention of the error shall correspond to the squareness sign between B' and Z-axes according to ISO 230-1:2012, 3.6.7, Note 2. The result of this test includes the possible E_{AA} positioning error of the A'-axis at 0°. This test might be influenced by the E_{YZ} vertical straightness error of the Z-axis.	

Object	**CG8**
Checking of squareness error $E_{A(0Y)B,A'=-90}$ of the B'-axis of rotation of the table, or receiver, in the vertical position (A' = - 90°), to the Y-axis motion	
Diagram	
	
Tolerance	
0,040/1 000	
Measured deviation	
Measuring instruments	
Gauge block and dial gauge	
Observations and references to ISO 230-1:2012, 10.3 and 10.3.3	
Z-axis locked, if possible. 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 spindle, if it can be locked, or on the spindle head; 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 again touches the gauge block in the same point. The dial gauge reading, divided by the Y displacement, is the error to be reported. Note the direction of the error. The sign convention of the error shall correspond to the squareness sign according to ISO 230-1:2012, 3.6.7, Note 2. The result of this test includes the possible E_{AA} positioning error of the A'-axis at - 90°. This test might be influenced by the E_{ZY} straightness error of the Y-axis.	

Object	**CG9**

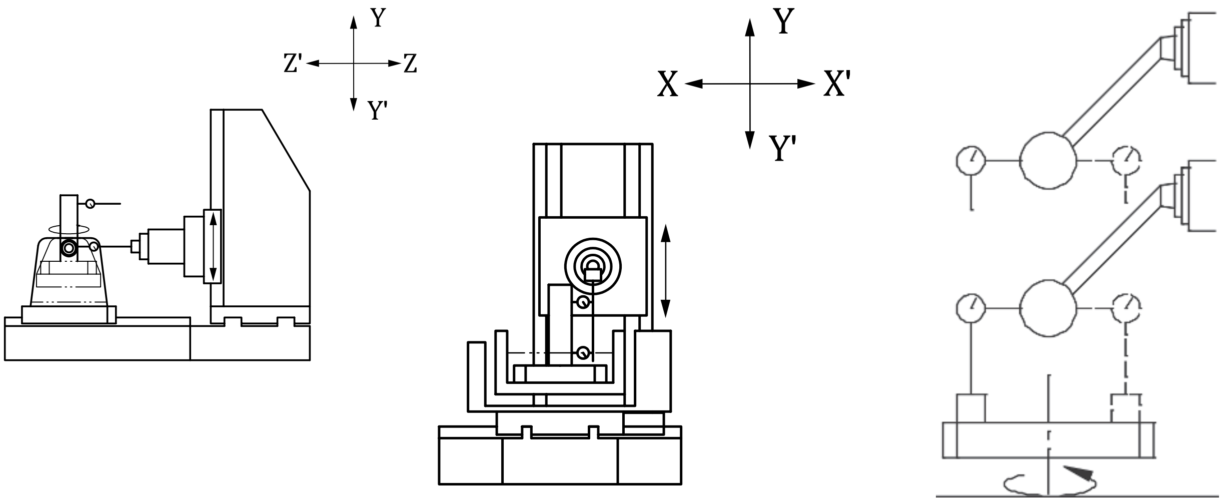
Checking of parallelism error of the B’-axis of rotation of the table, or receiver, in the horizontal position (A’ = 0°), to the Y-axis motion:

a) $E_{A(0Y)B}$ in the vertical YZ plane

b) $E_{C(0Y)B}$ in the vertical XY plane

Diagram

Alternative method



Tolerance

For a) and b) 0,040/1 000 (= 0,020/500)

Measured deviation

a) b)

Measuring instrument

Cylinder square with flange base, or test sphere as an alternative, and dial gauge

Observations and references to ISO 230-1:2012, 3.6.3, 10.1.4, 10.1.4.3, or 10.1.4.4 as alternative

a) Z-axis to be locked, if possible. The result of test a) includes the possible E_{AA} positioning error of the A’-axis at 0°.

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

1) Fix a cylinder square with a flange base on the table, and centre it on approximately on the axis of rotation.

2) Fix the dial gauge on the spindle head with the stylus oriented in the Z-axis direction for a) and X-axis direction for b).

3) Touch the cylinder square by the stylus, close to the cylinder bottom, and find the maximum dial gauge reading by small movements along the X-axis for a) and along Z-axis for b). Zero the dial gauge.

4) Move the head apart from the table along the Y-axis, and touch again the cylinder close to its top. Note the Y travel length. Find the maximum dial gauge reading by small movements along the X-axis for a) and along Z-axis for b) and note the new reading.

5) Turn the table by 180°, and repeat steps 3) and 4).

6) For both measurements a) and b), the average value (half the algebraic sum) of the two dial gauge readings on top of the cylinder, divided by the Y travel length, is the error to be reported. The sign convention of the error shall correspond to the parallelism sign between B’ and Y-axis according to ISO 230-1:2012, 3.6.3 Note 2.

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 B’-axis average line by moving X and Z-axes, while rotating the B’-axis. The Y-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.

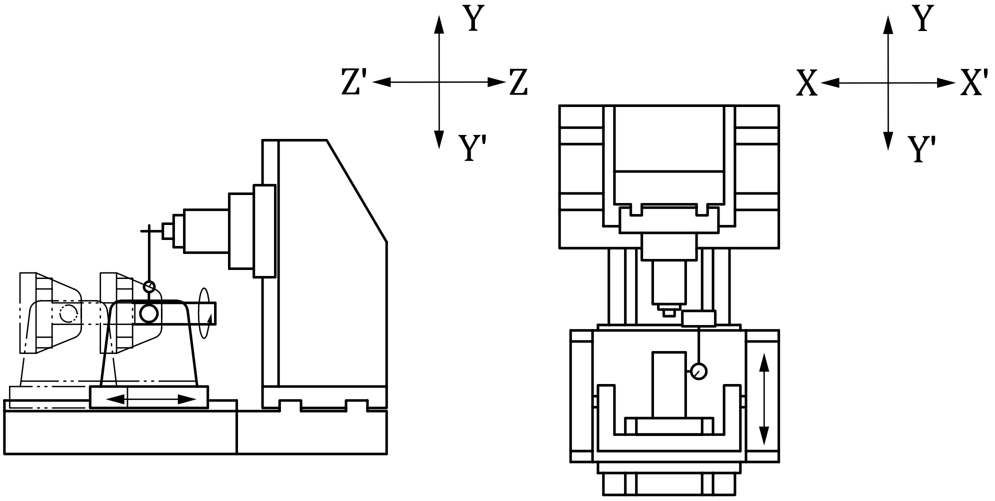
Object	**CG10**

Checking of parallelism error of the B'-axis of rotation of the table, or receiver, in the vertical position (A' = -90°), to the Z-axis motion:

a) $E_{A(0Z)B}$ in the vertical YZ plane

b) $E_{B(0Z)B}$ in the horizontal ZX plane

Diagram



NOTE: Alternative method mentioned in CG9 is not used to fixturing difficulties.

Tolerance

For a) and b) 0,050/1 000 (= 0,025/500)

Measured deviation

a)

b)

Measuring instruments

Cylinder square with flange base, or test sphere as an alternative, and dial gauge

Observations and references to ISO 230-1:2012, 3.6.3, 10.1.4, 10.1.4.3, or 10.1.4.4 as alternative

a) Y-axis to be locked, if possible. The result of test a) includes the possible E_{AA} positioning error of the A'-axis at – 90°.

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

1) Fix a cylinder square with a flange base on the table, and centre it on approximately on the axis of rotation.

2) Fix the dial gauge on the spindle head with the stylus oriented in the Y-axis direction for a) and X-axis direction for b).

3) Touch the cylinder square by the stylus, close to the cylinder bottom, and find the maximum dial gauge reading by small movements along the X-axis for a) and along Y-axis Y-axis for b). Zero the dial gauge.

4) Move the head apart from the table along the Z-axis, and touch again the cylinder close to its top. Note the Z travel length. Find the maximum dial gauge reading by small movements along the X-axis for a) and along Y-axis Y-axis for b) and note the new dial gauge reading.

5) Turn the table by 180°, and repeat steps 3) and 4).

6) For both measurements a) and b), the average value (half the algebraic sum) of the two dial gauge readings on top of the cylinder, divided by the Z travel length, is the error to be reported. The sign convention of the error shall correspond to the parallelism sign between B' and Z-axis according to ISO 230-1:2012, 3.6.3 Note 2.

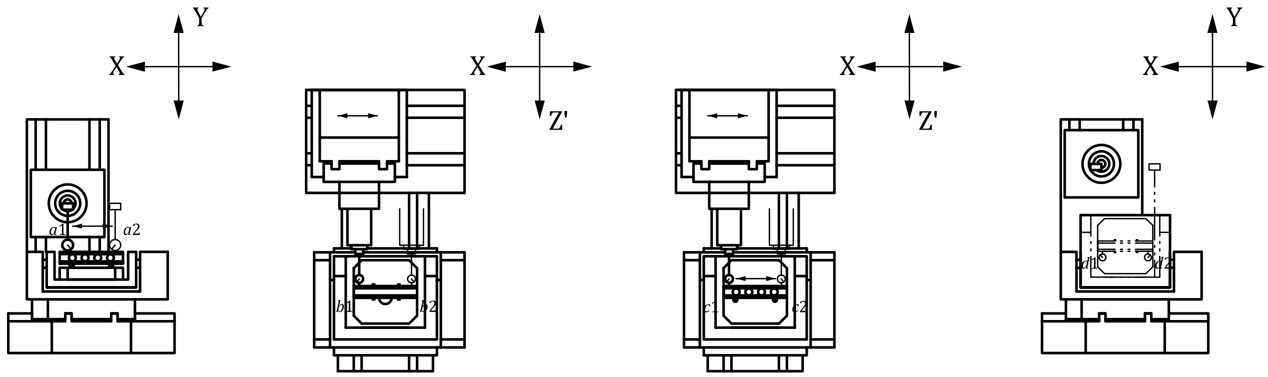
Object	**CG11**

Checking of parallelism error of the A'-axis of rotation of the table cradle, to the X-axis motion:

a) $E_{B(0X)A}$ in the horizontal ZX plane

b) $E_{C(0X)A}$ in the vertical XY plane

Diagram



Step 1) Step 2) Step 3) Step 4)

Tolerance

0,050/1 000

Measured deviation

a) b)

Measuring instruments

Straightedge or gauge blocks and dial gauge

Observations and references to ISO 230-1

1) Set the table horizontal (A' = 0°). Fix a straightedge on the table, approximately parallel to the X-axis with both reference planes. Let the dial gauge mounted on the spindle touch the straightedge top face in the Y direction. Measure at both ends of the measurement distance L, read the dial gauge in *a1* and *a2* and note the difference Δa = (*a2*-*a1*).

2) Turn the dial gauge into the Z direction and touch the straightedge side face. Measure at both ends of the measurement distance L, read the dial gauge in *b1* and *b2* and note the difference Δb = (*b2*-*b1*).

3) Set the table vertical (A' = −90°). With the dial gauge in the Z direction touch the straightedge top face in the same two points as in 1), take the readings *c1* and *c2* and note the difference Δc = (*c2*-*c1*).

4) Turn the dial gauge into the Y direction and touch the straightedge side face. Measure in the same two points as in 2), take the readings *d1* and *d2* and note the difference Δd = (*d2*-*d1*).

a) Parallelism error in the horizontal ZX plane is given by the following formula:

$E_{B(0X)A} = 1/2(-\Delta a+\Delta b+\Delta c-\Delta d)$ divided by the measurement distance L.

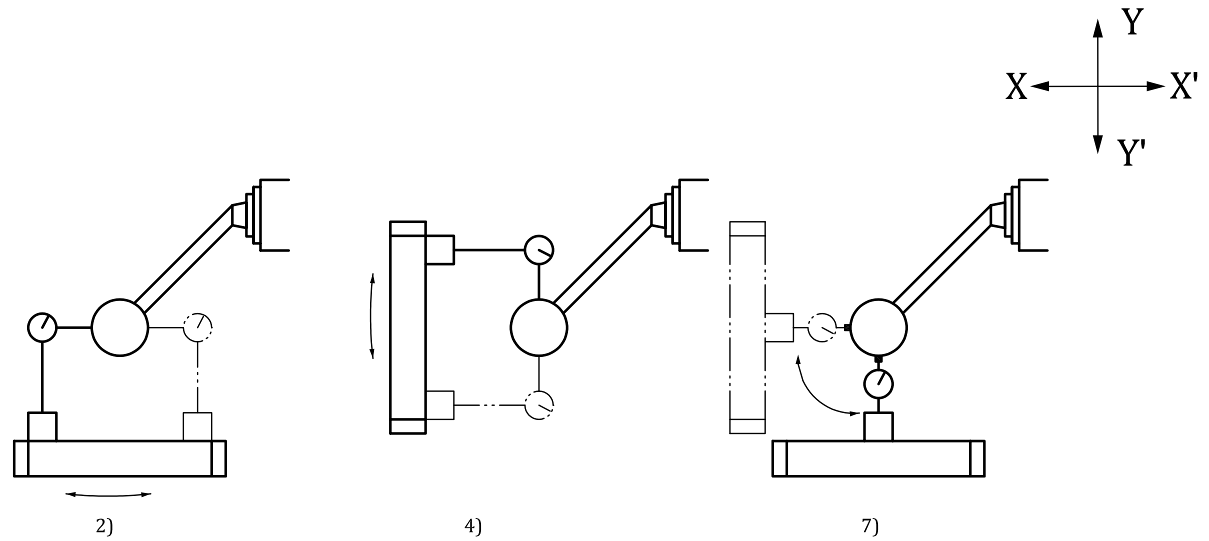
b) Parallelism error in the vertical YZ plane is given by the following formula:

$E_{C(0X)A} = 1/2(\Delta a+\Delta b-\Delta c-\Delta d)$ divided by the measurement distance L.

Object	**CG12**

Checking that the *B'*-axis of the table rotation and the *A'*-axis of the cradle tilting lie in the same plane (for table surfaces lower than the *A'*-axis) $E_{Z(0A)B}$ (only for machines with nominally zero offset between *A'* and B'-axis and without compensation facilities for any offset deviation)

Diagram



Tolerance

0,03

Measured deviation

Measuring instruments

Test sphere and dial gauge

Observations and references to ISO 230-1:2012, 10.4.3

1) Fix the sphere support in the spindle, if it can be locked, or on the spindle head. Fix the dial gauge on the table with the stylus parallel to the table surface in radial direction.

2) With the table in horizontal position (A' = 0°), align the B'-axis of the table rotation on the sphere centre, by means of rotations around B' and adjustments along X and Z.

3) Lock the X- and Z-axes.

4) Turn the table to the vertical position (A' = - 90°) and again align the B'-axis of the table rotation on the sphere centre, by means of rotations around B' and adjustments along Y.

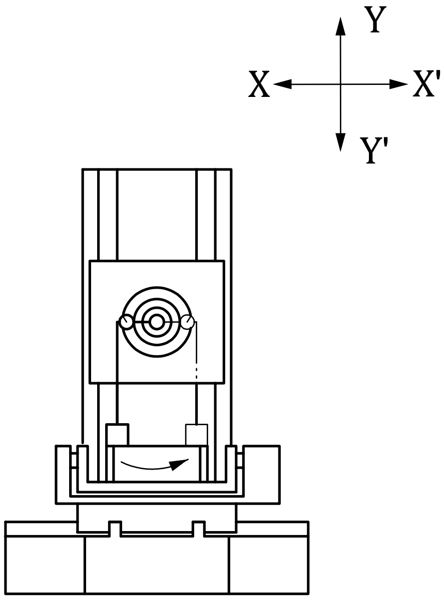
5) Lock the Y-axis.

6) With the table in horizontal position (A' = 0°), place a dial gauge, with flat tip, on top of the table, with the stylus oriented in the vertical direction, touch the sphere and zero the dial gauge.

7) Turn the table to the vertical position (A' = - 90°) and note the dial gauge reading.

Half of the new reading on the dial gauge is the error to be reported. Note the direction of the error.

The dial gauge arm shall be stiff enough so as to prevent any possible reading errors due to its opposite deflections in the different measurement positions.

Object	**CG13**
Checking that the B’-axis of rotation of the table and the spindle axis lie in the same YZ plane at a predefined position, with the table in the horizontal position (A’ = 0°) (i.e. measuring the $E_{X[0(C)]B}$ deviation in the X direction)	
Diagram  	
Tolerance 0,010	
Measured deviation	
Measuring instruments Test mandrel and dial gauge	
Observations and references to ISO 230-1 1) Adjust the A’-axis of the cradle rotation until the B’-axis of the table rotation is perpendicular to the Z-axis. 2) Move the X-axis to the central position where the B’-axis of rotation of the table and the spindle axis should lie in the same YZ plane. 3) Fix the test mandrel in the spindle and the dial gauge on the table with the stylus parallel to the table surface in radial direction. 4) With the dial gauge stylus oriented in the X-axis direction touch the test mandrel, close to the spindle nose, and find the maximum dial gauge reading by small movements along the Y-axis. Zero the dial gauge. 5) Move up the head along the Y direction, in order to take the test mandrel off the dial gauge. Turn both the table and the spindle by 180°, and again bring the test mandrel into contact with the dial gauge by means of Y-axis movements. 6) Find the maximum dial gauge reading by small movements along the Y-axis. 7) Half of the new reading on the dial gauge is the error to be reported. NOTE 1 If this test is carried out in different positions of the Z-axis it is affected by the $E_{B(0Z)(C)}$ parallelism error between the spindle axis and the Z-axis and by the E_{XZ} horizontal straightness error of the Z-axis. NOTE 2 If this test is carried out in different positions of the Y-axis it is affected by the $E_{C(0Y)B}$ parallelism error between the B’ axis of rotation of the table and the Y-axis and by the E_{XY} straightness error of the Y-axis .	

Object	**CG14**

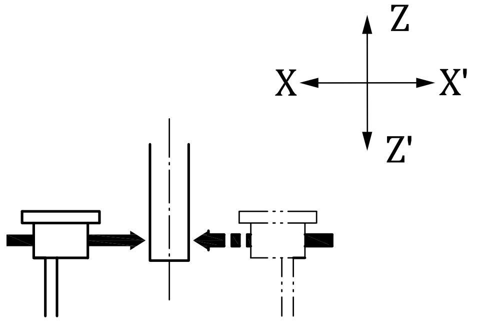
Checking of coincidence of the B'-axis of rotation of the table and the spindle axis at a predefined position, with the table in the vertical position (A' = - 90°):

a) $E_{X(0(C))B,\ A'=-90}$ along the horizontal X-axis

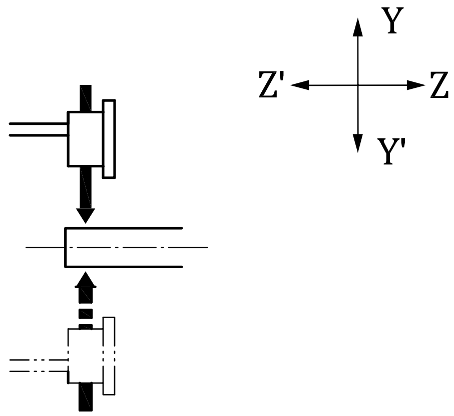
b) $E_{Y(0(C))B,\ A'=-90}$ along the vertical Y-axis

Diagram

a)



b)



Tolerance

0,010

Measured deviation

a) along the X-axis

b) along the Y-axis

Measuring instruments

Test mandrel and dial gauge

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

1) Adjust the A'-axis of the cradle rotation until the B'-axis of the table rotation is parallel to the Z-axis.

2) Move the X-axis and the Y-axis to the theoretical position where the B'-axis of rotation of the table and the spindle axis should coincide.

3) Fix the test mandrel in the spindle, and the dial gauge on the table with the stylus parallel to the table surface in radial direction.

4) With the dial gauge stylus oriented in the X-axis direction for a) and in the Y-axis direction for b), touch the test mandrel, close to the spindle nose, and find the maximum dial gauge reading by small movements [along the Y-axis for a) and along the X-axis for b)]. Zero the dial gauge.

5) Turn both the table and the spindle by 180°.

6) Find the maximum dial gauge reading as in point 4).

7) Half of the new reading on the dial gauge is the error to be reported.

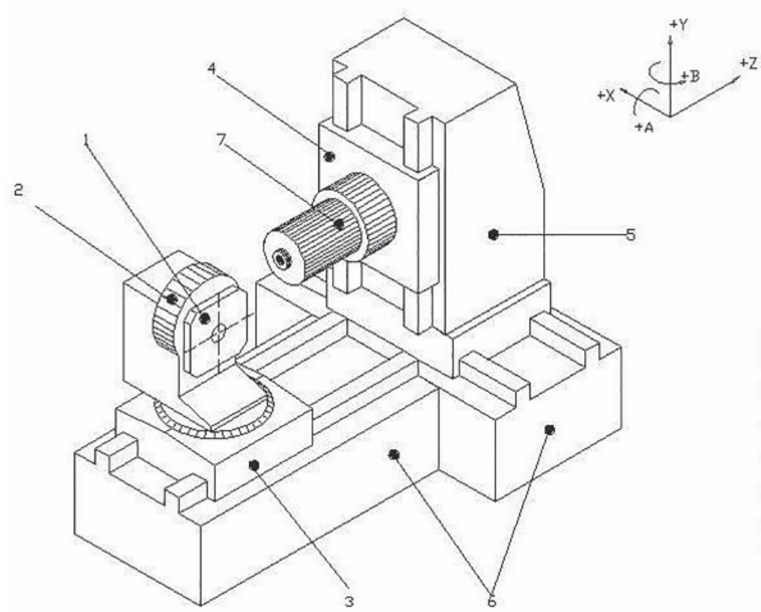
The dial gauge arm shall be stiff enough so as to prevent any possible reading errors due to its opposite deflections in the different measurement positions.

NOTE If this test is carried out in different positions of the Z-axis it is affected by the parallelism errors between the spindle axis and the Z-axis and between the B' axis of rotation of the table and the Z-axis, in both ZX and YZ planes.

Annex D
(normative)

Tables rotating around a horizontal A' axis and swivelling around a vertical B'axis

Figure D.1 shows a typical example of a machining centre with horizontal spindle and a vertical table, rotating around a horizontal A' axis and tilting around a vertical B' axis.



Key

1 rotary table (*A*'-axis)

2 swivelling table (*B*'-axis)

3 table saddle (Z'-axis)

4 spindle head (Y-axis)

5 column (XX-axis)

6 bed (b)

7 spindle [(C)]

Figure D.1 — Typical example of horizontal five-axis machining centre with a vertical table rotating around a horizontal *A'* axis and tilting around a vertical *B'* axis
Machining centre ISO 10791-1 H [w A' B' Z' b X Y (C) t] (see 3.12)

Object	**DG1**

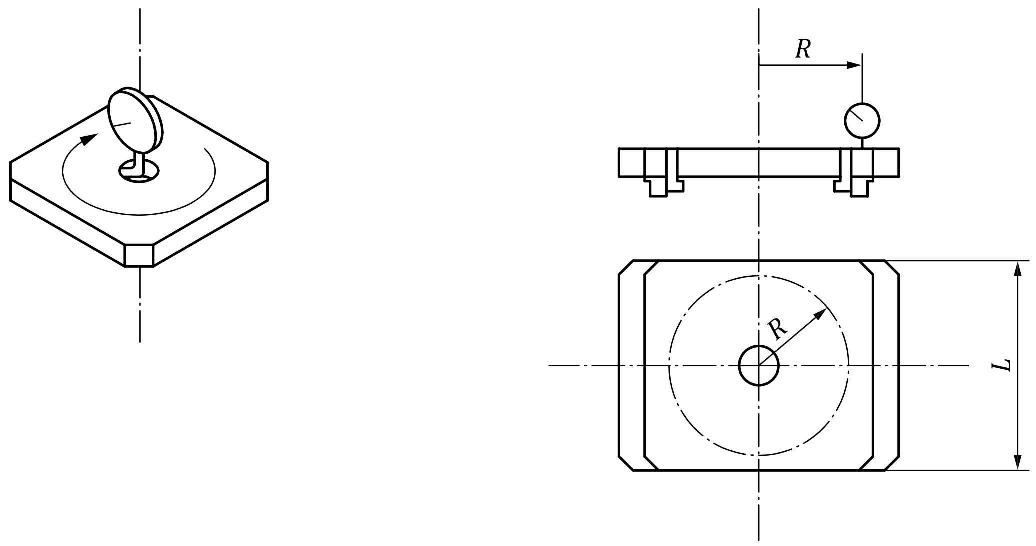
Checking of

a) run-out of the centre hole of the table[1)] (when the centre hole is used for locating purposes), and

b) face error motion of the table[1)] surface.

[1)] Built-in rotary table or one representative pallet clamped in position

Diagram



a) b)

Tolerance

a)		0,025
b)	$L \leq 500$	0,030
	$500 < L \leq 800$	0,040
	$800 < L \leq 1\,250$	0,050
	$1\,250 < L \leq 2\,000$	0,060

where *L* is the length of the shorter side of the table or pallet.

Measured deviation

For *L* =......

a) b)

Measuring instruments

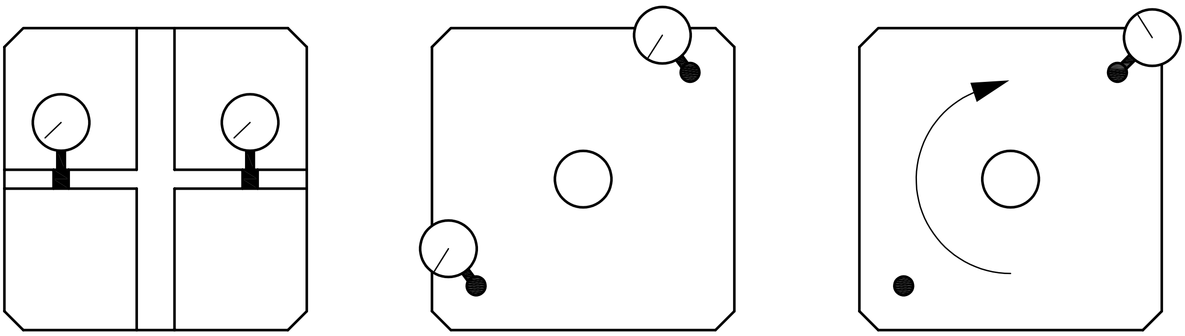
a) Dial gauge b) Gauge blocks and dial gauge

Observations and references to ISO 230-1:2012, 9.1 (see also ISO 230-7)

For a) and b), if the spindle can be locked, the dial gauge can be mounted on it. If the spindle cannot be locked, the dial gauge shall be placed on the spindle head of the machine.

For b), the radius *R* shall be as large as possible. Test b) can also be carried out without continuous contact between stylus and table surface, by using an intermediate gauge block and measuring in discrete positions (e.g. 8 points at 45° steps).

See also test GR1 in Annex G.

Object	**DG2**
Checking of a) intersection of the centre line of the longitudinal median T-slot, or of the cross tenon slot (when existing) or the line between the alignment holes, with the *A'*-axis of rotation of the table, and b) equidistance of the alignment holes with the *A'*-axis of rotation of the table[1]). [1]) Built-in rotary table or one representative pallet clamped in position	
Diagram a) b) 	
Tolerance For a) and b) 0,030	
Measured deviation a) b)	
Measuring instruments a) Straightedge, gauge blocks or master pins and dial gauge b) Master pins and dial gauge	
Observations and references to ISO 230-1 a) When a reference T-slot or a tenon slot is provided, insert two gauge blocks in the slot, at the same distance from the axis of rotation. Adjust the *A'*-axis in order to have the T-slot parallel to the X-axis (or Z-axis). Parallel means that the two readings on the gauge blocks are the same. The dial gauge, placed on a fixed part of the spindle head, is then zeroed. Turn the table by 180° and again adjust the *A'*-axis in order to have the same dial gauge readings on both gauge blocks, without resetting the dial gauge. Half the new reading on the dial gauge is the error to be reported. When the alignment holes are provided, two master pins which fit in the holes and have protruding parts of the same diameter shall be used instead of the gauge blocks. The same procedure as above is then to be followed. b) The dial gauge readings to be compared are the maximum radial readings on each master pin, which might also not precisely correspond to readings at 180° from each other, because of the error read in a).	

Object	**DG3**

Checking of $E_{C(0X)T}$ parallelism error of

— the longitudinal median or reference T-slot, or

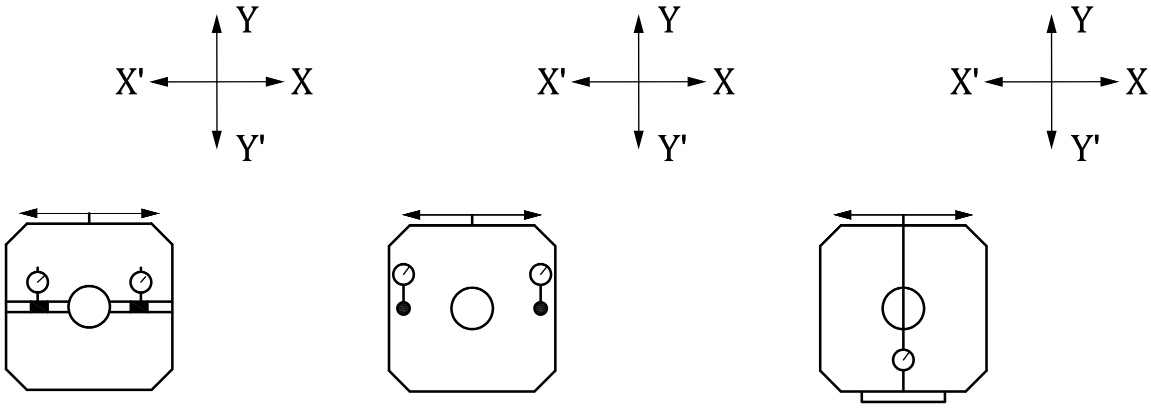
— the centre line of the alignment holes (if longitudinal), or

— the longitudinal edge locator of the table1), set perpendicular to the spindle axis (B' = 90°), with A' = 0°,

to the X-axis motion.

1) Built-in rotary table or one representative pallet clamped in position

Diagram



Tolerance

for all types

0,025 over a measuring length of 500

Measured deviation

Measuring instruments

Dial gauge and gauge blocks or master pins

Observations and references to ISO 230-1:2012, 12.3.2.5

Y-axis to be locked, if possible.

If the spindle can be locked, the dial gauge can be mounted on it. If the spindle cannot be locked, the dial gauge shall be placed on the spindle head of the machine.

When a reference T-slot or a tenon slot is provided, insert two gauge blocks in the slot, at the same distance from the A'-axis of rotation. Zero the dial gauge against one of the gauge blocks. The dial gauge reading on the second gauge block, divided by the distance between the gauge blocks, is the error to be reported. Note the direction of the error.

When the alignment holes exist, two master pins which fit in the holes and have protruding parts of the same diameter shall be used.

The result of this test includes the possible E_{AA} positioning error of the A'-axis at 0°.

Object	**DG4**

Checking of $E_{A(0Z)T}$ parallelism error of

— the longitudinal median or reference T-slot, or

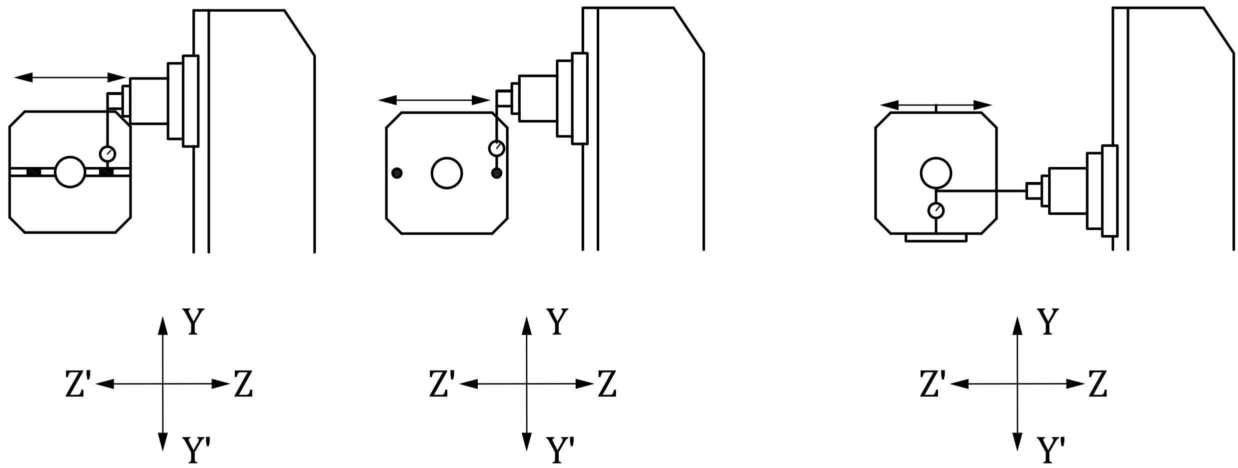
— the centre line of the alignment holes (if longitudinal), or

— the longitudinal edge locator of the table[1)], set parallel to the spindle axis (*B'* = 0° or 180°), with *A'* = 0°,

to the Z-axis motion.

1) Built-in rotary table or one representative pallet clamped in position

Diagram



Tolerance

for all types

0,025 over a measuring length of 500

Measured deviation

Measuring instruments

Gauge blocks or master pins and dial gauge

Observations and references to ISO 230-1:2012, 12.3.2.5

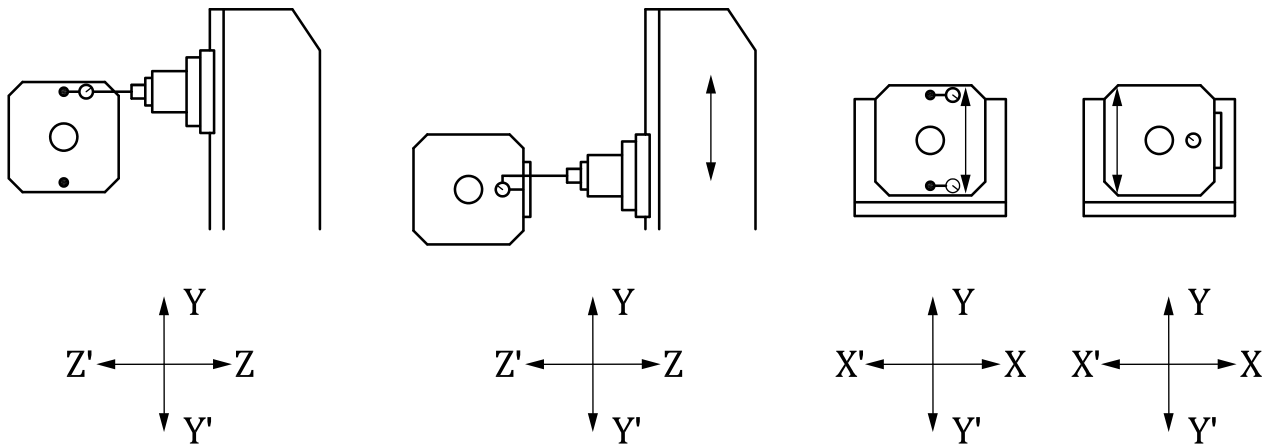
Y-axis to be locked, if possible.

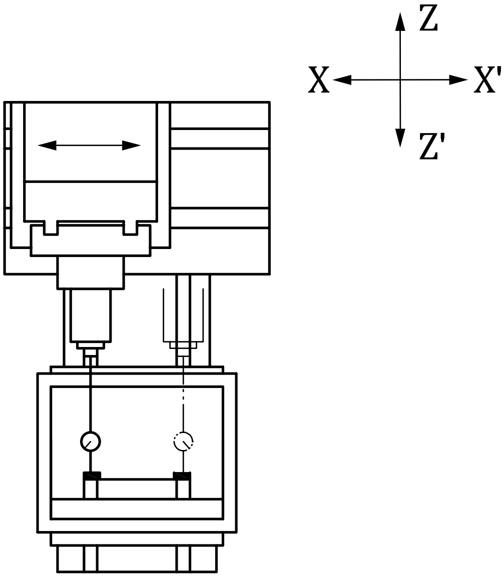
If the spindle can be locked, the dial gauge may be mounted on it. If the spindle cannot be locked, the dial gauge shall be placed on the spindle head of the machine.

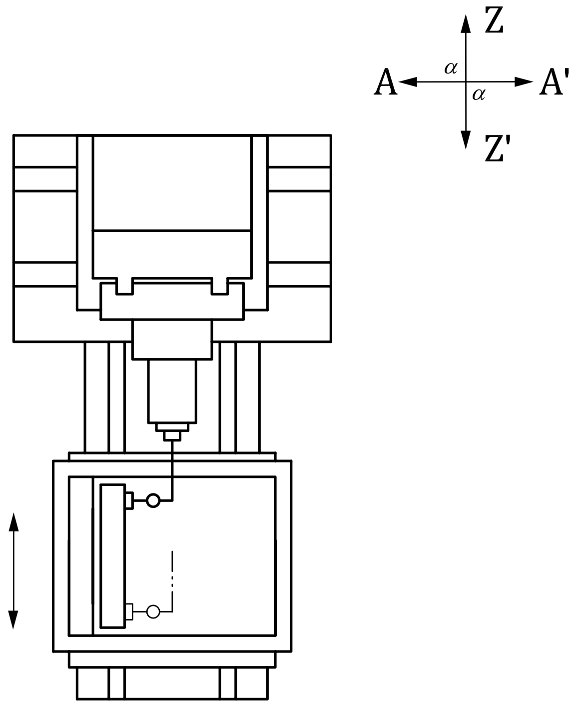
When a reference T-slot or a tenon slot is provided, insert two gauge blocks in the slot, at the same distance from the *A'*-axis of rotation. Zero the dial gauge against one of the gauge blocks. The dial gauge reading on the second gauge block, divided by the distance between the gauge blocks, is the error to be reported. Note the direction of the error.

When the alignment holes exist, two master pins which fit in the holes and have protruding parts of the same diameter shall be used.

The result of this test includes the possible E_{AA} positioning error of the *A'*-axis at 0°.

Object	**DG5**
Checking of parallelism error of — the centre line of the alignment holes (if transverse), or — the transverse edge locator of the table[1)] to the Y-axis motion: a) $E_{A(0Y)T}$ with the table parallel to the spindle axis (*B'* = 0° or 180°) b) $E_{C(0Y)T}$ with the table perpendicular to the spindle axis (*B'* = 90°) [1)] Built-in rotary table or one representative pallet clamped in position	
Diagram 	
Tolerance For both types 0,025 over a measuring length of 500	
Measured deviation a) b)	
Measuring instruments Gauge blocks or master pins and dial gauge	
Observations and references to ISO 230-1:2012, 12.3.2.5 a) Z-axis to be locked, if possible. b) X-axis to be locked, if possible. If the spindle can be locked, the dial gauge can be mounted on it. If the spindle cannot be locked, the dial gauge shall be placed on the spindle head of the machine. When a reference T-slot or a cross tenon slot is provided, insert two gauge blocks in the slot, at the same distance from the centre of the table. Zero the dial gauge against one of the gauge blocks. The dial gauge reading on the second gauge block, divided by the distance between the gauge blocks, is the error to be reported. Note the direction of the error. When the alignment holes exist, two master pins which fit in the holes and have protruding parts of the same diameter shall be used. The result of this test includes the possible E_{AA} positioning error of the *A'*-axis at 0°.	

Object	**DG6**
Checking of $E_{B(0X)A}$ squareness error of the *A'*-axis of rotation of the table, or receiver, with the table perpendicular to the spindle axis (*B'* = 90°), to the X-axis motion	
Diagram  	
Tolerance 0,040/1 000	
Measured deviation	
Measuring instruments Gauge block and dial gauge	
Observations and references to ISO 230-1:2012, 10.3 and 10.3.3 Z-axis to be locked, if possible. The result of this test includes the possible positioning deviation of the *B'*-axis. Place a gauge block on one edge of the table, in the X direction apart from the axis of rotation; fix the dial gauge on the spindle, if it can be locked, or on the spindle head; bring the stylus into contact with the gauge block and zero the dial gauge. Rotate the table by 180° and move the X-axis until the stylus again touches the gauge block in the same point. The dial gauge reading, divided by the X displacement, is the error to be reported. Note the direction of the error. The sign convention of the error shall correspond to the squareness sign according to ISO 230-1:2012, 3.6.7, Note 2. This test might be influenced by the E_{ZX} horizontal straightness error of the X-axis. The result of this test includes the possible E_{BB} positioning error of the *B'*-axis at 90°.	

Object	**DG7**
Checking of $E_{B(0Z)A}$ squareness error of the *A'*-axis of rotation of the table, or receiver, with the table parallel to the spindle axis (*B'* = 0°, or *B'* = 180° as shown in the diagram), to the Z-axis motion	
Diagram	
	
Tolerance 0,040/1 000	
Measured deviation	
Measuring instruments Gauge block and dial gauge	
Observations and references to ISO 230-1:2012, 10.3 and 10.3.3 X-axis to be locked, if possible. The result of test a) includes the possible positioning deviation of the *B'*-axis. Place a gauge block on one edge of the table, in the Z direction apart from the axis of rotation; fix the dial gauge on the spindle, if it can be locked, or on the spindle head; bring the stylus into contact with the gauge block and zero the dial gauge. Rotate the table by 180° and move the Z-axis until the stylus again touches the gauge block in the same point. The dial gauge reading, divided by the Z displacement, is the error to be reported. Note the direction of the error. The sign convention of the error (α) shall correspond to the squareness sign according to ISO 230-1:2012, 3.6.7, Note 2. The result of this test includes the possible E_{BB} positioning error of the *B'*-axis (at 0° or at 180°). The value of angle α, being less than, equal to or greater than 90°, shall be noted.	

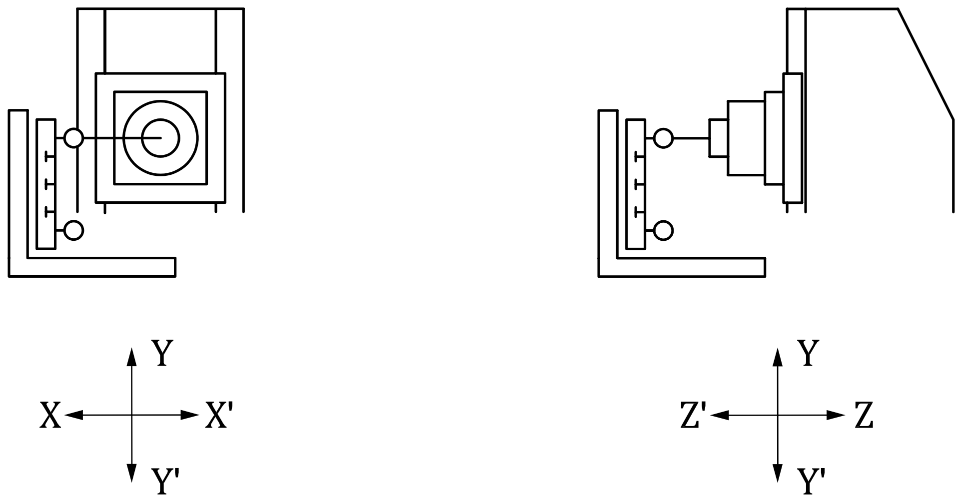
Object	**DG8**

Checking of squareness error of the *A'*-axis of rotation of the table, or receiver, to the Y-axis motion:

a) $E_{C(0Y)A}$ with the table parallel to the spindle axis (B' = 0°, or B' = 180° as shown in the diagram)

b) $E_{A(0Y)A}$ with the table perpendicular to the spindle axis (B' = 90°)

Diagram



a) b)

Tolerance

0,040/1 000

Measured deviation

a) b)

Measuring instruments

Gauge block and dial gauge

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

a) X-axis to be locked, if possible.

b) Z-axis to be locked, if possible.

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 spindle, if it can be locked, or on the spindle head; 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 again touches the gauge block in the same point. The dial gauge reading, divided by the Y displacement, is the error to be reported.

Note the direction of the error. The sign convention of the error shall correspond to the squareness sign according to ISO 230-1:2012, 3.6.7, Note 2.

Test a) might be influenced by the E_{XY} straightness error of the Y-axis, and test b) by the E_{ZY} straightness error.

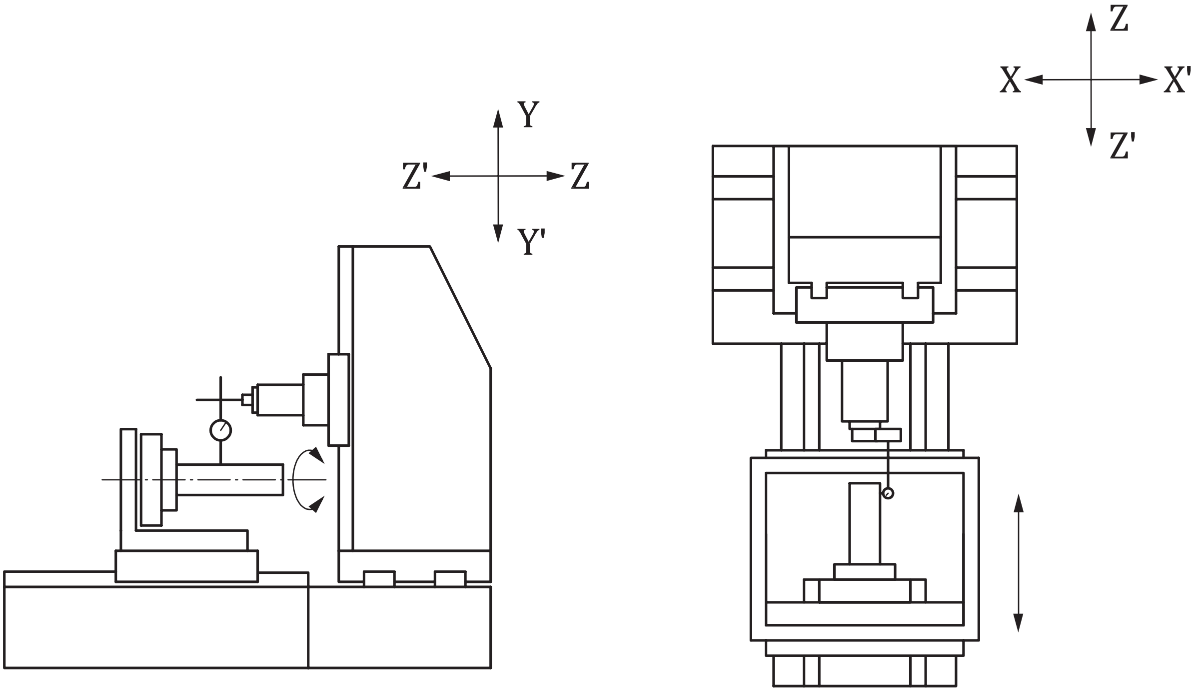
Object | **DG9**

Checking of parallelism error of the *A'*-axis of rotation of the table, or receiver, with the table perpendicular to the spindle axis (*B'* = 90°), to the Z-axis motion:

a) $E_{A(0Z)A}$ in the vertical YZ plane

b) $E_{B(0Z)A}$ in the horizontal ZX plane

Diagram



Tolerance

For a) and b) 0,040/1 000 (= 0,020/500)

Measured deviation

a)

b)

Measuring instruments

Cylinder square with flange base, or test sphere as an alternative, and dial gauge

Observations and references to ISO 230-1:2012, 3.6.3, 10.1.4, 10.1.4.3, or 10.1.4.4 as alternative

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

b) X-axis to be locked, if possible. The result of test b) includes the possible E_{BB} positioning deviation of the *B'*-axis at 90°.

1) Fix a cylinder square with a flange base on the table, and centre it on approximately on the axis of rotation.

2) Fix the dial gauge on the spindle head with the stylus oriented in the Y-axis direction for a) and X-axis direction for b).

3) Touch the cylinder square by the stylus, close to the cylinder bottom, and find the maximum dial gauge reading by small movements along the X-axis for a) and along Y-axis for b). Zero the dial gauge.

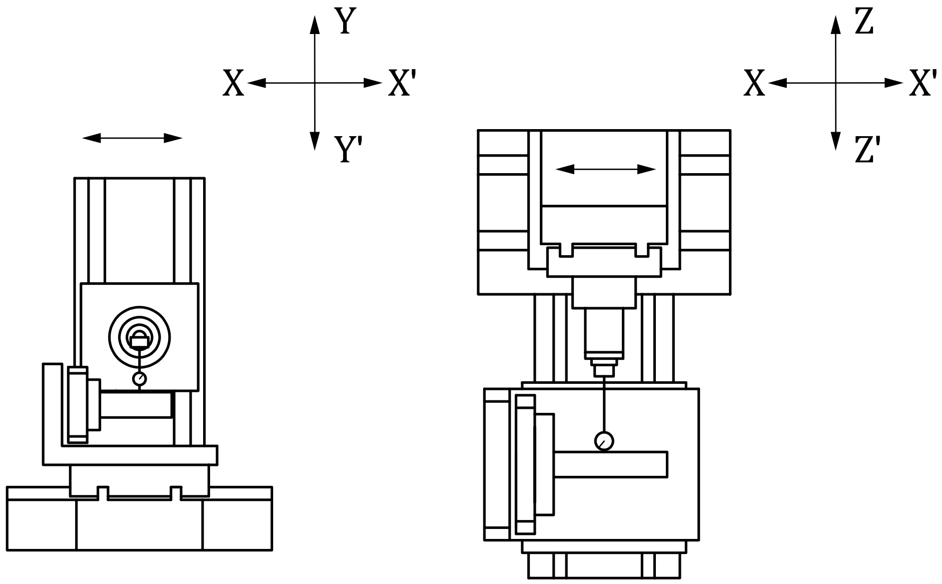
4) Move the head apart from the table along the Z-axis, and touch again the cylinder close to its top. Note the Z travel length. Find the maximum dial gauge reading by small movements along the X-axis for a) and along Y-axis for b) and note the new dial guage reading.

5) Turn the table by 180° and repeat steps 3) and 4).

6) For both measurements a) and b), the average value (half the algebraic sum) of the two dial gauge readings on top of the cylinder, divided by the Z travel length, is the error to be reported. The sign convention of the error shall correspond to the parallelism sign between *A'* and Z-axes according to ISO 230-1:2012, 3.6.3 Note 2.

Object	**DG10**
Checking of parallelism error of the *A'*-axis of rotation of the table, or receiver, with the table parallel to the spindle axis (*B'* = 0°, or *B'* = 180° as shown in the diagram), to the X-axis motion: a) $E_{\mathrm{C(0X)A}}$ in the vertical XY plane b) $E_{\mathrm{B(0X)A}}$ in the horizontal ZX plane	

Diagram



Tolerance

For a) and b) 0,040/1 000 (= 0,020/500)

Measured deviation

a) b)

Measuring instruments

Cylinder square with flange base, or test sphere as an alternative, and dial gauge

Observations and references to ISO 230-1:2012, 3.6.3, 10.1.4, and 10.1.4.3

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

b) Z-axis to be locked, if possible. The result of test b) includes the possible E_{BB} positioning deviation of the *B'*-axis at 0°.

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 the spindle head of the machine.

1) Fix a cylinder square with a flange base on the table, and centre it on approximately on the axis of rotation.

2) Fix the dial gauge on the spindle head with the stylus oriented in the Y-axis direction for a) and Z-axis direction for b).

3) Touch the cylinder square by the stylus, close to the cylinder bottom, and find the maximum dial gauge reading by small movements along the Z-axis for a) and along Y-axis for b). Zero the dial gauge.

4) Move the head apart from the table along the X-axis, and touch again the cylinder close to its top. Note the X travel length. Find the maximum dial gauge reading by small movements along the Z-axis for a) and along Y-axis for b) and note the new dial gauge reading.

5) Turn the table by 180° and repeat steps 3) and 4).

6) For both measurements a) and b), the average value (half the algebraic sum) of the two dial gauge readings on top of the cylinder, divided by the Z travel length, is the error to be reported. The sign convention of the error shall correspond to the parallelism sign between *A'* and X-axis according to ISO 230-1:2012, 3.6.3 Note 2.

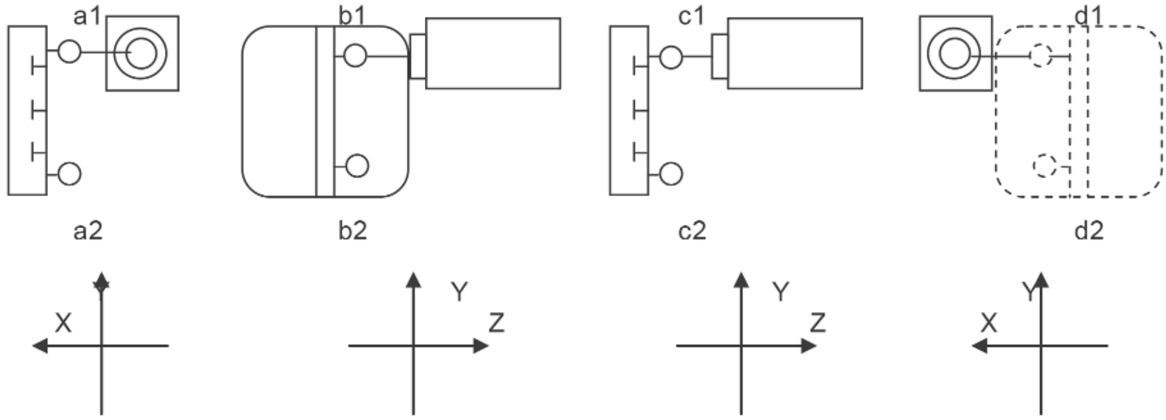
Object	**DG11**

Checking of parallelism error of the *B'*-axis of rotation of the swivelling table, to the Y-axis motion:

a) $E_{C(0Y)B}$ in the vertical XY plane

b) $E_{A(0Y)B}$ in the vertical YZ plane

Diagram



Tolerance

0,050/1 000

Measured deviation

Measuring instruments

Gauge blocks and dial gauge

Observations and references to ISO 230-1

1) Set the table parallel to the spindle axis (*B'* = 180° in the diagram). Fix a straightedge on the table, approximately parallel to the Y-axis with both reference planes. Let the dial gauge mounted on the spindle touch the straightedge top face in the X direction. Measure at both ends of the measurement distance *L*, read the dial gauge in *a1* and *a2* and note the difference Δ*a* = (*a2*-*a1*).

2) Turn the dial gauge into the Z direction and touch the straightedge side face. Measure at both ends of the measurement distance *L*, read the dial gauge in *b1* and *b2* and note the difference Δ*b* = (*b2*-*b1*).

3) Swivel the *B'*-axis to 90° position (table perpendicular to the spindle axis). With the dial gauge in the Z direction touch the straightedge top face in the same two points as in 1), take the readings *c1* and *c2* and note the difference Δ*c* = (*c2*-*c1*).

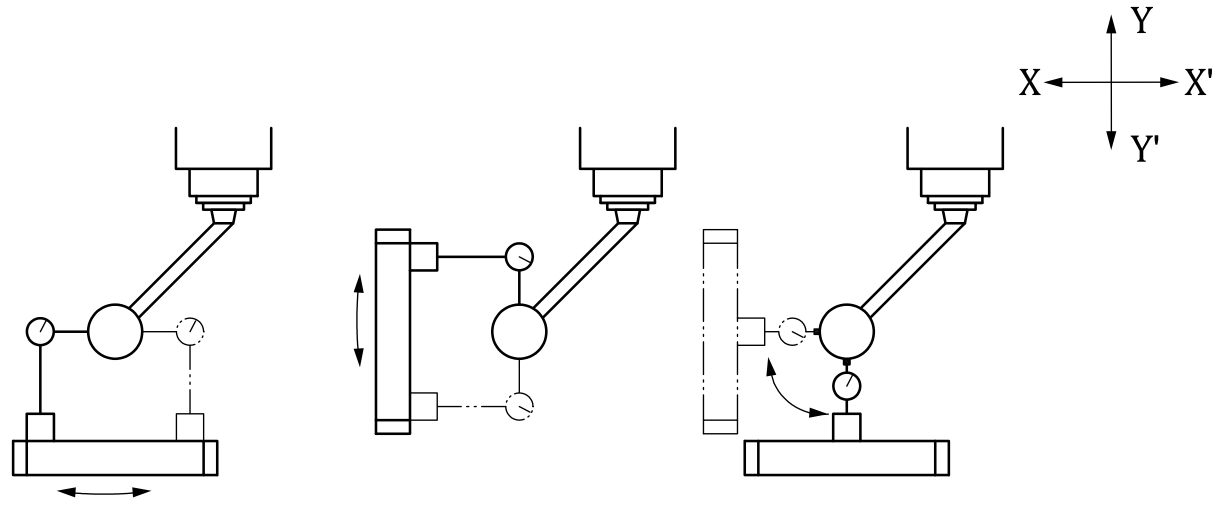
4) Turn the dial gauge into the X direction and touch the straightedge side face. Measure in the same two points as in 2), take the readings *d1* and *d2* and note the difference Δ*d* = (*d2*-*d1*).

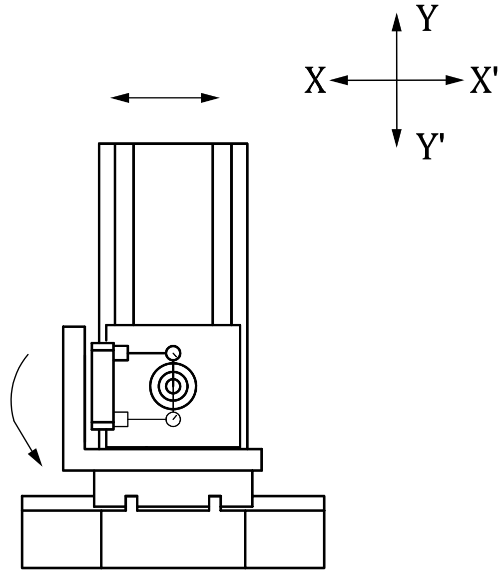
a) Parallelism error in the vertical XY plane is given by the following eformula:

$E_{C(0Y)B} = 1/2(\Delta a+\Delta b-\Delta c-\Delta d)$ divided by the measurement distance *L*

b) Parallelism error in the vertical YZ plane is given by the following formula:

$E_{A(0Y)B} = 1/2(-\Delta a+\Delta b+\Delta c-\Delta d)$ divided by the measurement distance *L*.

Object	**DG12**
Checking that the *A′*-axis of the table rotation and the *B′*-axis of the table swivelling lie in the same plane (for tables with the *B′*-axis outside the table surface): $E_{Z(0B)A}$ (only for machines with nominally zero offset between *A′* and *B′*-axis and without compensation facilities for any offset deviation)	
Diagram	
 	
Tolerance	
0,03	
Measured deviation	
Measuring instruments	
Test sphere and dial gauge	
Observations and references to ISO 230-1:2012, 10.4.3	
1) Fix the sphere support in the spindle, if it can be locked, or on the spindle head. Fix the dial gauge on the table with the stylus parallel to the table surface in radial direction. 2) With the table parallel to the spindle axis (*B′* = 0°, or *B′* = 180°), align the *A′*-axis of the table rotation on the sphere centre, by means of rotations around *A′* and adjustments along Y and Z. 3) Lock the Y- and Z-axes. 4) Turn the table to be perpendicular to the spindle axis (*B′* = 90°) and again align the *A′*-axis of the table rotation on the sphere centre, by means of rotations around *A′* and adjustments along X. 5) Lock the X-axis. 6) With the table perpendicular to the spindle axis (*B′* = 90°), place a dial gauge, with flat tip, on top of the table, with the stylus parallel to the spindle axis, touch the sphere and zero the dial gauge. 7) Turn the table to be parallel to the spindle axis (*B′* = 0°, or *B′* = 180°), and note the dial gauge reading. Half of the new reading on the dial gauge is the error to be reported. Note the direction of the error. The dial gauge arm shall be stiff enough so as to prevent any possible reading errors due to its opposite deflections in the different measurement positions.	

Object	**DG13**
Checking that the *A'*-axis of rotation of the table and the spindle axis lie in the same ZX plane at a predefined position, with the table parallel to the spindle axis (*B'* = 0°, or *B'* = 180°) (i.e. measuring the $E_{Y(0(C))A}$ deviation in the Y direction)	
Diagram	
	
Tolerance	
0,010	
Measured deviation	
Measuring instruments	
Test mandrel and dial gauge	
Observations and references to ISO 230-1	
1) Adjust the *B'*-axis of the swivelling table until the *A'*-axis of rotation of the table is perpendicular to the Z-axis.	
2) Move the Y-axis to the vertical position where the *A'*-axis of rotation of the table and the spindle axis should lie in the same ZX plane.	
3) Fix the test mandrel in the spindle, and the dial gauge on the table with the stylus parallel to the table surface in radial direction.	
4) With the dial gauge stylus oriented vertically in the Y-axis direction touch the test mandrel, close to spindle nose, and find the maximum dial gauge reading by small movements along the X-axis. Zero the dial gauge.	
5) Move the X-axis, in order to take the test mandrel off the dial gauge. Turn both the table and the spindle by 180°, and again bring the test mandrel into contact with the dial gauge by means of X-axis movements.	
6) Find the maximum dial gauge reading by small movements along the X-axis.	
7) Half of the new reading on the dial gauge is the error to be reported.	
The dial gauge arm shall be stiff enough so as to prevent any possible reading errors due to its opposite deflections in the different measurement positions.	
NOTE 1 If this test is carried out in different positions of the Z-axis it is affected by the $E_{A(0Z)(C)}$ parallelism error between the spindle axis and the Z-axis and by the E_{YZ} vertical straightness error of the Z-axis.	
NOTE 2 If this test is carried out in different positions of the X-axis it is affected by the $E_{C(0Z)A}$ parallelism error between the *A'* axis of rotation of the table and the X-axis and by the E_{YX} vertical straightness error of the X-axis.	

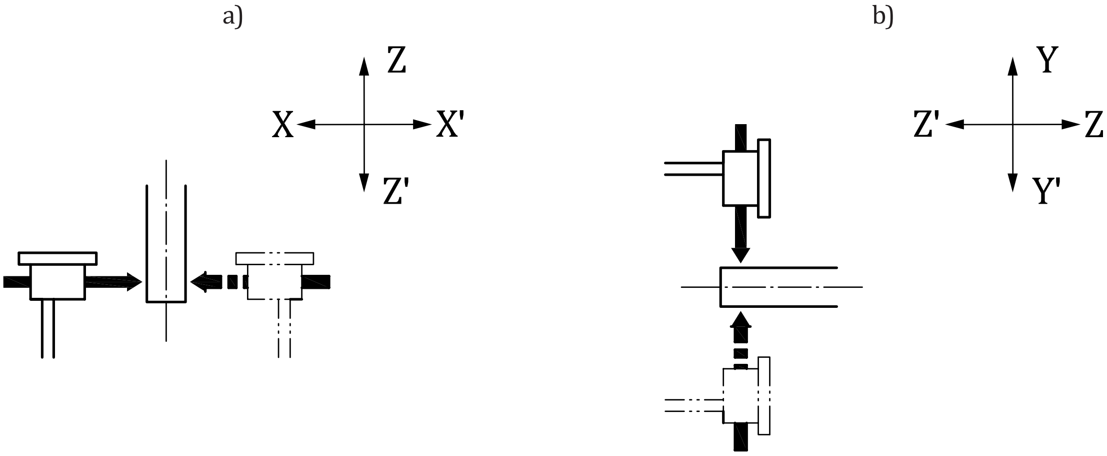
Object	**DG14**

Checking of coincidence of the *A'*-axis of rotation of the table and the spindle axis at a predefined position, with the table parallel to the X-axis:

a) $E_{X(0(C))A}$ along the horizontal X-axis

b) $E_{Y(0(C))A}$ along the vertical Y-axis

Diagram



Tolerance

0,010

Measured deviation

a) along the X-axis b) along the Y-axis

Measuring instruments

Test mandrel and dial gauge

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

1) Adjust the *B'*-axis of the swivelling table until the *A'*-axis of the table rotation is parallel to the Z-axis.

2) Move the X-axis and the Y-axis to the theoretical position where the *B'*-axis of the swivelling table and the spindle axis should coincide.

3) Fix the test mandrel in the spindle, and the dial gauge on the table with the stylus parallel to the table surface in radial direction.

4) With the dial gauge stylus oriented in the X-axis direction for a) and in the Y-axis direction for b), touch the test mandrel, close to the spindle nose, and find the maximum dial gauge reading by small movements [along the Y-axis for a) and along the X-axis for b)]. Zero the dial gauge.

5) Turn both the table and the spindle by 180°.

6) Find the maximum dial gauge reading as in point 4).

7) Half of the new reading on the dial gauge is the error to be reported.

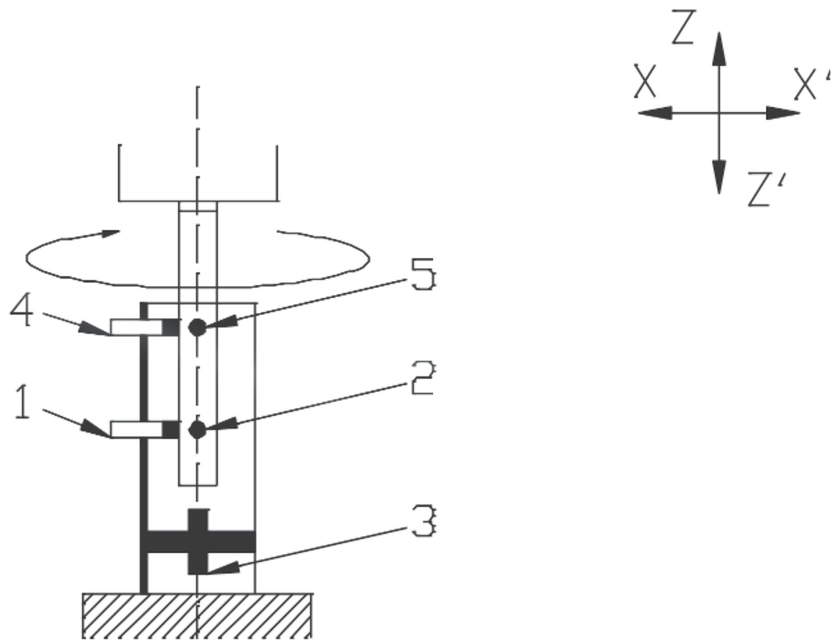
The dial gauge arm shall be stiff enough so as to prevent any possible reading errors due to its opposite deflections in the different measurement positions.

NOTE If this test is carried out in different positions of the Z-axis it is affected by the parallelism errors between the spindle axis and the Z-axis and between the *A'* axis of rotation of the table and the Z-axis, in both ZX and YZ planes.

Annex E
(informative)

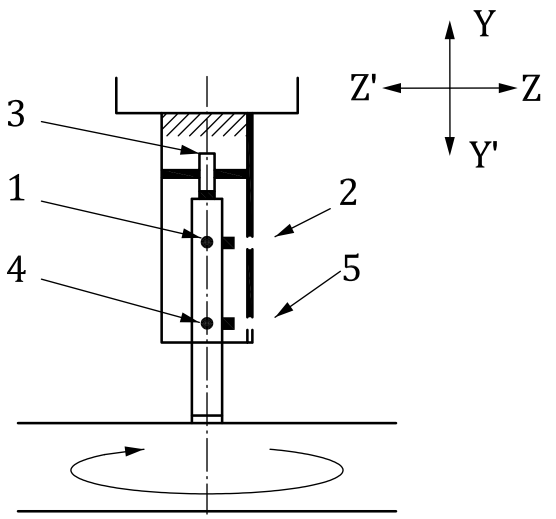
Error motions of tool holding spindle and work holding rotary table axes

E.1 Error motions of tool holding spindle (C) axis

Object	**ER1**
Axis of rotation error motion for tool holding spindle(s) (C) a) radial error motion $E_{XY(C)}$ b) axial error motion $E_{Z(C)}$ c) tilt error motion $E_{AB(C)}$	
Diagram 	
Tolerance[1)] at percentage of maximum speed 10 % 50 % 100 % a) total radial error motion value $E_{xy(C)}$ b) total axial error motion value $E_{z(C)}$ c) total tilt error motion value $E_{AB(C)}$ NOTE If the minimum speed is larger than 10 % of the maximum speed, then the spindle should be operated at minimum speed instead. Different spindle speeds can be selected based on mutual agreement between the manufacturer/supplier and the user. 1) If the manufacturer/supplier and the user would decide, by mutual agreement, to include this test in the contractual machine acceptance procedures, then they should also define, by mutual agreement, the corresponding tolerances to be applied. A future edition of this part of ISO 10791 can provide tolerances for this test when solid data from such measurements for table performance in industrial environment are available.	

Measured deviation a) b) c)
Measuring instruments Test mandrel, non-contacting probes, and angular measuring device or two precision spheres located slightly eccentric to table average line and non-contacting probes
Observations and references to ISO 230-7 This test is a table test with rotating sensitive direction (ISO 230-7:—, 5.4). After set up of the measuring instrument, the spindle shall be warmed up at 50 % of the maximum spindle speed for a time period of 10 min, if not otherwise agreed between manufacturer/supplier and user. Total error motion is defined in ISO 230-7:—, 3.2.4, total error motion value in ISO 230-7:—, 3.5.1. a) total radial error motion value $E_{XY(C)}$ (using probes 4 and 5) Radial error motion measurement is described in ISO 230-7:—, 5.4.2. The radial error motion shall be measured as close as possible to the table surface (sensors 4 and 5 in the diagram of this test). For the radial error motion $E_{XY(C)}$, a total error motion polar plot (ISO 230-7:—, 3.3.1) with a least squares circle (LSC) centre (ISO 230-7:—, 3.4.3) shall be provided. b) total axial error motion value $E_{Z(C)}$ (using probe 3) Axial error motion measurement is described in ISO 230-7:—, 5.4.4. For the axial error motion $E_{Z(C)}$, a total error motion polar plot (ISO 230-7:—, 3.3.1) with a polar chart (PC) centre (ISO 230-7:—, 3.4.1) shall be provided. c) total tilt error motion values $E_{AB(C)}$ (using probes 1,2,4,5) Tilt error motion measurement is described in ISO 230-7:—, 5.4.3. The tilt error motion can be also be checked with just two non-contacting probes (see ISO 230-7:—, 5.4.3.1 and 5.4.3.2). For the tilt error motion $E_{AB(C)}$, a total error motion polar plot (ISO 230-7:—, 3.3.1) with a polar chart (PC) centre (ISO 230-7:—, 3.4.1) shall be provided. For these tests, the following parameters shall be stated: a the radial, axial, or face locations at which the measurements are made; b identification of all artefacts, targets, and fixtures used; c the location of the measurement setup; d the position of any linear or rotary positioning stages that are connected to the device under test; e the direction angle of the sensitive direction, e.g. axial, radial or intermediate angles as appropriate; f presentation of the measurement result, for example: error motion value, polar plot, time based plot, frequency content plot; g the rotational speed of the table (zero for static error motion); h the time duration in seconds or number of table rotations; i appropriate warm up or break-in procedure; j the frequency response of the instrumentation, given as hertz or cycles per rev, including roll off characteristics of any electronic filters. In the case of digital instrumentation, the displacement resolution and sampling rate; k the structural loop, including the position and orientation of sensors relative to the table housing from which the error motion is reported, specified objects with respect to which the table axes and the reference coordinate axes are located and the elements connecting these objects (see ISO 230-1:2012, 3.3.1); l time and date of measurement; m type and calibration status of all measurement instrumentation; n other operating conditions which can influence the measurement such as ambient temperature. If the tilt measurements are not needed (by agreement between the supplier and the user), then only three displacement sensors are used (3, 4, and 5) and test mandrel can be replaced by precision test sphere.

E.2 Error motions of work holding rotary table (see Annex B)

Object	**ER2**
Axis of rotation error motion for workholding table a) radial error motion in the X direction E_{XB} b) radial error motion in the Z direction E_{ZB} c) axial error motion E_{YB} d) tilt error motion around X-axis E_{AB} e) tilt error motion around Z axis E_{CB}	
Diagram	
	
Tolerance[1)] at percentage of maximum speed 10 % 50 % 100 % a) total radial error motion value E_{XB} b) total radial error motion value E_{ZB} c) total axial error motion value E_{YB} d) total tilt error motion value E_{AB} e) total tilt error motion value E_{CB} NOTE If the minimum speed is larger than 10 % of the maximum speed, then the table should be operated at minimum speed instead. Different table speeds may be selected based on mutual agreement between the manufacturer/supplier and the user. 1) If the manufacturer/supplier and the user would decide, by mutual agreement, to include this test in the contractual machine acceptance procedures, then they should also define, by mutual agreement, the corresponding tolerances to be applied. A future edition of this part of ISO 10791 can provide tolerances for this test when solid data from such measurements for rotary table performance in industrial environment are available. **Measured deviation** a) b) c) d) e)	

Measuring instruments

Test mandrel, non-contacting probes, and angular measuring device or

two precision spheres located slightly eccentric to table average line and non-contacting probes

Observations and references to ISO 230-7

This test is a test with fixed sensitive direction (ISO 230-7:—, 5.5).

If the table can be used for turning operations, after set up of the measuring instrument, the table shall be warmed up at 50 % of the maximum table speed for a time period of 10 min, if not otherwise agreed between manufacturer/supplier and user.

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

a), b) total radial error motion values $E_{X(B)}$ and $E_{Z(B)}$ (using probes 4 and 5)

Radial error motion measurement is described in ISO 230-7:—, 5.5.3. The radial error motion shall be measured as close as possible to the table surface (sensors 4 and 5 in the diagram).

For each radial error motion $E_{X(B)}$ and $E_{Z(B)}$, a total error motion polar plot (ISO 230-7:—, 3.3.1) with a least squares circle (LSC) centre (ISO 230-7:—, 3.4.3) shall be provided.

c) total axial error motion value $E_{Y(B)}$ (using probe 3)

Axial error motion measurement is described in ISO 230-7:—, 5.4.4.

For the axial error motion $E_{Y(B)}$, a total error motion polar plot (ISO 230-7:—, 3.3.1) with a polar chart (PC) centre (ISO 230-7:—, 3.4.1) shall be provided.

d), e) total tilt error motion values $E_{A(B)}$ and $E_{C(B)}$ (using probes 2 and 5, 1 and 4)

Tilt error motion measurement is described in ISO 230-7:—, 5.5.5. Any tilt error motion can be also checked with just one non contacting probe (see ISO 230-7:—, 5.5.5.2 and 5.5.5.4).

For each tilt error motion $E_{A(B)}$ and $E_{C(B)}$, a total error motion polar plot (ISO 230-7:—, 3.3.1) with a polar chart (PC) centre (ISO 230-7:—, 3.4.1) shall be provided.

For these tests the following parameters shall be stated:

— the radial, axial or face locations at which the measurements are made;

— identification of all artefacts, targets and fixtures used;

— the location of the measurement setup;

— the position of any linear or rotary positioning stages that are connected to the device under test;

— the direction angle of the sensitive direction, e.g. axial, radial or intermediate angles as appropriate;

— presentation of the measurement result, for example: error motion value, polar plot, time based plot, frequency content plot;

— the rotational speed of the table (zero for static error motion);

— the time duration in seconds or number of table rotations;

— appropriate warm up or break-in procedure;

— the frequency response of the instrumentation, given as hertz or cycles per rev, including roll off characteristics of any electronic filters. In the case of digital instrumentation, the displacement resolution and sampling rate;

— the structural loop, including the position and orientation of sensors relative to the table housing from which the error motion is reported, specified objects with respect to which the table axes and the reference coordinate axes are located and the elements connecting these objects;

— time and date of measurement;

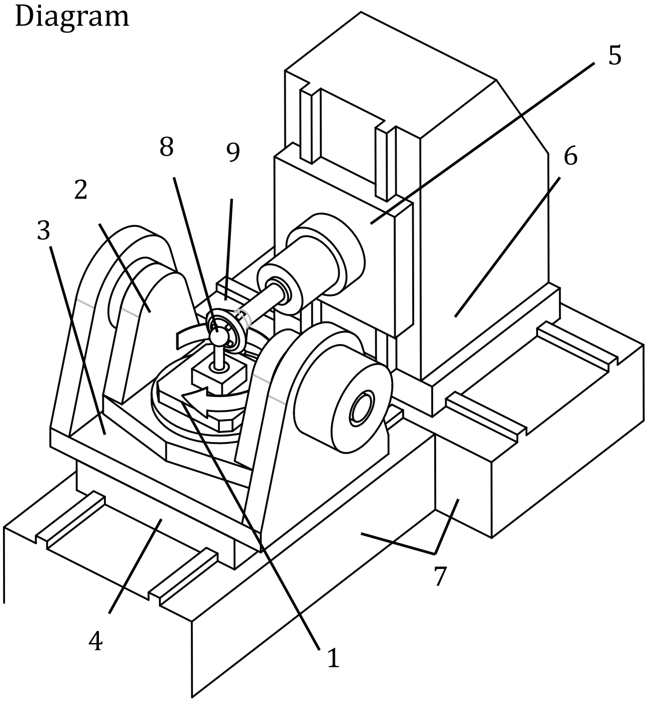
— type and calibration status of all measurement instrumentation;

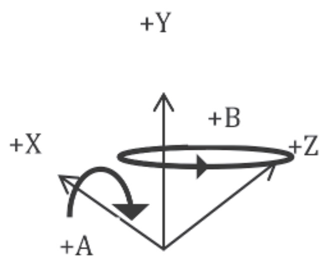
— other operating conditions which can influence the measurement, such as ambient temperature.

If the tilt measurements are not needed (by agreement between the supplier and the user), then only three displacement sensors are used (1,2, and 3) and test mandrel can be replaced by precision test sphere.

Annex F
(informative)

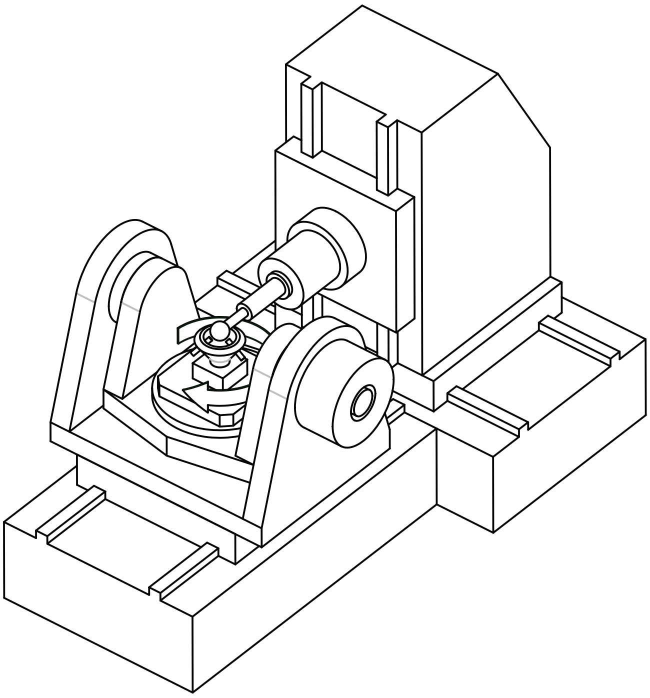
Error motions of axes of rotation of rotary and tilting tables (see Annex C)

<table>
<tr><th>Object</th><th>FR1</th></tr>
<tr><td colspan="2">Axis of rotation error motion for work holding table (B'-axis)
a) radial error motion in the X direction E_{XB}
b) radial error motion in the Z direction E_{ZB}
c) axial error motion E_{YB}
d) tilt error motion around X-axis E_{AB}
e) tilt error motion around Z-axis E_{CB}</td></tr>
<tr><td colspan="2">Diagram




Key
1 rotary table (B'-axis)
2 cradle (A'-axis)
3 trunnion
4 table saddle (Z-axis)
5 spindle head (Y-axis)
6 column (X-axis)
7 bed
8 precision sphere
9 sensors nest

Setup I: The sensors nest is mounted in the spindle and the precision sphere is mounted on the table.</td></tr>
</table>



Setup II: The precision sphere is mounted in the spindle and the sensors nest is mounted on the table.

Tolerance

	CW		CW	
	Static	Continuous	Static	Continuous
a) Radial error motion in the X direction E_{XB}				
b) Radial error motion in the Z direction E_{ZB}				
c) Axial error motion E_{YB}				
d) Tilt error motion around X axis E_{AB}				
e) Tilt error motion around Z axis E_{CB}				

The tolerances to be applied are to be agreed between the machine manufacturer/supplier and the user.

For the static test, the *B'*-axis is stopped at given angular positions, e.g. at every 30° and then the sphere displacement is measured. For the continuous (quasi-static) test, the sphere displacement is continuously measured as the *B'*-axis rotates in a sufficiently low speed, or in a speed representative for normal machine operation. The speed of the rotary table is to be agreed between the machine manufacturer/supplier and the user. The speed used shall be reported.

Measured deviation

	CW		CW	
	Static	Continuous	Static	Continuous
a) Radial error motion in the X direction E_{XB}				
b) Radial error motion in the Z direction E_{ZB}				
c) Axial error motion E_{YB}				
d) Tilt error motion around X axis E_{AB}				
e) Tilt error motion around Z axis E_{CB}				

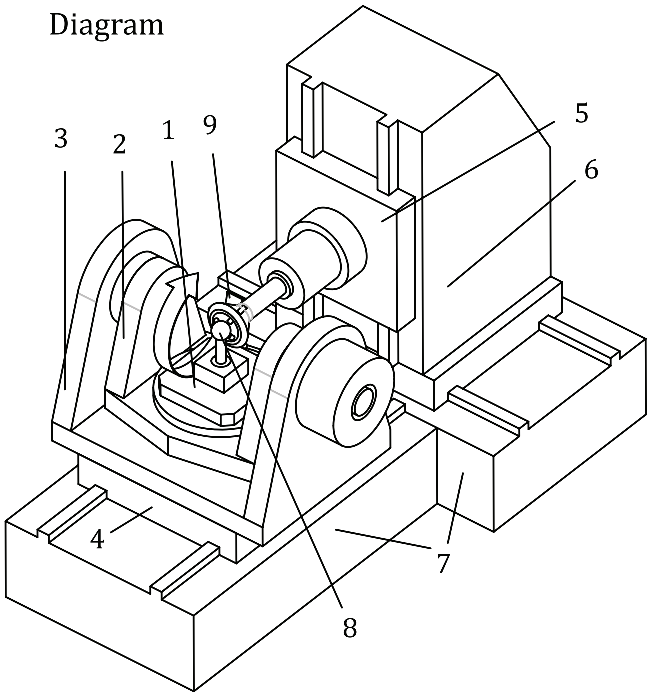
Measurement table speed: $\quad$ min^{-1} (rpm)

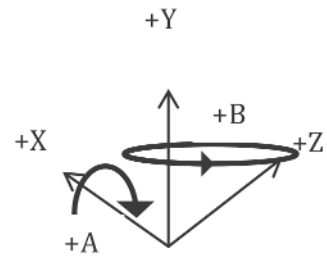
Measuring instruments Precision sphere and sensors nest (or 3D probe). For setup I only: Precision cylinder/test mandrel or dual precision sphere (i.e. two precision spheres on one stem separated axially) and sensors nest. The sensors nest can be contact and/or non-contact type.
Observations and references to ISO 230-7 This test is performed statically and dynamically along the fixed sensitive direction (ISO 230-7:—, 5.5). Measurements shall be performed clockwise as well as counter-clockwise preferably combined in one measurement. Multiple revolutions can be measured and are required to compute synchronous and asynchronous error motions of the rotary axis. The spindle is locked for this test. The precision sphere (i.e. setup I) or the origin of the sensors nest (i.e. setup II) shall be as close to the table as possible to limit the effect of *B'*-axis tilt error motion but preventing collision between the spindle and/or sensors nest and the table. The precision sphere (i.e. setup I) or sensors nest (i.e. setup II) is positioned near the axis of rotation of the *B'*-axis in such a way that the sphere remains in the measuring range of the sensors nest. When the precision sphere or sensors nest cannot be mounted close enough to the axis of rotation of the *B'*-axis, the X and Z-axes need to move to follow the precision sphere. In such a case, the measured deviations contain not only the radial, tilt, and axial error motions of the *B'*-axis but also the error motions of the linear axes as well as the squareness errors between the X, Z and *B'*-axis, as only the difference between both circular movements (i.e. *B'*-axis rotation and the combined X and Z axis motions) is measured by the sensors nest. This test is described in ISO 10791-6, BK2. Radial error motion measurement is described in ISO 230-7:—, 5.5.3 and equals at maximum the total error motion value. It can further be divided into synchronous and asynchronous error motion. Radial error motion is provided in a polar plot. Axial error motion measurement is described in ISO 230-7:—, 5.4.4 and equals at maximum the total error motion value and can further be divided into fundamental, residual synchronous and asynchronous error motion. Axial error motion is provided in a polar plot. Tilt error motion measurement is described in ISO 230-7:—, 5.5.5 and is obtained, if needed, by subtracting the radial error motion determined at different heights (i.e. for setup I by using short and long sphere stem or by using a mandrel; for setup II by mounting sensor nest at different heights above the table) divided by the separation distance. This is done for static measurements only. Tilt error motion can further be divided into synchronous and asynchronous error motion and is provided in a polar plot. Total error motion and total error motion value are defined in ISO 230-7:—, 3.2.4 and 3.5.1 respectively and represent the maximum errors of the *B'*-axis in the respective direction (i.e. radial, tilt, or axial). Setup I The sensors nest (or 3D probe) is mounted in the machine's spindle and its measurement axes are aligned and remain fixed to the X, Y, Z axes of the machine. Setup II The measurement axes of the sensors nest, which rotate along with the table (i.e. representing work piece coordinates) are aligned with the X, Y, Z axes of the machine with the *B'*-axis in zero position. To obtain the fixed sensitive direction radial (and tilt if needed) error motions, coordinate transformations are required to counter act the *B'*-axis rotation i.e. the coordinate frame of the sensors nest remains the same with respect to the orientation of the machine's coordinate frame. It is recommended to compensate the error motions of the linear axes before performing this test to limit their impact on the obtained result if the test is not performed at the axis of rotation of the *B'*-axis. NOTE In principle, both setups are equivalent and the choice depends on the mounting possibilities available. If the position and orientation of the *B'*-axis are evaluated with the same setup, the tool length is required and should be measured with sufficient accuracy (i.e. using a tool-setter). The offset of the sensors nest in X-direction should be zero (or known) with sufficient accuracy, see ISO 10791-6:—.

For these tests, the following parameters shall be stated:
— location of the measurement setup;
— height of precision sphere centre above the table in mm for setup I;
— height of sensors nest origin above the table in mm for setup II;
— position of the other axes A, X, Y and Z;
— measured range *B'*-axis;
— direction of rotation (for unidirectional test: CW or CCW);
— identification of all artefacts (i.e. precision sphere or test mandrel), sensors nest, fixture used;
— presentation of measurement result, for example error motion value, a polar plot, time based plot, *B'*-axis angle — based plot, frequency content plot;
— rotation speed of the table (zero for static error motion);
— the time duration in seconds or number of table rotations;
— warm-up procedure;
— calibration status of all measurement instrumentation used:
    — roundness error of precision sphere or test mandrel in mm;
    — measurement uncertainty of sensors nest in mm;
    — calibration date and procedure of sensors nest;
— time and date of measurement;
— operation conditions that might affect the measured results such as ambient temperature.
For setup I, the precision sphere can be replaced by a precision cylinder/test mandrel for determining tilt error motions of the *B'*-axis directly as this enables the simultaneous measurement of two radial error motions performed at different heights in a single setup. The sensors nest shall be compatible with such a precision cylinder having at least two axially separated radial sensors.

Object	**FR2**
Axis of rotation error motion for *A′* tilting axis (for table surfaces lower than the *A′*-axis) a) Radial error motion in the Y direction E_{YA} b) Radial error motion in the Z direction E_{ZA} c) Axial error motion E_{XA} d) Tilt error motion around Y-axis E_{BA} e) Tilt error motion around Z- axis E_{CA}	

Diagram

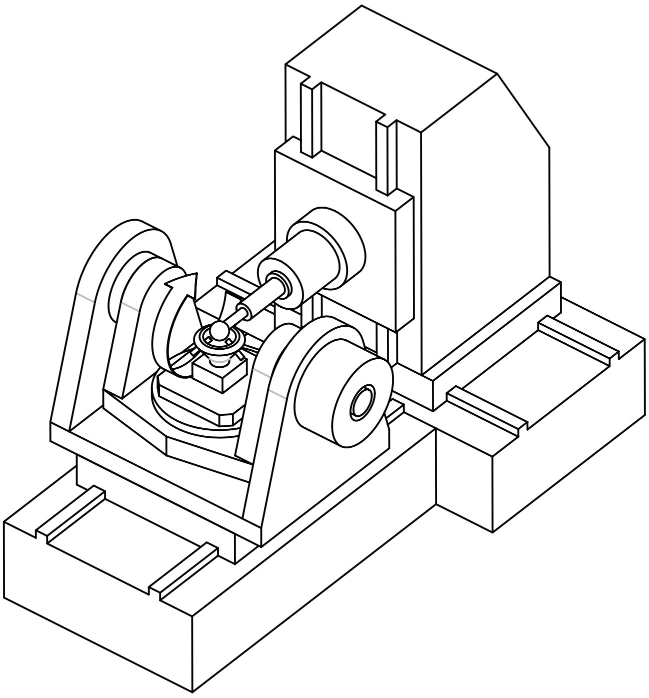




Key

1 rotary table (*B′*-axis)
2 cradle (*A′*-axis)
3 trunnion
4 table saddle (Z-axis)
5 spindle head (Y-axis)
6 column (X-axis)
7 bed
8 precision sphere
9 sensors nest

Setup I: The sensors nest is mounted in the spindle and the precision sphere is mounted on the table.



Setup II: The precision sphere is mounted in the spindle and the sensors nest is mounted on the table.

Tolerance

	CW		CW	
	Static	Continuous	Static	Continuous
a) Radial error motion in the Y direction E_{YA}				
b) Radial error motion in the Z direction E_{ZA}				
c) Axial error motion E_{XA}				
d) Tilt error motion around Y axis E_{BA}				
e) Tilt error motion around Z axis E_{CA}				

The tolerances to be applied are to be agreed between the machine manufacturer/supplier and the user.

For the static test, the *A'*-axis is stopped at given angular positions, e.g. at every 10°, and then the sphere displacement is measured. For the continuous (quasi-static) test, the sphere displacement is continuously measured as the *A'*-axis rotates in a sufficiently low speed, or in a speed representative for normal machine operation. The rotating speed of the cradle is to be agreed between the machine manufacturer/supplier and the user. The speed used shall be reported.

Measured deviation

	CW		CW	
	Static	Continuous	Static	Continuous
a) Radial error motion in the Y direction E_{YA}				
b) Radial error motion in the Z direction E_{ZA}				
c) Axial error motion E_{XA}				
d) Tilt error motion around Y axis E_{BA}				
e) Tilt error motion around Z axis E_{CA}				

Measurement speed: min^{-1} (rpm)

Measuring instruments Precision sphere and sensors nest (or 3D probe). For setup I only: Precision cylinder/test mandrel or dual precision sphere (i.e. two precision spheres on one stem separated axially) and sensors nest. The sensors nest can be contact and/or non-contact type.
Observations and references to ISO 230-7 This test is performed statically and dynamically along the fixed sensitive direction (ISO 230-7:—, 5.5). Measurements shall be performed clockwise as well as counter-clockwise preferably combined in one measurement. Multiple circular segments or arcs can be measured and are required to compute synchronous and asynchronous error motions of the rotary axis. The spindle is locked for this test. The precision sphere (i.e. setup I) or the origin of the sensors nest (i.e. setup II) shall be mounted as close to the axis of rotation of the *A'*-axis as possible. The precision sphere (i.e. setup I) or sensors nest (i.e. setup II) is positioned near the axis of rotation of the *A'*-axis in such a way that the sphere remains in the measuring range of the sensors nest. Movements of the Y and Z axis to follow the precision sphere are allowed only if the precision sphere or sensors nest cannot be mounted close enough to the axis of rotation of the *A'*-axis. The machine is commanded to move/rotate the *A'*-axis while the Y and Z axes follow as good as possible, if needed. During this cycle the relative movements/ displacements between the precision sphere and the sensors nest are measured. In case the Y and Z axis have to follow the difference between both circular movements (i.e. *A'*-axis rotation and the combined Y and Z axis motions) is measured by the sensors nest. The measured deviations contain then next to the radial, tilt and axial error motions of the A'-axis also the error motions of the linear Y- and Z-axes as well as the squareness errors between the Y-, Z-, and A'-axis, as only the difference between both circular movements (i.e. *A'*-axis rotation and the combined Y and Z axis motions) is measured by the sensor nest. Radial error motion measurement is described in ISO 230-7:—, 5.5.3 and equals at maximum the total error motion value. It can further be divided into synchronous and asynchronous error motion. Radial error motion is provided in a polar plot. Axial error motion measurement is described in ISO 230-7:—, 5.4.4 and equals at maximum the total error motion value and can further be divided into fundamental, residual synchronous and asynchronous error motion. Axial error motion is provided in a polar plot. Tilt error motion measurement is described in ISO 230-7:—, 5.5.5 and is obtained, if needed, by subtracting the radial error motion determined at different X axis positions (i.e. by using short and long sphere stem or using a mandrel) divided by the separation distance. Tilt error motion can further be divided into synchronous and asynchronous error motion and is provided in a polar plot. Total error motion and total error motion value are defined in ISO 230-7:—, 3.2.4 and 3.5.1 respectively and represent the maximum errors of the A'-axis in the respective direction (i.e. radial, tilt or axial). Setup I The sensors nest (or 3D probe) is mounted in the machine's spindle and its measurement axes are aligned and remain fixed to the X-, Y-, Z-axes of the machine. Setup II The measurement axes of the sensors nest, which rotate along with the table (i.e. representing work piece coordinates) are aligned with the X-, Y-, Z-axes of the machine with the A'-axis in zero position. To obtain the fixed sensitive direction radial (and tilt if needed) error motions, coordinate transformations are required to counter act the *A'*-axis rotation i.e. the coordinate frame of the sensors nest remains the same with respect to the orientation of the machine's coordinate frame.

It is recommended to compensate the error motions of the linear axes before performing this test to limit their impact on the obtained result if the test is not performed at the axis of rotation of the A'-axis.

NOTE In principle, both setups are equivalent and the choice depends on the mounting possibilities available.

If the position and orientation of the *A'*-axis are evaluated with the same setup, the tool length is required and should be measured with sufficient accuracy (i.e. using a tool-setter). The offset of the sensors nest in Y-direction (relative to spindle axis average line) should be zero (or known) with sufficient accuracy, see ISO 10791-6:--.

For these tests, the following parameters shall be stated:

— the location of the measurement setup;

— height of precision sphere centre and of the *A'*-axis above the table in mm for setup I;

— height of sensors nest origin and of the A'-axis above the table in mm for setup II;

— position of the other axes B, X, Y and Z;

— measured range *A'*-axis;

— direction of rotation (for unidirectional test: CW or CCW);

— identification of all artefacts (i.e. precision sphere or test mandrel), sensors nest, fixture used;

— presentation of measurement result, for example error motion value, a polar plot, time based plot, — *A'*-axis angle based plot, frequency content plot;

— rotation speed of the cradle (zero for static error motion);

— the time duration in seconds or number of cradle rotations;

— warm-up procedure;

— calibration status of all measurement instrumentation used:

  — roundness error of precision sphere or test mandrel in mm;

  — measurement uncertainty of sensors nest in mm;

  — calibration date and procedure of sensors nest;

— time and date of measurement;

— operation conditions that might affect the measured results such as ambient temperature.

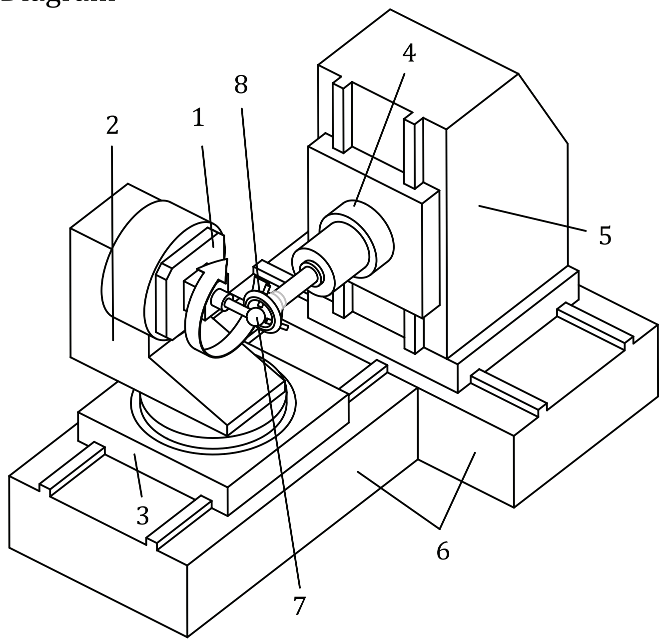
For Setup I: The precision sphere can be replaced by a precision cylinder/test mandrel for determining tilt error motions of the *A'*-axis directly as this enables the simultaneous measurement of two radial error motions performed at different heights in a single setup. The sensors nest shall be compatible with such a precision cylinder having at least two axially separated radial sensors.

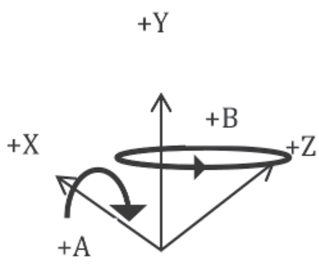
Annex G
(informative)

Error motions of axes of rotation of rotary and swivelling tables (see Annex D)

Object	**GR1**
Axis of rotation error motion for workholding table (A'-axis)	
a) Radial error motion in the Y direction E_{YA}	
b) Radial error motion in the Z direction E_{ZA}	
c) Axial error motion E_{XA}	
d) Tilt error motion around Y-axis E_{BA}	
e) Tilt error motion around Z-axis E_{CA}	

Diagram

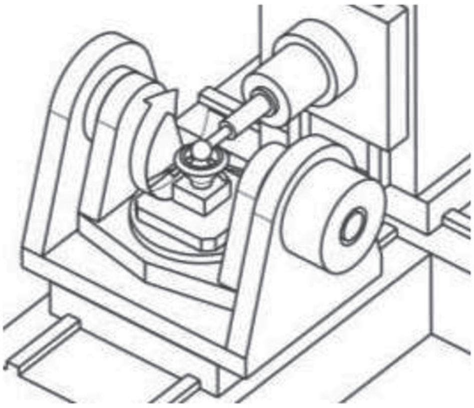




Key

1 rotary table (*A'*-axis)
2 vertical trunnion table (*B'*-axis)
3 table saddle (Z'-axis)
4 spindle head (Y-axis)
5 column (X-axis)
6 bed
7 precision sphere
8 sensors nest

Setup I: The sensors nest is mounted in the spindle and the precision sphere is mounted on the table.



Setup II: The precision sphere is mounted in the spindle and the sensors nest is mounted on the table.

Tolerance

	CW		CW	
	Static	Continuous	Static	Continuous
a) Radial error motion in the Y direction E_{YA}				
b) Radial error motion in the Z direction E_{ZA}				
c) Axial error motion E_{XA}				
d) Tilt error motion around Y axis E_{BA}				
e) Tilt error motion around Z axis E_{CA}				

The tolerances to be applied are to be agreed between the machine manufacturer/supplier and the user.

The speed of the rotary table is to be agreed between the machine manufacturer/supplier and the user. For dynamic measurements, it is recommended to use a speed representative for normal machine operation. The speed used shall be reported.

Measured deviation

	CW		CW	
	Static	Continuous	Static	Continuous
a) Radial error motion in the Y direction E_{YA}				
b) Radial error motion in the Z direction E_{ZA}				
c) Axial error motion E_{XA}				
d) Tilt error motion around Y axis E_{BA}				
e) Tilt error motion around Z axis E_{CA}				

Measurement speed: min^{-1} (rpm)

Measuring instruments

Precision sphere and sensors nest (or 3D probe).

Precision cylinder/test mandrel or dual precision sphere (i.e. two precision spheres on one stem separated axially) and sensors nest.

The sensors nest can be contact and/or non-contact type.

Observations and references to ISO 230-7

This test is performed statically and dynamically along the fixed sensitive direction (ISO 230-7:—, 5.5).

Measurements shall be performed clockwise as well as counter-clockwise preferably combined in one measurement. Multiple revolutions can be measured and are required to compute synchronous and asynchronous error motions of the rotary axis.

The spindle is locked for this test.

The precision sphere (i.e. setup I) or the origin of the sensors nest (i.e. setup II) shall be as close to the table as possible to limit the effect of *A'*-axis tilt error motion but preventing collision between the spindle and/or sensors nest and the table.

The precision sphere (i.e. setup I) or sensors nest (i.e. setup II) is positioned near the axis of rotation of the *A'*-axis in such a way that the sphere remains in the measuring range of the sensors nest. Movements of the Y- and Z-axis to follow the precision sphere are allowed only if the precision sphere or sensors nest cannot be mounted close enough to the axis of rotation of the *A'*-axis.

The machine is commanded to move/rotate the *A'*-axis while the Y and Z axes follow as good as possible, if needed. During this cycle the relative movements/displacements between the precision sphere and the sensors nest are measured.

In case the Y and Z axis have to follow the difference between both circular movements (i.e. *A'*-axis rotation and the combined Y- and Z-axis motions) is measured by the sensors nest. The measured deviations contain then next to the radial, tilt and axial error motions of the *A'*-axis also the error motions of the linear Y- and Z- axes as well as the squareness errors between the Y-, Z-, and *A'*-axis.

Radial error motion measurement is described in ISO 230-7:—, 5.5.3 and equals at maximum the total error motion value. It can further be divided into synchronous and asynchronous error motion. Radial error motion is provided in a polar plot.

Axial error motion measurement is described in ISO 230-7:—, 5.4.4 and equals at maximum the total error motion value and can further be divided into fundamental, residual synchronous and asynchronous error motion. Axial error motion is provided in a polar plot.

Tilt error motion measurement is described in ISO 230-7:—, 5.5.5 and is obtained, if needed, by subtracting the radial error motion determined at different X-axis positions (i.e. by using short and long sphere stem or a mandrel) divided by the separation distance. Tilt error motion can further be divided into synchronous and asynchronous error motion and is provided in a polar plot.

Total error motion and total error motion value are defined in ISO 230-7:—, 3.2.4 and 3.5.1, respectively and represent the maximum errors of the *A'*-axis in the respective direction (i.e. radial, tilt or axial).

Setup I

The sensors nest (or 3D probe) is mounted in the machine's spindle and its measurement axes are aligned and remain fixed to the X-, Y-, Z-axes of the machine.

Setup II

The measurement axes of the sensors nest, which rotate along with the table (i.e. representing work piece coordinates) are aligned with the X, Y, Z axes of the machine with the *A'*-axis in zero position.

To obtain the fixed sensitive direction radial (and tilt if needed) error motions, coordinate transformations are required to counter act the *A'*-axis rotation i.e. the coordinate frame of the sensors nest remains the same with respect to the orientation of the machine's coordinate frame.

It is recommended to compensate the error motions of the linear axes before performing this test to limit their impact on the obtained result if the test is not performed at the axis of rotation of the *A'*-axis.

NOTE In principle, both setups are equivalent and the choice depends on the mounting possibilities available.

If the position and orientation of the *A'*-axis are evaluated with the same setup, the tool length is required and should be measured with sufficient accuracy (i.e. using a tool-setter). The offset of the sensors nest in Y-direction should be zero (or known) with sufficient accuracy, see ISO 10791-6:--.

For these tests, the following parameters shall be stated:

— the location of the measurement setup;

— distance between the precision sphere centre and the table in mm for setup I;

— distance between the sensors nest origin and the table in mm for setup II;

— position of the other axes B, X, Y, and Z;

— measured range *A'*-axis;

— direction of rotation (for unidirectional test: CW or CCW);

— identification of all artefacts (i.e. precision sphere or test mandrel), sensors nest, fixture used;

— presentation of measurement result, for example error motion value, a polar plot, time based plot, A'-axis angle based plot, frequency content plot;

— rotation speed of the table (zero for static error motion);

— time duration in seconds or number of table rotations;

— warm-up procedure;

— calibration status of all measurement instrumentation used:

  — roundness error of precision sphere or test mandrel in mm;

  — measurement uncertainty of sensors nest in mm;

  — calibration date and procedure of sensors nest;

— time and date of measurement;

— operation conditions that might affect the measured results such as ambient temperature.

For setup I, the precision sphere can be replaced by a precision cylinder/test mandrel for determining tilt error motions of the *A'*-axis directly as this enables the simultaneous measurement of two radial error motions performed at different heights in a single setup. The sensors nest shall be compatible with such a precision cylinder having at least two axially separated radial sensors.

Object	**GR2**

Axis of rotation error motion for swivelling axis (B'-axis)

a) Radial error motion in the X direction E_{XB}

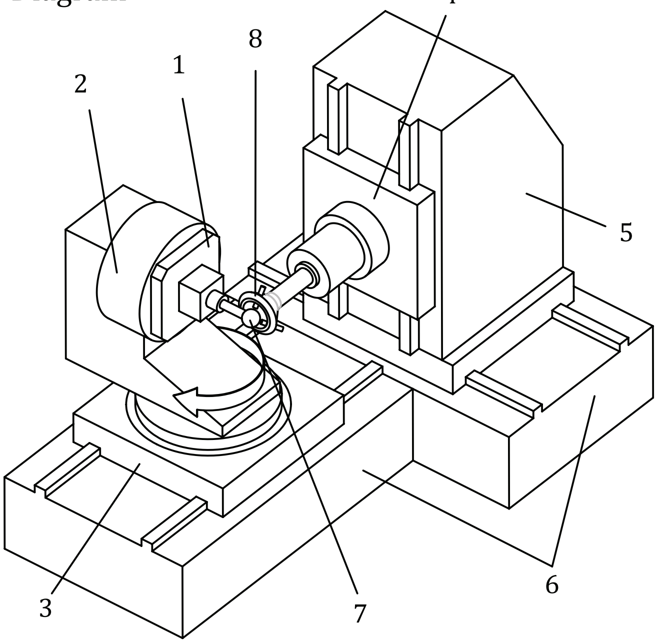
b) Radial error motion in the Z direction E_{ZB}

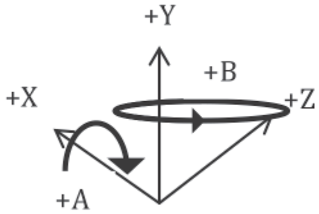
c) Axial error motion E_{YB}

d) Tilt error motion around X-axis E_{AB}

e) Tilt error motion around Z-axis E_{CB}

Diagram

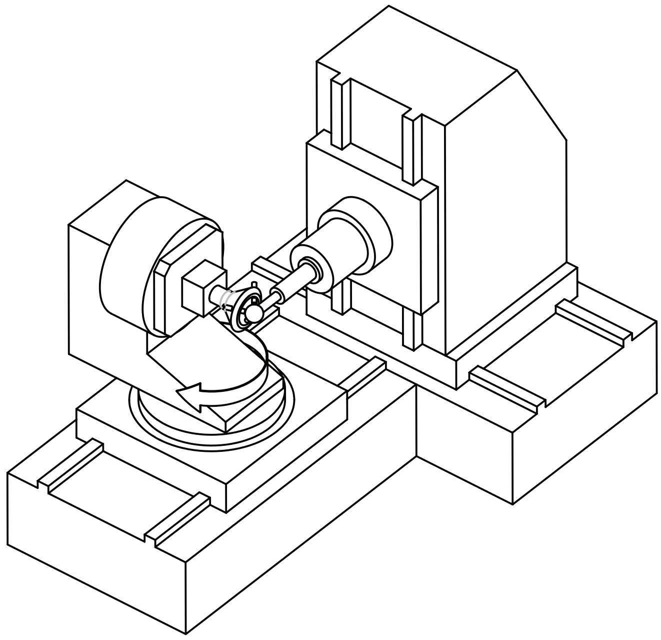




Key

1 rotary table (A'-axis)
2 vertical trunnion table (B'-axis)
3 table saddle (Z'-axis)
4 spindle head (Y-axis)
5 column (X-axis)
6 bed
7 precision sphere
8 sensors nest

Setup I: The sensors nest is mounted in the spindle and the precision sphere is mounted on the table.



Setup II: The precision sphere is mounted in the spindle and the sensors nest is mounted on the table.

Tolerance				
	CW		CW	
	Static	Continuous	Static	Continuous
a) Radial error motion in the X direction E_{XB}				
b) Radial error motion in the Z direction E_{ZB}				
c) Axial error motion E_{YB}				
d) Tilt error motion around X-axis E_{AB}				
e) Tilt error motion around Z axis E_{CB}				

The tolerances to be applied are to be agreed between the machine manufacturer/supplier and the user.

The speed of the rotary table is to be agreed between the machine manufacturer/supplier and the user. For dynamic measurements, it is recommended to use a speed representative for normal machine operation. The speed used shall be reported.

Measured deviation				
	CW		CW	
	Static	Continuous	Static	Continuous
a) Radial error motion in the X direction E_{XB}				
b) Radial error motion in the Z direction E_{ZB}				
c) Axial error motion E_{YB}				
d) Tilt error motion around X-axis E_{AB}				
e) Tilt error motion around Z axis E_{CB}				

Measurement speed: min^{-1} (rpm)

Measuring instruments

Precision sphere and sensors nest (or 3D probe).

Precision cylinder/test mandrel or dual precision sphere (i.e. two precision spheres on one stem separated axially) and sensors nest.

The sensors nest can be contact and/or non-contact type.

Observations and references to ISO 230-7

This test is performed statically and dynamically along the fixed sensitive direction (ISO 230-7:—, 5.5).

Measurements shall be performed clockwise as well as counter-clockwise preferably combined in one measurement. Multiple circular segments or arcs can be measured and are required to compute synchronous and asynchronous error motions of the rotary axis.

The spindle is locked for this test.

The precision sphere (i.e. setup I) or the origin of the sensors nest (i.e. setup II) shall be as close to the *B'*-axis base as possible to limit the effect of *B'*-axis tilt error motion but preventing collision between the spindle and/or sensors nest and the table.

The precision sphere (i.e. setup I) or sensors nest (i.e. setup II) is positioned near the axis of rotation of the *B'*-axis in such a way that the sphere remains in the measuring range of the sensors nest. Movements of the X and Z axis to follow the precision sphere are allowed only if the precision sphere or sensors nest cannot be mounted close enough to the axis of rotation of the *B'*-axis.

The machine is commanded to move/rotate the *B'*-axis while the X and Z axes follow as good as possible, if needed. During this cycle, the relative movements/displacements of the precision sphere and the sensors nest are measured.

In case the X and Z axis have to follow the difference between both circular movements (i.e. *B'*-axis rotation and the combined X and Z axis motions) is measured by the sensors nest. The measured deviations contain then next to the radial, tilt and axial error motions of the *B'*-axis also the error motions of the linear X- and Z- axes as well as the squareness errors between the X, Z, and *B'*-axis.

Radial error motion measurement is described in ISO 230-7:—, 5.5.3 and equals at maximum the total error motion value. It can further be divided into synchronous and asynchronous error motion. Radial error motion is provided in a polar plot.

Axial error motion measurement is described in ISO 230-7:—, 5.4.4 and equals at maximum the total error motion value and can further be divided into fundamental, residual synchronous and asynchronous error motion. Axial error motion is provided in a polar plot.

Tilt error motion measurement is described in ISO 230-7:—, 5.5.5 and is obtained, if needed, by subtracting the radial error motion determined at different Y-axis positions (i.e. by using short and long sphere stem or a mandrel) divided by the height difference or separation distance. Tilt error motion can further be divided into synchronous and asynchronous error motion and is provided in a polar plot.

Total error motion and total error motion value are defined in ISO 230-7:—, 3.2.4 and 3.5.1, respectively and represent the maximum errors of the *B'*-axis in the respective direction (i.e. radial, tilt, or axial).

Setup I

The sensors nest (or 3D probe) is mounted in the machine's spindle and its measurement axes are aligned and remain fixed to the X, Y, Z axes of the machine.

Setup II

The measurement axes of the sensors nest, which rotate along with the table (i.e. representing work piece coordinates) are aligned with the X, Y, Z axes of the machine with the *B'*-axis in zero position.

To obtain the fixed sensitive direction radial (and tilt if needed) error motions, coordinate transformations are required to counter act the *B'*-axis rotation i.e. the coordinate frame of the sensors nest remains the same with respect to the orientation of the machine's coordinate frame.

It is recommended to compensate the error motions of the linear axes before performing this test to limit their impact on the obtained result if the test is not performed at the axis of rotation of the *A'*-axis.

NOTE In principle, both setups are equivalent and the choice depends on the mounting possibilities available.

If the position and orientation of the *B'*-axis are evaluated with the same setup, the tool length is required and should be measured with sufficient accuracy (i.e. using a tool-setter). The offset of the sensors nest in X-direction should be zero (or known) with sufficient accuracy, see ISO 10791-6:—.

For these tests, the following parameters shall be stated:

— location of the measurement setup;

— distance between the precision sphere centre and the table in mm for setup I;

— distance between the sensors nest origin and the table in mm for setup II;

— position of the other axes A, X, Y and Z;

— measured range *B'*-axis;

— direction of rotation (for unidirectional test: CW or CCW);

— identification of all artefacts (i.e. precision sphere or test mandrel), sensors nest, fixture used;

— presentation of measurement result, for example error motion value, a polar plot, time based plot, *B'*-axis angle based plot, frequency content plot;

— rotation speed of the table (zero for static error motion);

— the time duration in seconds or number of table rotations;

— warm-up procedure;

— calibration status of all measurement instrumentation used:

  — roundness error of precision sphere or test mandrel in mm;

  — measurement uncertainty of sensors nest in mm;

  — calibration date and procedure of sensors nest;

— time and date of measurement;

— operation conditions that might affect the measured results such as ambient temperature.

For setup I, the precision sphere can be replaced by a precision cylinder/test mandrel for determining tilt error motions of the *B'*-axis directly as this enables the simultaneous measurement of two radial error motions performed at different heights in a single setup. The sensors nest shall be compatible with such a precision cylinder having at least two axially separated radial sensors.

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[1] ISO 8526-1:1990, *Modular units for machine tools — Workholding pallets — Part 1: Workholding pallets up to 800 mm nominal size*

[2] ISO 8526-2:1990 + ISO 8526-1990/Cor. 1:1992, *Modular units for machine tools — Work holding pallets — Part 2: Work holding pallets of nominal size greater than 800 mm*

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