INTERNATIONAL STANDARD

ISO 10791-2

Second edition
2023-04

Test conditions for machining centres —

Part 2: Geometric tests for machines with vertical spindle (vertical Z-axis)

Conditions d'essai pour centres d'usinage —

Partie 2: Essais géométriques des machines à broche verticale (axe Z vertical)

Reference number
ISO 10791-2:2023(E)

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

Published in Switzerland

Contents

Page

Foreword

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

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

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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

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

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

This second edition cancels and replaces the first edition (ISO 10791-2:2001), which has been technically revised.

The main changes are as follows:

— Tests applying to all configurations of machines have now been grouped in Clause 5 (tests G5.1 to G5.14).

— Tests for optional horizontal spindles and integral or accessory spindle heads forming the object of Annexes A through C in the first edition of this document, have been deleted and will be covered by a more general standard, as they are not only used in machining centres.

— Tests for the movements of four types of work holding tables have been introduced, respectively as Clauses 6, 7, 8 and 9, as explained in 4.5 and Table 1.

— Three new Annexes A, B and C have been introduced, dealing with error motion of rotary axes belonging to spindles and to rotary and tilting tables.

— The test of the table flatness (formerly G15) has been deleted for several reasons, including:

  — 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 table surface can be unsuitable for accurate measurements, mostly on large machines.

A list of all parts in the ISO 10791 series can be found on the ISO website.

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

Introduction

A 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 the ISO 10791 series is to provide information as widely and comprehensively as possible on tests which can be carried out for comparison, acceptance, maintenance or any other purpose deemed necessary by user or manufacturer/supplier.

Test conditions for machining centres —

Part 2:
Geometric tests for machines with vertical spindle (vertical Z-axis)

1 Scope

This document specifies, with reference to the ISO 230 series, the geometric tests for machining centres with vertical spindle (i.e. vertical Z-axis).

This document also establishes the tolerances for the test results corresponding to general purpose and normal accuracy machining centres.

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

This document applies to machining centres having three numerically controlled linear axes (X-axis up to 5 000 mm length, Y-axis up to 2 000 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. Further tests, contained in Annexes A, B and C, cover axes of rotation of spindles, rotary tables and tilting cradles. Movements other than those mentioned are considered as special features and the relevant tests are not included in this document.

This document takes into consideration in Clauses 6 through 9 four possible types of tables, fixed and rotary, as hereunder described:

— Clause 6: horizontal non-rotating tables;

— Clause 7: tables rotating only around a vertical C'-axis;

— Clause 8: tables rotating around a vertical C'-axis and tilting around a horizontal A'-axis;

— Clause 9: tables rotating around a vertical C'-axis and tilting around a horizontal B'-axis.

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

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

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

ISO 841:2001, *Industrial automation systems and integration — Numerical control of machines — Coordinate system and motion nomenclature*

3 Terms and definitions

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

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

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

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

4 Preliminary remarks

4.1 Measurement units

In this document all linear dimensions, errors, and corresponding tolerances are expressed in millimetres; angular dimensions are expressed in degrees, and angular errors 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. Formula (1) should be used for conversion of the units of angular errors or tolerances:

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

4.2 Reference to the ISO 230 series

4.2.1 General

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

Where the test concerned is in compliance with the specifications of the relevant part of the ISO 230 series (i.e. ISO 230-1 or ISO 230-7), a reference to the corresponding subclause of that standard is shown before the instructions in the "Observations" block of the tests described in Clauses 5 to 9 and Annexes A to C.

4.2.2 Consideration of relative measurements

As indicated in ISO 230-1, all geometric measurements are carried out between the tool side and the workpiece side of the machine.

When such measurement is not possible using a single instrument (e.g. a precision level), and the motion of the axis under test causes an angular movement of both spindle head and workholding component, differential measurements are required.

4.3 Reference to ISO 10791-6

In ISO 10791-6:2014, Annexes 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 b) in ISO 10791-6:2014 can be used as an alternative for the following tests if all relevant geometric error compensation functions are identical: see G7.6, G7.7, G8.6 b), G8.7, G9.6 b) and G9.7.

4.4 Testing sequence

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

4.5 Tests to be performed

When testing a machine tool, it is not always necessary, nor possible, to carry out all the tests described in this document. When the tests are required for acceptance purposes, it is up to the user to choose, in agreement with the manufacturer/supplier, those tests relating to the components and/or the properties of the machine tool which are of interest. These tests are to be clearly stated when ordering a machine tool. Simple reference to this document for the acceptance tests, without specifying the tests to be carried out, cannot be considered as binding for any contracting party.

Tests considered in Clause 5 (G5.1 to G5.14) apply to all vertical machining centres, whichever is the type of work holding table. Moreover, depending on the type of table, each one of Clauses 6 to 9 contains all the relevant geometric tests, and there is no need of taking similar tests from different clauses. Therefore, depending on the configuration of the machine, the following choice is available for a complete geometric test:

— for machines with horizontal non-rotating tables, Clauses 5 and 6 and test AR1 in Annex A are applicable;

— for machines with tables rotating only around a vertical C'-axis, Clauses 5 and 7 and Annex A are applicable;

— for machines with tables rotating around a vertical C'-axis and tilting around a horizontal A'-axis, Clause 5 and 8, Annexes A and B are applicable;

— for machines with tables rotating around a vertical C'-axis and tilting around a horizontal B'-axis, Clauses 5 and 9, Annexes A and C are applicable.

For a better understanding, the above list is summarized in Table 1.

Table 1 — Tests applicable to different configurations of vertical machining centres

	Main body of this document					Annex		
Rotary axes on the table	Clause 5	Clause 6	Clause 7	Clause 8	Clause 9	Annex A	Annex B	Annex C
No one	G5.1 to G5.14	G6.1 to G6.5				AR1		
C'	G5.1 to G5.14		G7.1 to G7.8			AR1 and AR2		
C' + A'	G5.1 to G5.14			G8.1 to G8.18		AR1 and AR2	BR1 and BR2	
C' + B'	G5.1 to G5.14				G9.1 to G9.18	AR1 and AR2		CR1 and CR2

4.6 Tolerances

In this document, all tolerance values are guidelines. When the tolerances 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 tool.

When establishing the tolerance for a measuring length different from that given in this document 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, unless otherwise specified.

4.7 Measuring instruments

Measuring instruments indicated in the tests described in the following clauses 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 transformers (LVDTs), linear scale displacement gauges, or non-contact sensors, when applicable to the test concerned.

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

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

When a “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.

4.8 Diagrams

4.8.1 General

For reasons of simplicity, each diagram in this document illustrates only one type of machininig centre. Diagrams do not always show the same type.

4.8.2 Alphabetic characters used for the E error expressions

In most cases, the diagrams show the coordinate axes with their own codes and orientations. In this document the linear X, Y and Z axes and the rotary A’, B’ and C’ axes are mentioned, but some other alphabetic characters used in the texts are shown in the diagrams, mainly for parallelism and squareness tests. They are (C), T and L, with the following meaning:

— (C): spindle axis; it shall not be confused with the C-axis of a possible universal spindle head mounted on the machine;

— T: projection of the table surface representative line on the measurement plane;

— L: reference line on the table surface represented by a T-slot, an edge locator or an artefact clamped on the table.

4.8.3 Error direction

For parallelism and squareness errors, the diagrams show in different ways the positive direction of the error between the checked element (physical component or axis) and the reference axis, as follows:

— for parallelism tests an arrow in the diagram shows the positive direction of the error, whose algebraic sign is to be noted in the “Measured error” box;

— for squareness tests the character α is shown, and in the “Measured error” the positive direction of the error shall be indicated as “$\alpha > 90°$” and the negative direction shall be indicated as “$\alpha < 90°$”.

Particular care shall be taken in noting the correct algebraic sign of the readings, mostly for measurements whose results are to be combined in formulae for other tests.

4.9 Pallets

For machine tools working with several pallets, the tests concerning the intrinsic geometric features or their behaviour related to the axes of the machine tool (tests in Clauses 6 to 9) 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.

4.10 Software compensation

When built-in software facilities are available for compensating certain geometric errors, 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.

4.11 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.

4.12 Machine configurations

Figure 1 and Table 2 show 12 possible configurations of vertical 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 2 to each other. For the axes orientation and nomenclature, reference shall be made to ISO 841.

Several configurations of tilting rotary tables can be mounted on vertical machining centres. An important test for them is the checking of parallelism of the tilting axis to one horizontal axis, where the positions used for the readings are –90°, 0° and +90°, although the tilting axis can reach further angular positions. The test methods are different for

— axes which can reach opposite positions 180° from each other (–90° to +90°), and

— axes which can reach positions only 90° apart from 0° (–90° or +90°).

All possible cases and relevant tests are shown in Clauses 8 and 9, with the different orientations of the axes and algebraic signs, in order to allow the users to choose the tests fitting the actual machining centre under test without the need of adapting or re-calculating the combination of errors.

The possible cases considered in Clauses 8 and 9 are listed hereunder:

— tables tilting around the A'-axis (see Clause 8)
  — tables tilting from A' = –90° to A' = +90° (see 8.2),
  — tables tilting from A' = –90° to A' = 0° (see 8.3), and
  — tables tilting from A' = 0° to A' = +90° (see 8.4);
— tables tilting around the B'-axis (see Clause 9)
  — tables tilting from B' = –90° to B' = +90° (see 9.2),
  — tables tilting from B' = –90° to B' = 0° (see 9.3), and
  — tables tilting from B' = 0° to B' = +90° (see 9.4).

4.13 Designation

A designation is also supplied in Table 2 in order to define the architecture of a machining centre, being a short code; this designation is given by

— the number of this document,

— the letter V for “vertical”, and

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

Table 2 shows examples of designations referred to the machine configurations shown in Figure 1, where

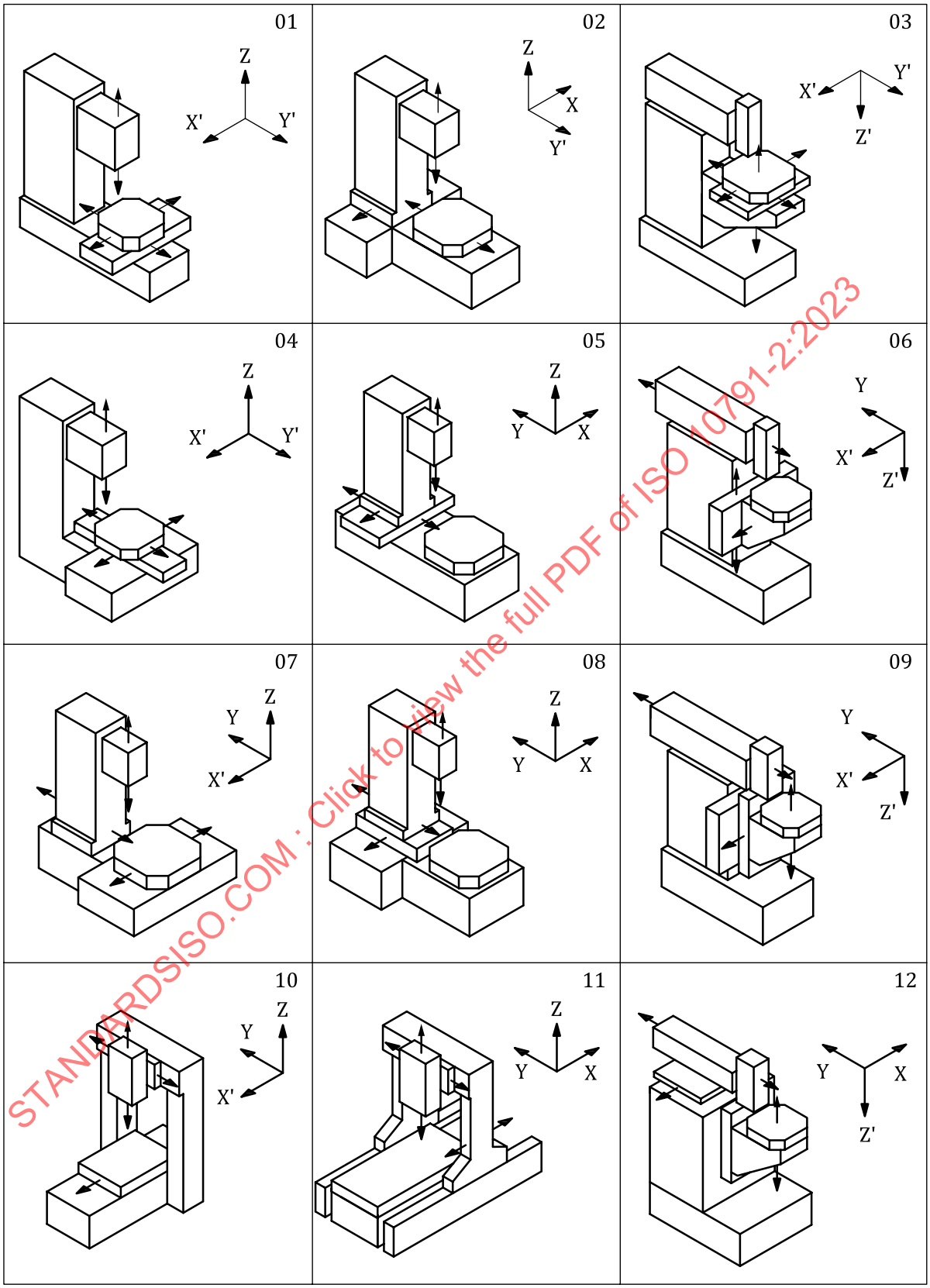
— the kinematic chain of moving axes is described in square brackets,

— the spindle 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 stationary components (e.g. bed, column).

Table 2 — Designations of configurations shown in Figure 1

01	ISO 10791-2 V [w X’ Y’ b Z (C) t]	07	ISO 10791-2 V [w X’ b Y Z (C) t]
02	ISO 10791-2 V [w Y’ b X Z (C) t]	08	ISO 10791-2 V [w b X Y Z (C) t]
03	ISO 10791-2 V [w X’ Y’ Z’ b (C) t]	09	ISO 10791-2 V [w Z’ X’ b Y (C) t]
04	ISO 10791-2 V [w Y’ X’ b Z (C) t]	10	ISO 10791-2 V [w X’ b Y Z (C) t]
05	ISO 10791-2 V [w b Y X Z (C) t]	11	ISO 10791-2 V [w b X Y Z (C) t]
06	ISO 10791-2 V [w X’ Z’ b Y (C) t]	12	ISO 10791-2 V [w Z’ b X Y (C) t]



NOTE Some configurations with rotary and tilting axes of the table are shown in Figures 3 to 5 and diagrams in Clauses 7 to 9.

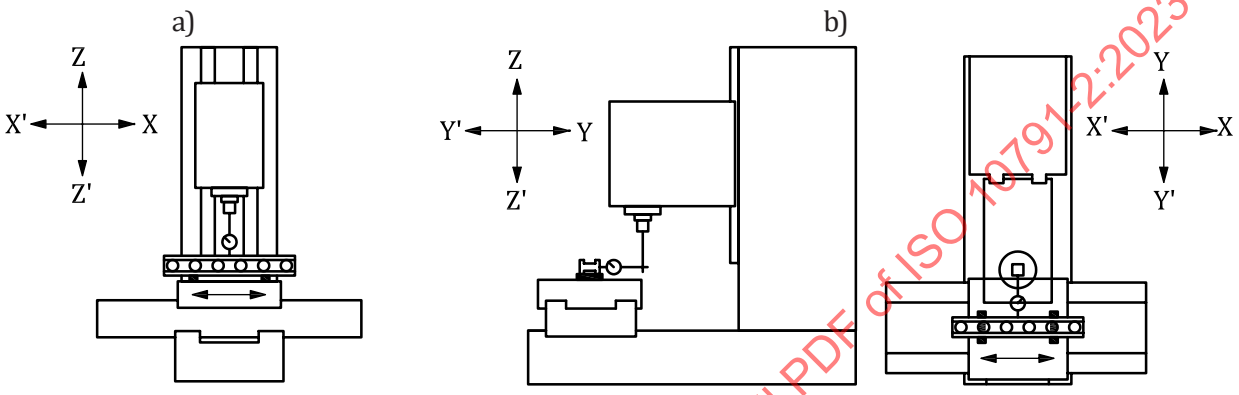
Figure 1 — Possible configurations of linear axes

5 Geometric tests

5.1 Straightness errors of linear motions

Object	**G5.1**
Checking of straightness of the X-axis motion: a) in the vertical ZX plane (E_{ZX}), b) in the horizontal XY plane (E_{YX}).	

Diagram



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 any measuring length of 300.

Measured error

For X = ...

a) b)

Maximum local error:

a) b)

Measuring instruments

a) Straightedge and dial gauge or optical instruments.

b) Straightedge and dial gauge or microscope and taut wire or optical instruments.

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 may 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 reference straight line applied should 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.

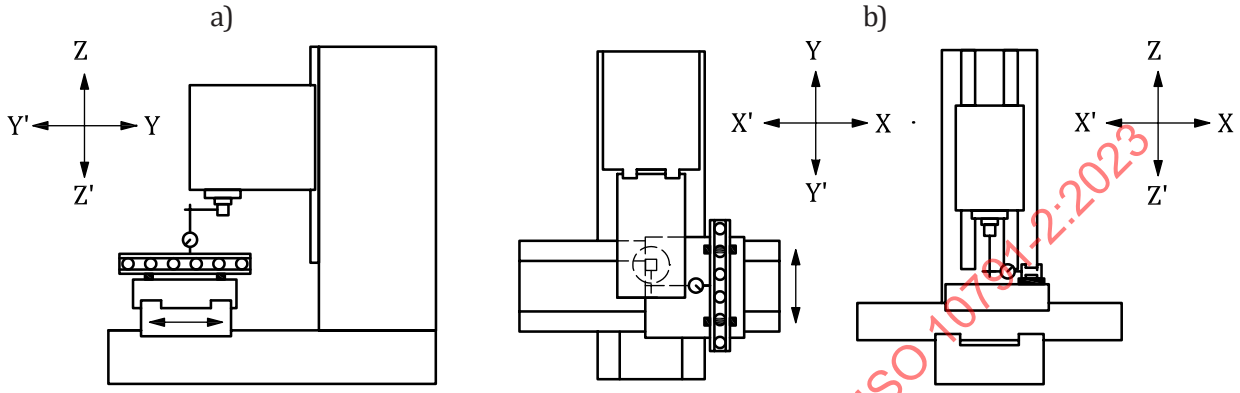
Object	**G5.2**

Checking of straightness of the Y-axis motion:

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

b) in the horizontal XY plane (E_{XY}).

Diagram



Tolerance

		Y	≤	500	a) and b)	0,010
500	<	Y	≤	800	a) and b)	0,015
800	<	Y	≤	1 250	a) and b)	0,020
1 250	<	Y	≤	2 000	a) and b)	0,025

Local tolerance 0,007 for any measuring length of 300.

Measured error

For Y = ...

a) b)

Maximum local error:

a) b)

Measuring instruments

Straightedge and dial gauge or optical instruments.

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

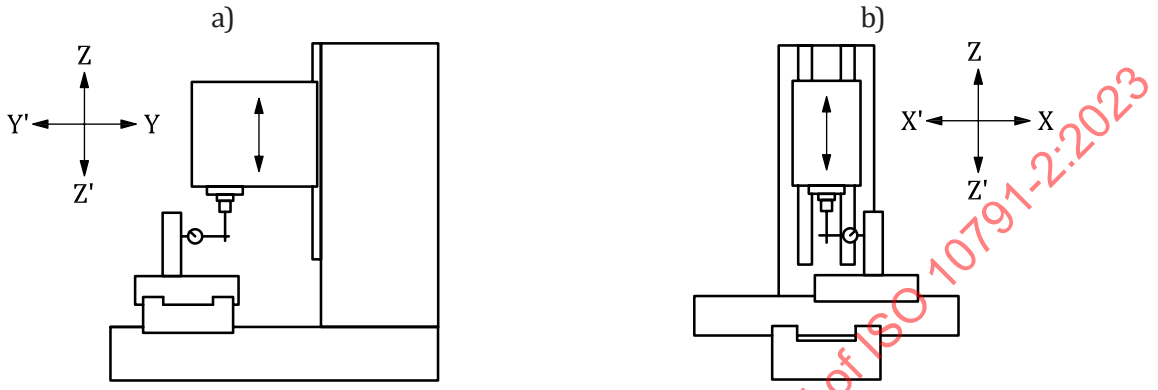
For all machine configurations, the straightedge or the straightness reflector shall be placed on the table. If the spindle can be locked, the dial gauge or the interferometer may be mounted on it; if the spindle cannot be locked, the instrument shall be placed on the spindle head of the machine.

The measuring line should pass as close as possible to the centre of the table. The reference straight line applied should 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	**G5.3**
Checking of straightness of the Z-axis motion: a) in the YZ plane (E_{YZ}), b) in the ZX plane (E_{XZ}).	

Diagram



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 any measuring length of 300

Measured error

For Z = ...

a) b)

Maximum local error:

a) b)

Measuring instruments

Cylindrical square and dial gauge or optical instruments.

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

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

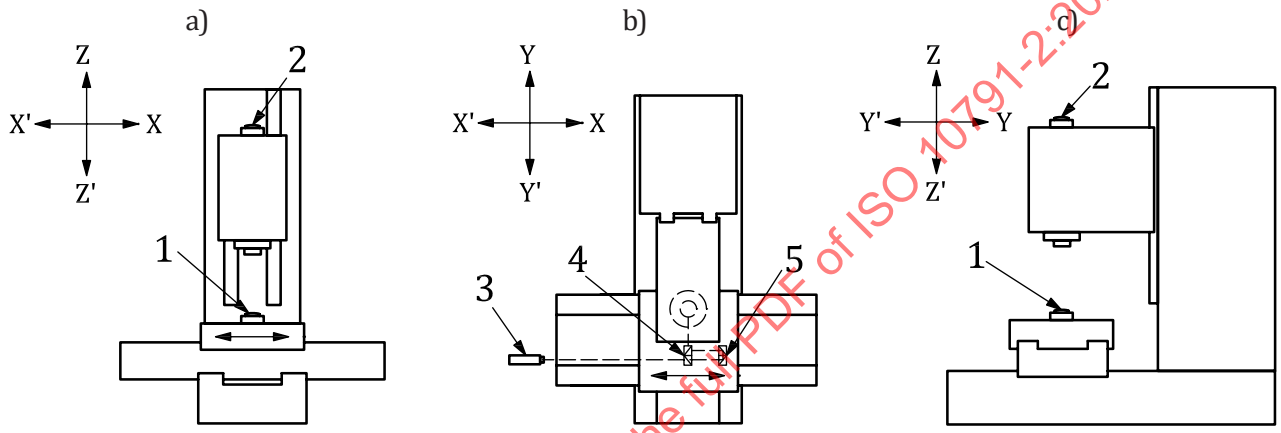
The position of the measuring line on the table and the offsets to the spindle (C) shall be stated in the test report. The reference straight line applied should be stated in the test report.

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.

5.2 Angular errors of linear motions

Object	**G5.4**
Checking of angular errors of the X-axis motion: a) in the vertical ZX plane (pitch E_{BX}), b) in the horizontal XY plane (yaw E_{CX}), c) in the vertical YZ plane (roll E_{AX}).	

Diagram



Key

1 measuring precision level	3 laser head	5 angular reflector
2 reference precision level	4 angular interferometer	

Tolerance

For a), b) and c)

		X	≤ 2 000	0,060/1 000, or 60 µrad or 12”
2 000	<	X	≤ 3 200	0,065/1 000, or 65 µrad or 13”
3 200	<	X	≤ 5 000	0,070/1 000, or 70 µrad or 14”

Local tolerance: 0,016/1 000, or 16 µrad or 3,2”, for any measuring length of 300

Measured error

For X = ...	a)	b)	c)
Maximum local error:	a)	b)	c)

Measuring instruments

a) (pitch E_{BX})	precision level or optical angular error measuring instruments.
b) (yaw E_{CX})	optical angular error 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_{BX}): longitudinally; b) (yaw E_{CX}): 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.

Object	**G5.5**

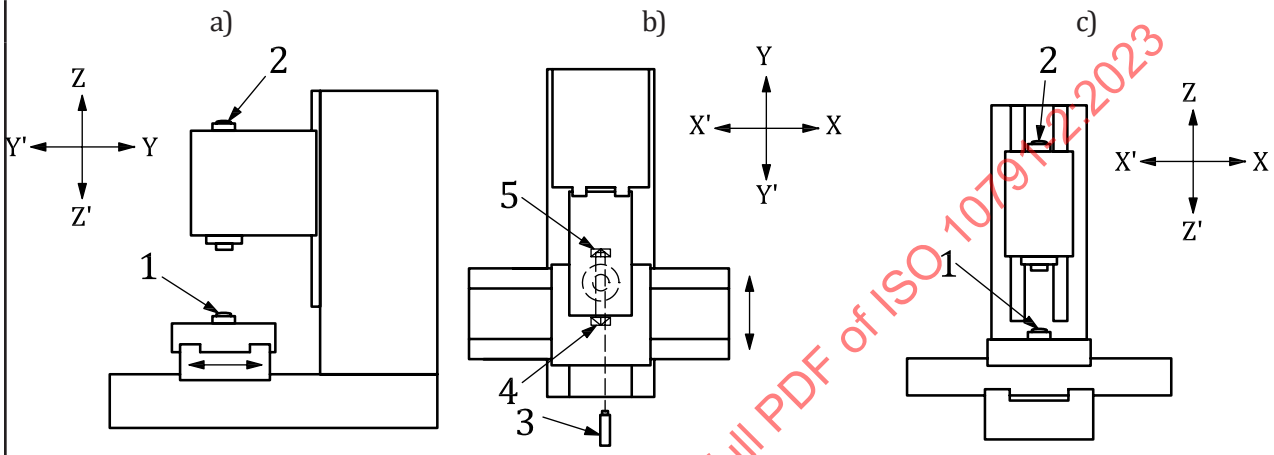
Checking of angular errors of the Y-axis motion:

a) in the vertical YZ plane (pitch E_{AY}),

b) in the horizontal XY plane (yaw E_{CY}),

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

Diagram



Key

1 measuring precision level	3 laser head	5 angular reflector
2 reference precision level	4 angular interferometer	

Tolerance

For a), b) and c): Y ≤ 2 000 0,060/1 000, or 60 µrad or 12”

Local tolerance: 0,016/1 000, or 16 µrad or 3,2”, for any measuring length of 300

Measured error

For Y = ...	a)	b)	c)
Maximum local error:	a)	b)	c)

Measuring instruments

a) (pitch E_{AY}) precision level or optical angular error measuring instruments.

b) (yaw E_{CY}) optical angular error measuring instruments.

c) (roll E_{BY}) 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_{AY}): longitudinally;

b) (yaw E_{CY}): horizontally;

c) (roll E_{BY}): 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.

Object	**G5.6**

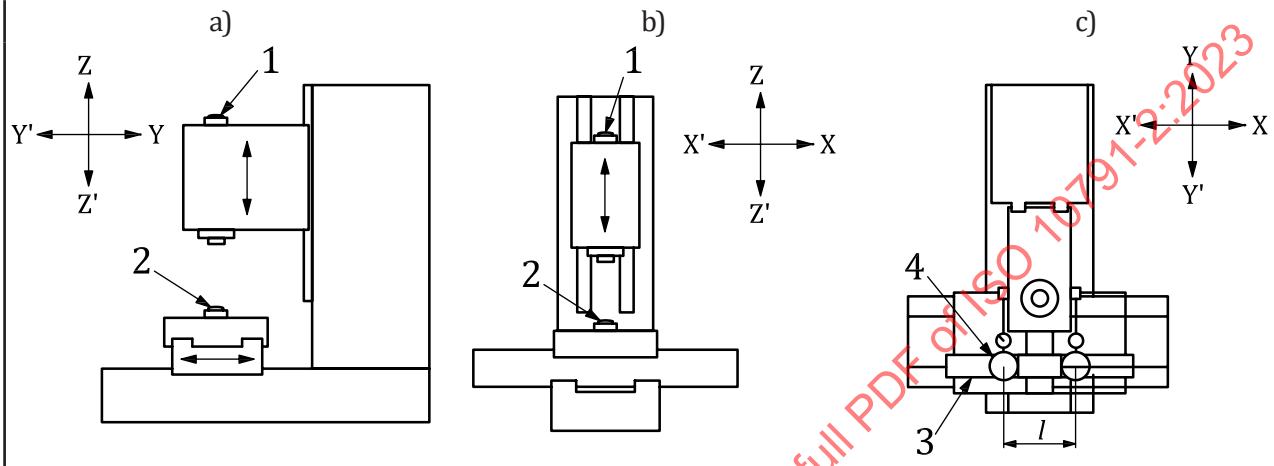
Checking of angular errors of the vertical Z-axis motion:

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

b) in the vertical ZX plane (E_{BZ}),

c) in the horizontal XY plane (roll E_{CZ}).

Diagram



Key

1 measuring precision level	3 straightedge	*l* measurement distance
2 reference precision level	4 cylindrical square	

Tolerance

For a), b) and c):	Z ≤ 2 000	0,060/1 000, or 60 µrad or 12”
Local tolerance:	for a) and b)	0,016/1 000, or 16 µrad or 3,2”, for any measuring length of 300
	for c)	0,024/1 000, or 24 µrad or 4,8”, for any measuring length of 300

Measured error

For Z = ...	a)	b)	c)
Maximum local error:	a)	b)	c)

Measuring instruments

a) and b)	Precision level or optical angular error measuring instruments.
c) (roll E_{CZ})	Cylindrical square 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 c) (roll E_{CZ}), when a sweeping alignment laser is not used, place a cylindrical square (or a precision cube) on the table, approximately parallel to the Z-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 cylindrical 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 error of the X-axis motion shall be measured and taken into account (if a precision cube is used, no X-axis motion is required).

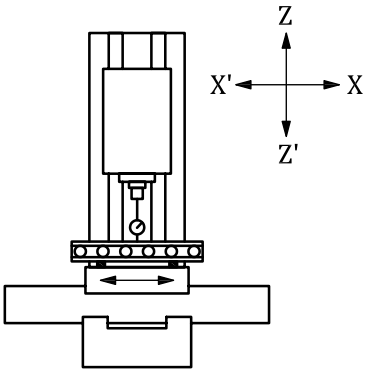
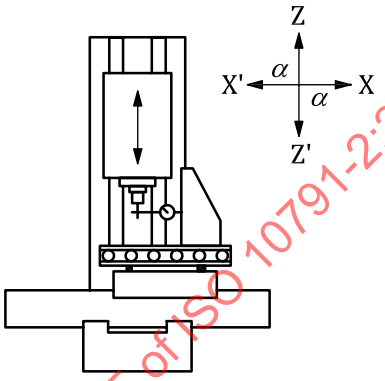
The dial gauge shall be zeroed again and the new measurements shall be taken at the same heights of the previous ones, then noted.

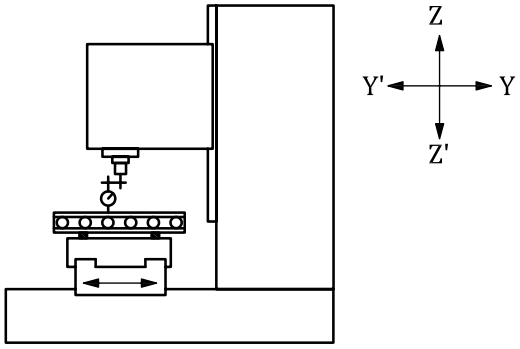
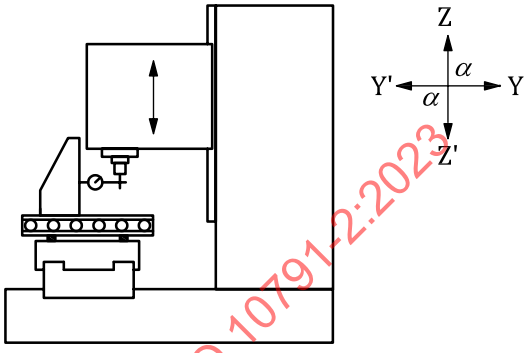
For each measurement height, calculate the difference Δ of the two readings.

The algebraic maximum and minimum of these differences shall be selected and the result of ($\Delta_{max} - \Delta_{min}$)/$l$, is the error to be reported, "l" being the distance between the two positions of the dial gauge.

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

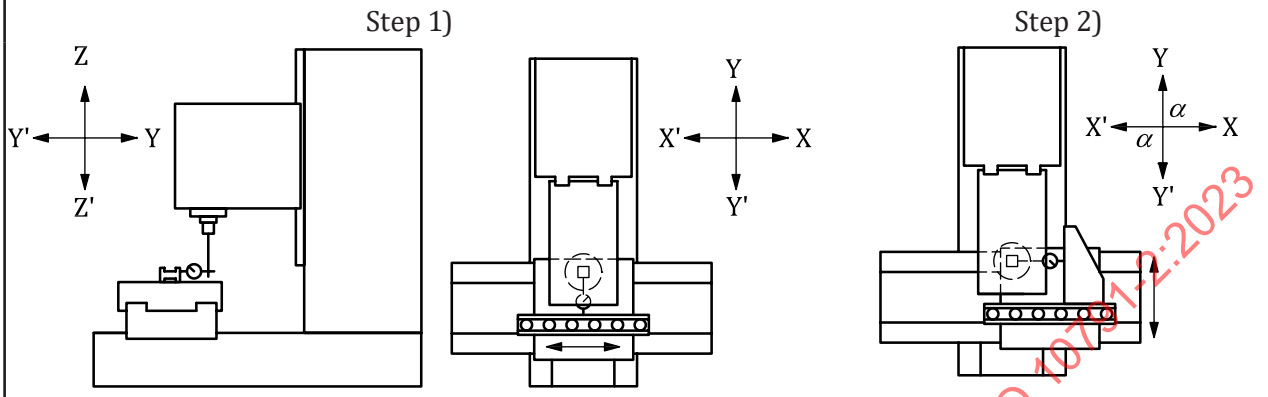
5.3 Squareness errors between linear motions

Object	**G5.7**
Checking of $E_{B(0X)Z}$ squareness of the Z-axis motion to the X-axis motion.	
Diagram Step 1)  Step 2)  	
Tolerance 0,040/1 000 (= 0,020/500, or 40 µrad or 8”)	
Measured error For Z = ...	
Measuring instruments Straightedge or surface plate, square, and dial gauge or optical instruments.	
Observations and references to ISO 230-1:2012, 3.6.7 Note 2, 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 Z-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 may 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. The measured error $E_{B(0X)Z}$ is positive when $\alpha > 90°$ and is negative when $\alpha < 90°$.	

Object	**G5.8**
Checking of $E_{A(0Y)Z}$ squareness of the Z-axis motion to the Y-axis motion.	
Diagram Step 1)  Step 2)  	
Tolerance 0,040/1 000 (= 0,020/500, or 40 µrad or 8”)	
Measured error For Z = ...	
Measuring instruments Straightedge or surface plate, square and dial gauge or optical instruments.	
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 Y-axis, or the lack of parallelism shall be considered in the measurement. In step 2), the Z-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 may 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. The measured error $E_{A(0Y)Z}$ is positive when $\alpha > 90°$ and is negative when $\alpha < 90°$.	

Object	**G5.9**
Checking of $E_{C(0X)Y}$ squareness of the Y-axis motion to the X-axis motion.	

Diagram



Tolerance

0,040/1 000 (= 0,020/500, or 40 µrad or 8”)

Measured error

For Y = ...

Measuring instruments

Straightedge, square, and dial gauge or optical instruments.

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 $E_{C(0X)Y}$ or parallel to the Y-axis for $E_{C(0Y)X}$, or the lack of parallelism shall be considered in the measurement.

In step 2), the Y (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.

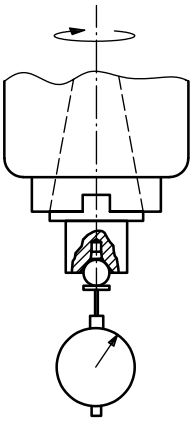
If the spindle can be locked, the dial gauge may be mounted on it; if the spindle cannot be locked, the dial gauge shall be placed on the spindle head of the machine.

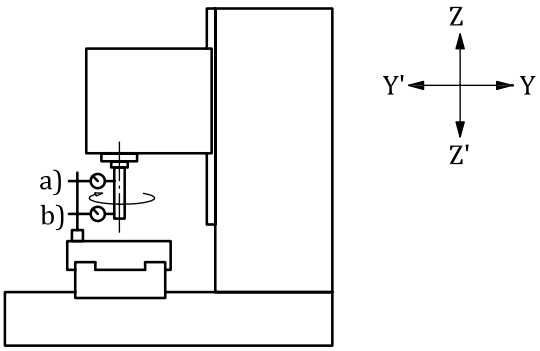
The height above the table shall be stated in the test report.

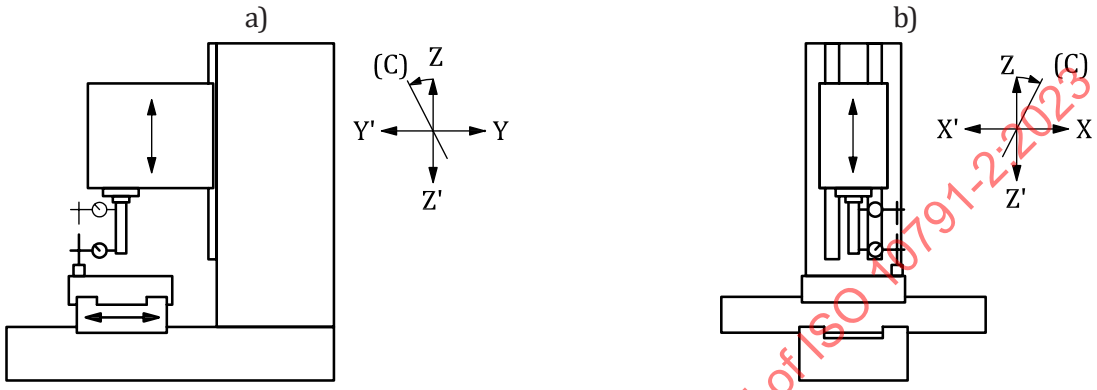
The value of angle α, being less than, equal to or greater than 90°, shall be noted.

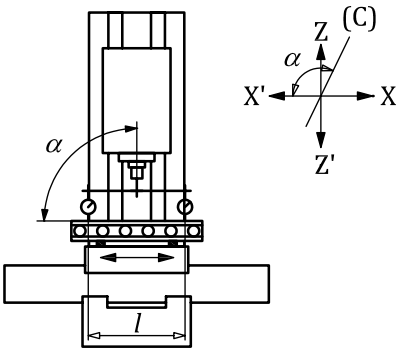
The measured error $E_{C(0X)Y}$ is positive when $\alpha > 90°$ and is negative when $\alpha < 90°$.

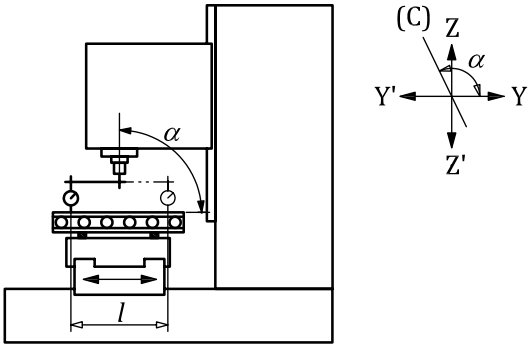
5.4 Spindle

Object	**G5.10**
Checking of axial error motion $E_{Z(C)}$ of the spindle.	
Diagram 	
Tolerance 0,005	
Measured error	
Measuring instruments Dial gauge with flat ended stylus tip.	
Observations and references to ISO 230-1:2012, 9.1 and ISO 230-7:2015, 5.3 and 5.4 See also test AR1 in Annex A.	

Object	**G5.11**
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 measuring position in a).	
Diagram  	
Tolerance a) 0,010 b) 0,015	
Measured error a) b)	
Measuring instruments Test mandrel and dial gauge.	
Observations and references to ISO 230-1:2012, 12.5.3 and ISO 230-7:2015, 5.3 and 5.4 See also test AR1 in Annex A. In order to make the reading easier, the spindle should rotate slowly at a speed not exceeding 100 r/min. The test report shall state whether the rotation is achieved by spindle motor or manually.	

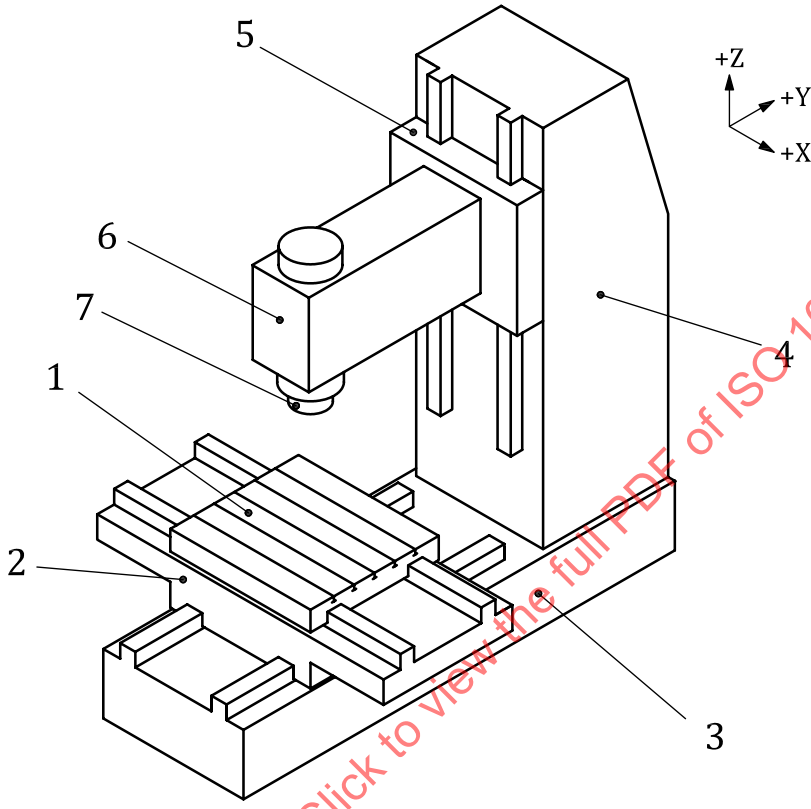
Object	**G5.12**
Checking of parallelism of the spindle axis (C) to the Z-axis motion: a) $E_{A(0Z)(C)}$ in the vertical YZ plane, b) $E_{B(0Z)(C)}$ in the vertical ZX plane.	
Diagram 	
Tolerance For a) and b): 0,050/1 000 (= 0,015/300, or 50 µrad or 10”)	
Measured error a) b)	
Measuring instruments Test mandrel and dial gauge.	
Observations and references to ISO 230-1:2012, 3.6.2, 10.1.4, and 10.1.4.3 X- and Y-axes at centre of the travel. The signs of the parallelism errors in both planes shall be reported. In both planes, the arrow between the spindle axis (C) and the Z-axis shows the positive direction of the error.	

Object	**G5.13**
Checking of $E_{B(0X)(C)}$ squareness of the spindle axis (C) to the X-axis motion.	
Diagram  **Key** l measurement distance	
Tolerance 0,050/1 000 (= 0,015/300, or 50 µrad or 10”)	
Measured error	
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 4.10). 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. The dial gauge reading, divided by the measurement distance l in the X direction, is the error to be reported. In this case, the measurement is influenced by the E_{ZX} vertical straightness error of the X-axis. The squareness error obtained with this test can be cross checked with the results of tests G5.7 and G5.12 b). The value of angle α, being less than, equal to or greater than 90°, shall be noted. The measured error $E_{B(0X)(C)}$ is positive when $\alpha > 90°$ and is negative when $\alpha < 90°$.	

Object	**G5.14**
Checking of $E_{A(0Y)(C)}$ squareness of the spindle axis (C) to the Y-axis motion.	
Diagram  **Key** l measurement distance	
Tolerance 0,050/1 000 (= 0,015/300, or 50 µrad or 10”)	
Measured error	
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 4.10). The straightedge shall be set parallel to the Y-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 Y-axis shall be moved in order to make the stylus touch the special arm in the same point. The dial gauge reading, divided by the measurement distance l in the Y direction, is the error to be reported. In this case, the measurement is influenced by the E_{ZY} vertical straightness error of the Y-axis. The squareness error obtained with this test can be cross checked with the results of tests G5.8 and G5.12 a). The value of angle α, being less than, equal to or greater than 90°, shall be noted. The measured error $E_{A(0Y)(C)}$ is positive when $\alpha > 90°$ and is negative when $\alpha < 90°$.	

6 Horizontal non-rotating tables

Figure 2 shows an example of a machining centre with vertical spindle and a horizontal non-rotating table.



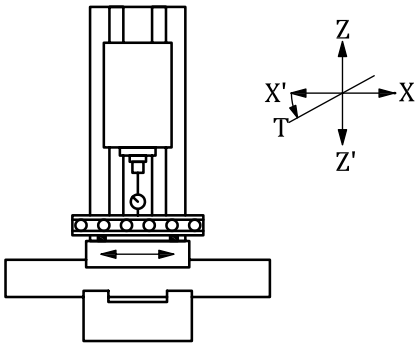
Key

1	table (X'-axis)	5	spindle head slide (Z-axis)
2	table saddle (Y'-axis)	6	spindle head
3	bed (b)	7	spindle [(C)]
4	column		

Figure 2 — Example of vertical machining centre with a non-rotating table — Machining centre ISO 10791-2 V [w X' Y' b Z (C) t]

Object	**G6.1**
Checking of $E_{B(0X)T}$ parallelism of a representative line T of the table surface to the X-axis motion. NOTE This test is performed on the built-in table of the machine or on one representative pallet clamped in position.	

Diagram



Tolerance

		L_T	≤	500	0,020
500	<	L_T	≤	800	0,025
800	<	L_T	≤	1 250	0,030
1 250	<	L_T	≤	2 000	0,040
2 000	<	L_T	≤	3 200	0,060
3 200	<	L_T	≤	5 000	0,080

where L_T is the table length in the X direction.

Measured error

For L_T = ...

Measuring instruments

Straightedge, equal height spacer blocks and dial gauge.

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

Z-axis to be locked, if possible.

The stylus of the dial gauge shall be placed approximately at the working position of the tool. The measurement may be made on a straightedge laid parallel to the table surface.

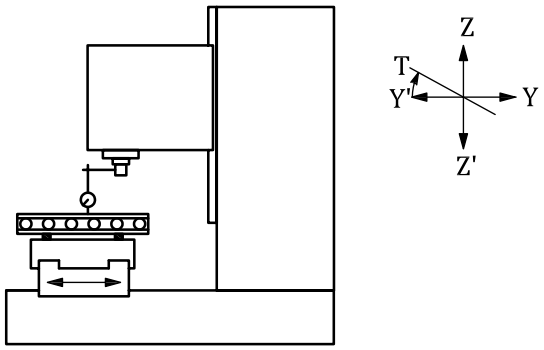
If the table is newly ground, the dial gauge stylus may directly touch the table surface.

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.

The arrow between the table representative line T and the X-axis shows the positive direction of the $E_{B(0X)T}$ error.

Object	**G6.2**
Checking of $E_{A(0Y)T}$ parallelism of a representative line T of the table surface to the Y-axis motion. NOTE This test is performed on the built-in table of the machine or on one representative pallet clamped in position.	

Diagram



Tolerance

		W_T	≤ 500	0,020
500	<	W_T	≤ 800	0,025
800	<	W_T	≤ 1 250	0,030
1 250	<	W_T	≤ 2 000	0,040

where W_T is the table length in the Y direction.

Measured error

For W_T = ...

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

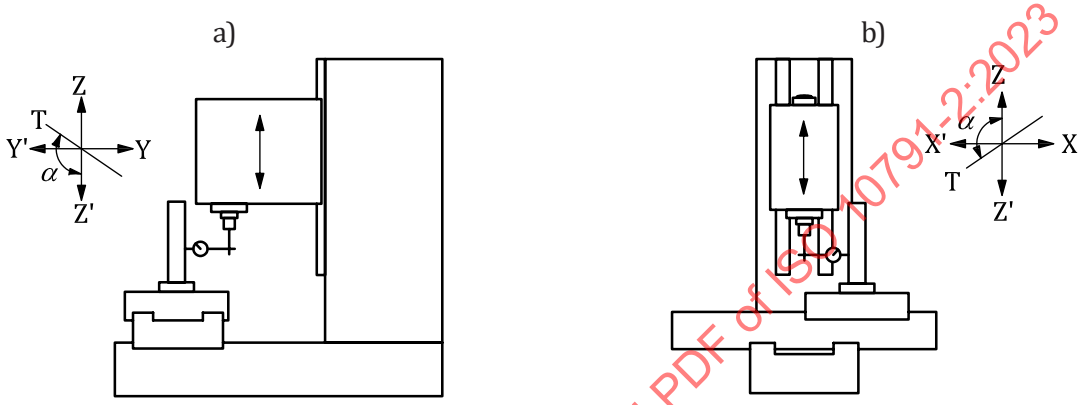
Z-axis to be locked, if possible.

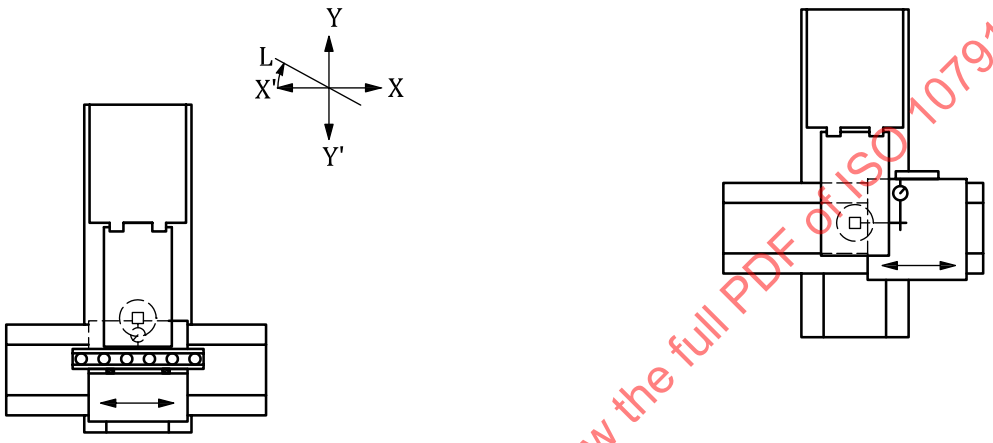
The stylus of the dial gauge shall be placed approximately at the working position of the tool. The measurement may be made on a straightedge laid parallel to the table surface.

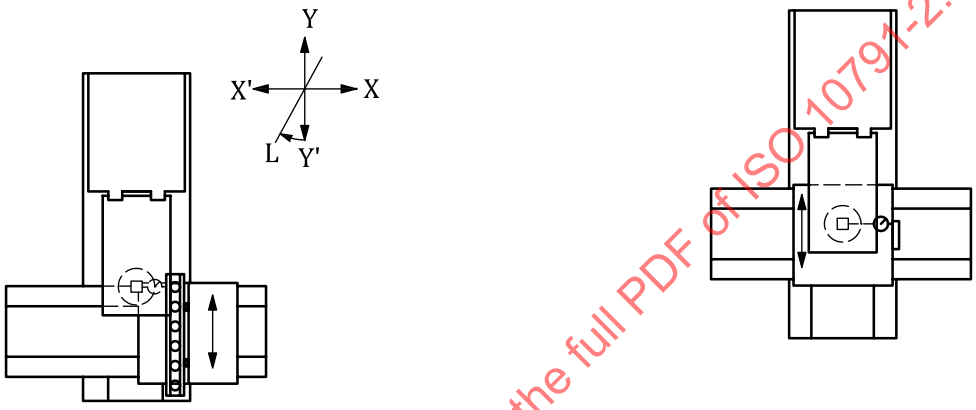
If the table is newly ground, the dial gauge stylus may directly touch the table surface.

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.

The arrow between the table representative line T and the Y-axis shows the positive direction of the $E_{A(0Y)T}$ error.

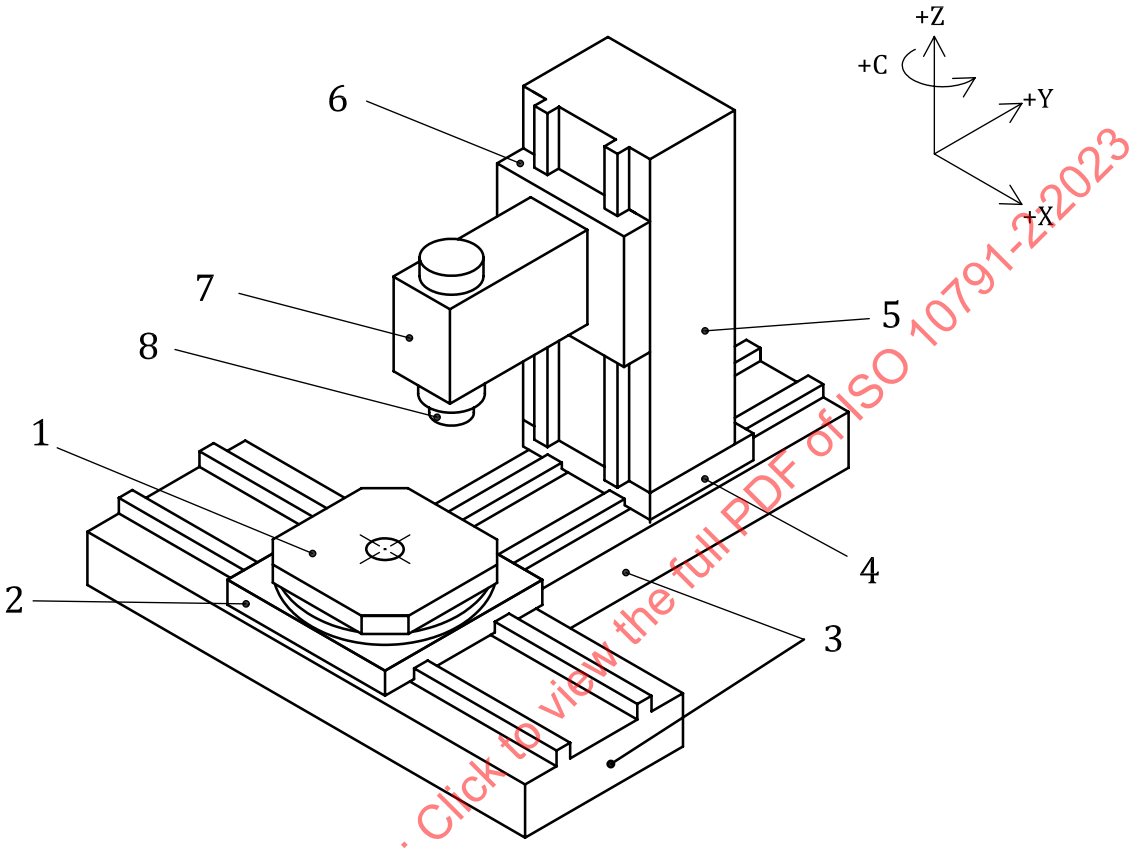
Object	**G6.3**
Checking of squareness of the table surface to the Z-axis motion: a) $E_{A(0Z)T}$ in the vertical YZ plane, b) $E_{B(0Z)T}$ in the vertical ZX plane. NOTE This test is performed on the built-in table of the machine or on one representative pallet clamped in position.	
Diagram  	
Tolerance For a) and b): 0,050 over a measuring length of 1 000	
Measured error 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) Y-axis to be locked, if possible. b) X-axis to be locked, if possible. If a surface plate is used, it 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. 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. The dial gauge stylus shall touch the cylindrical square and the difference between the readings on the bottom and on the top of the square shall be noted. The value of angle α, being less than, equal to or greater than 90°, shall be noted. In both planes the measured error is positive when $\alpha > 90°$ and is negative when $\alpha < 90°$. The squareness errors measured with this test can be cross checked with the results of the following tests: for a), tests G5.8 and G6.2; for b), tests G5.7 and G6.1.	

Object	**G6.4**
Checking of $E_{C(0X)L}$ parallelism of the reference line L, represented by: a) the longitudinal median or reference T-slot, or b) the longitudinal edge locator of the table to the X-axis motion. NOTE This test is performed on the built-in table of the machine or on one representative pallet clamped in position.	
Diagram a) b)  	
Tolerance For a) and b): 0,025 over a measuring length of 500	
Measured error a) b)	
Measuring instruments Gauge blocks, straightedge 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 centre of the table. Zero the dial gauge against one of the gauge blocks. The dial gauge reading on the second gauge block is the error to be reported. The measurement may also be made on a straightedge laid parallel to the reference T-slot, or longitudinal edge locator. Note the direction of the error. The arrow between the reference line L and the X-axis shows the positive direction of the $E_{C(0X)L}$ error.	

Object	**G6.5**
Checking of $E_{C(0Y)L}$ parallelism of the reference line L, represented by: a) the median or reference T-slot (if transverse), or b) the transverse edge locator of the table to the Y-axis motion. NOTE This test is performed on the built-in table of the machine or on one representative pallet clamped in position.	
Diagram a) b)  	
Tolerance For a) and b): 0,025 over a measuring length of 500	
Measured error a) b)	
Measuring instruments Gauge blocks, straightedge 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 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 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 is the error to be reported. The measurement may also be made on a straightedge laid parallel to the reference T-slot or transverse edge locator. Note the direction of the error. The arrow between the reference line L and the Y-axis shows the positive direction of the $E_{C(0Y)L}$ error.	

7 Tables rotating around a vertical C'-axis

Figure 3 shows an example of a machining centre with vertical spindle and a horizontal table rotating around a vertical C'-axis.



Key

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

Figure 3 — Example of vertical machining centre with a rotating table — Machining centre ISO 10791-2 V [w C' X' b Y Z (C) t]

NOTE Tables rotating only around a vertical C'-axis, without tilting around a horizontal axis, are not common on single spindle vertical machining centres, but are often used when a horizontal rotary axis is provided in a universal head, accessory or integral to the machine.

Object **G7.1**

Checking of:

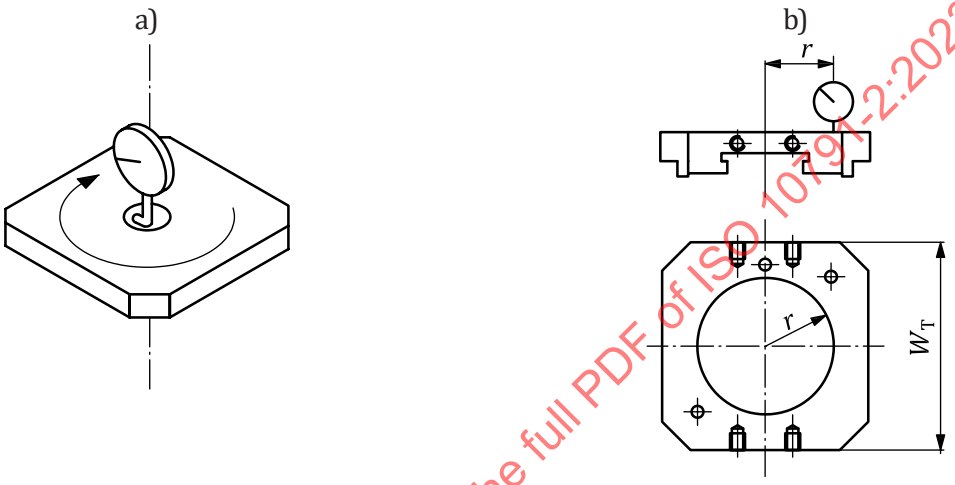
a) run-out of the centre hole of the table (when the centre hole is used for locating purposes),

b) face error motion of the table surface.

NOTE This test is performed on the built-in table of the machine or on one representative pallet clamped in position.

For indexing tables, check at least four positions at 90° from each other.

Diagram



Key

W_T length of the shorter side of the table or pallet r measurement radius

Tolerance

a)					0,025
b)			W_T	≤	500 0,030
	500	<	W_T	≤	800 0,040
	800	<	W_T	≤	1 250 0,050
	1 250	<	W_T	≤	2 000 0,060

Measured error

For W_T = and r =

a) b)

Measuring instruments

a) Dial gauge. b) Gauge blocks and dial gauge.

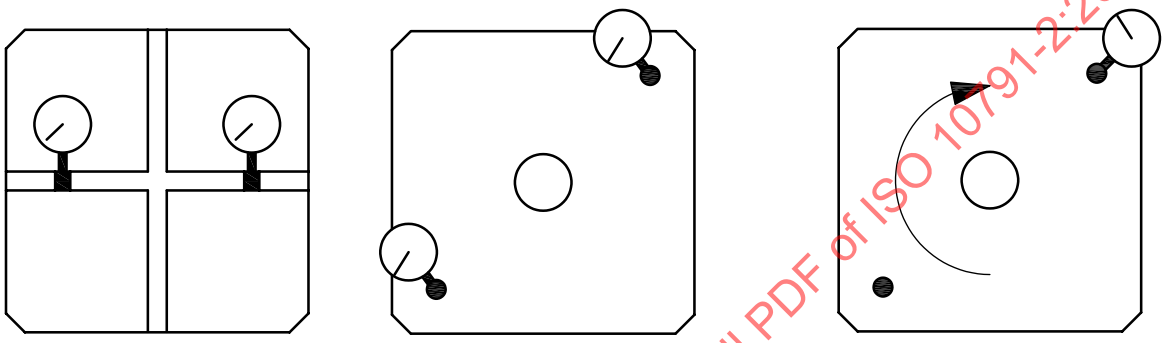
Observations and references to ISO 230-1:2012, 12.5.2 and 12.5.2.3 and ISO 230-7:2015, 5.3 and 5.4

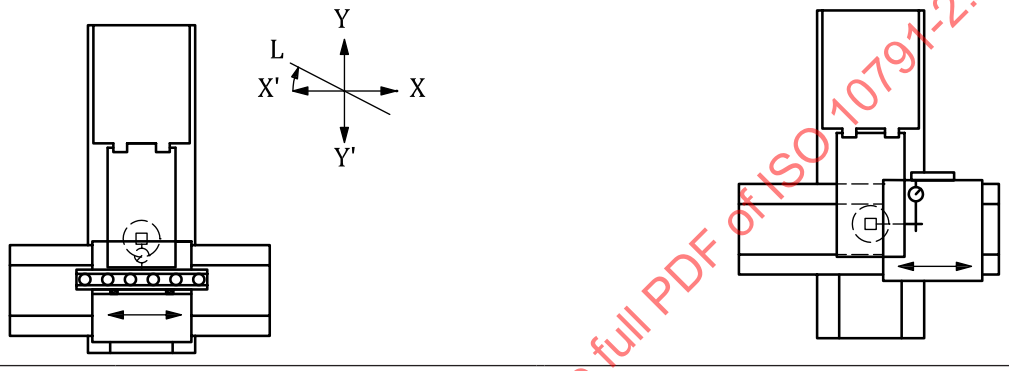
If the spindle can be locked, the dial gauge may be mounted on it. If the spindle cannot be locked, the dial gauge shall be placed on the spindle head of the machine.

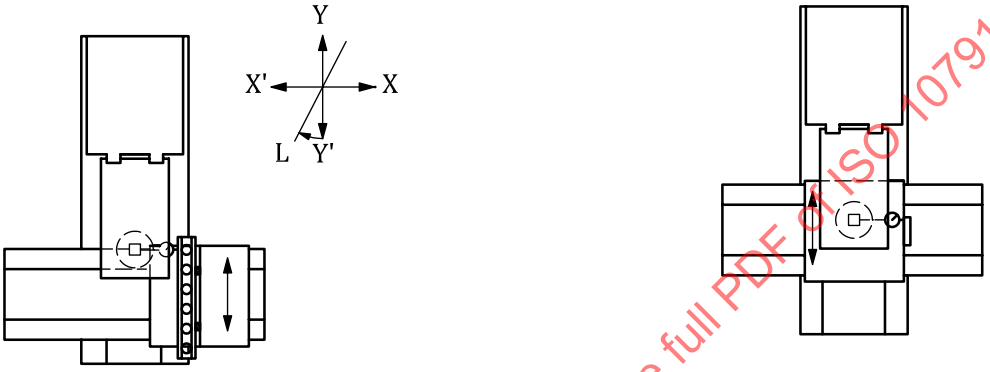
For b) the radius r shall be as large as possible.

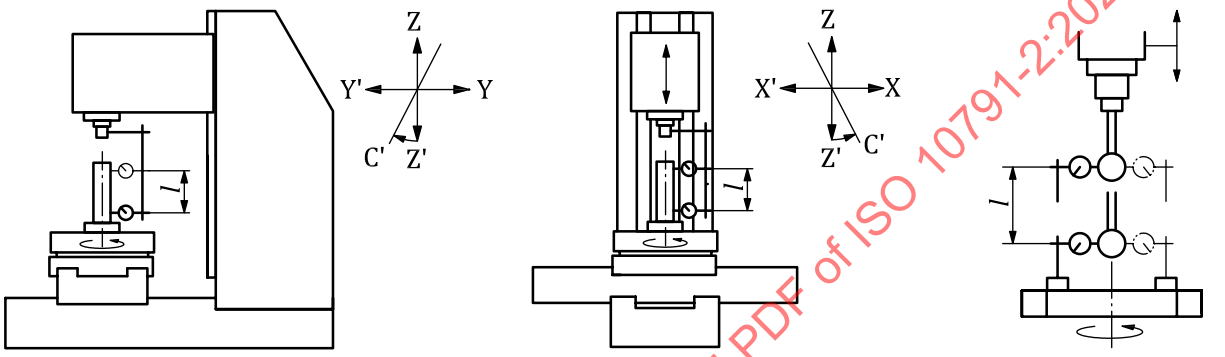
Test b) may also be carried out without continuous contact between stylus and table surface, by using an intermediate gauge block and measuring in discrete positions (e.g. 8 points at 45° steps).

See also AR2 in Annex A for radial, axial and tilt error motion tests, especially if the rotary table is foreseen for turning operations.

Object	**G7.2**
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 C'-axis (table rotation), b) equidistance of the alignment holes with the C'-axis (table rotation). NOTE This test is performed on the built-in table of the machine or on one representative pallet clamped in position.	
Diagram a) b) 	
Tolerance For a) and b): 0,030	
Measured error 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 C'-axis in order to have the T-slot parallel to the X-axis (or Y-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 C'-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 error read in a).	

Object	**G7.3**
Checking of $E_{C(0X)L}$ parallelism of the reference line L, represented by: a) the longitudinal median or reference T-slot, or b) the longitudinal edge locator of the table, with C' = 0°, to the X-axis motion. NOTE This test is performed on the built-in table of the machine or on one representative pallet clamped in position.	
Diagram a) b)  	
Tolerance For a) and b): 0,025 over a measuring length of 500	
Measured error a) b)	
Measuring instruments Gauge blocks, straightedge 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 C'-axis of rotation. Zero the dial gauge against one of the gauge blocks. The dial gauge reading on the second gauge block is the error to be reported. The measurement may also be made on a straightedge laid parallel to the reference T-slot, or longitudinal edge locator. Note the direction of the error. The arrow between the reference line L and the X-axis shows the positive direction of the $E_{C(0X)L}$ error. NOTE The result of this tests includes the possible E_{CC} positioning error of the C'-axis at 0°.	

Object	**G7.4**
Checking of $E_{C(0Y)L}$ parallelism of the reference line L, represented by: a) the median or reference T-slot (if transverse), or b) the transverse edge locator of the table, with C' = 0°, to the Y-axis motion. NOTE This test is performed on the built-in table of the machine or on one representative pallet clamped in position.	
Diagram a) b)  	
Tolerance For a) and b): 0,025 over a measuring length of 500	
Measured error a) b)	
Measuring instruments Gauge blocks, straightedge 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 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 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 is the error to be reported. The measurement may also be made on a straightedge laid parallel to the reference T-slot, or transverse edge locator. Note the direction of the error. The arrow between the reference line L and the Y-axis shows the positive direction of the $E_{C(0Y)L}$ error. NOTE The result of this tests includes the possible E_{CC} positioning error of the C'-axis at 0°.	

Object	**G7.5**
Checking of parallelism of the C'-axis (table rotation) to the Z-axis motion: a) $E_{A(0Z)C'}$ in the vertical YZ plane, b) $E_{B(0Z)C'}$ in the vertical ZX plane. NOTE This test is performed on the built-in table of the machine or on any pallet clamped in position.	
Diagram a) b) Alternative method  **Key** *l* measurement distance	
Tolerance For a) and b): 0,040/1 000 (= 0,020/500, or 40 µrad or 8")	
Measured error a) b)	
Measuring instruments Cylindrical square with flange base, or test sphere as an alternative, and dial gauge, or optical instruments.	

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

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

b) X-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.

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

Step 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).

Step 3) Touch the cylindrical 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 the Y-axis for b). Zero the dial gauge.

Step 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 the Y-axis for b) and note the new dial gauge reading.

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

Step 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 measurement distance *l* in the Z direction, is the error to be reported.

As an alternative, a test sphere shall be mounted on the spindle head of the machine and the dial gauge shall be mounted on the table.

The test sphere shall be centred with respect to the C'-axis average line by moving X and Y-axes, while rotating the C'-axis.

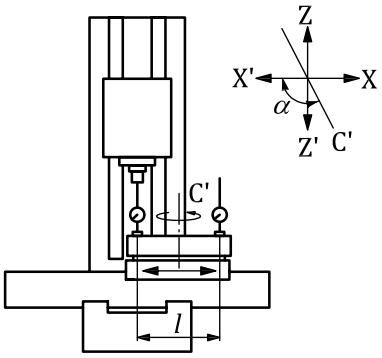
The Z-axis shall then be moved to another location.

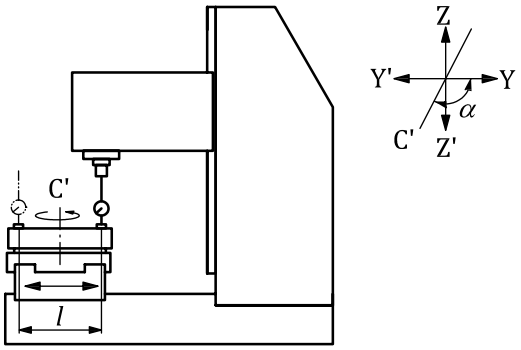
The dial gauge is re-positioned to read against the test sphere at this new location.

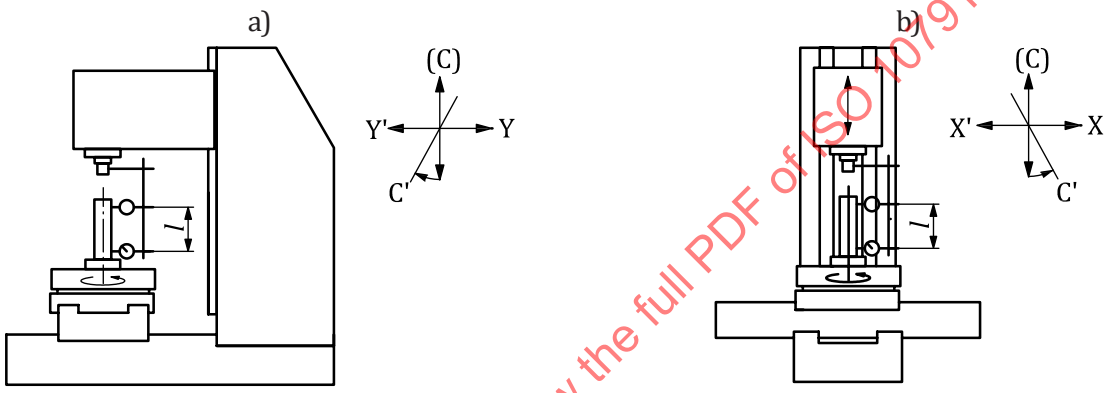
The error in the centre position shall be recorded as half the difference of the readings of the dial gauge at opposite points on the sphere, divided by the measurement distance *l* in the Z direction.

This alternative method can be used when it is possible to touch a complete horizontal circumference of the sphere.

In both planes, the arrow between the C'-axis and the Z-axis shows the positive direction of the error.

Object	**G7.6**
Checking of $E_{B(0X)C'}$ squareness of the C'-axis (table rotation) to the X-axis motion. NOTE This test is performed on the built-in table of the machine or on any pallet clamped in position.	
Diagram  **Key** l measurement distance	
Tolerance 0,030/1 000 (= 0,015/500, or 30 µrad or 6")	
Measured error	
Measuring instruments Gauge block and dial gauge.	
Observations and references to ISO 230-1 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 C'-axis (table rotation) 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 measurement distance l in the X direction, is the error to be reported. The value of angle α, being less than, equal to or greater than 90°, shall be noted. The measured error $E_{B(0X)C'}$ is positive when $\alpha > 90°$ and is negative when $\alpha < 90°$. This test can be influenced by the E_{ZX} vertical straightness error of the X-axis. The squareness error obtained with this test can be cross checked with the results of tests G5.7 and G7.5 b). As an alternative, this squareness can be evaluated by test BK2 b) from ISO 10791-6:2014.	

Object	**G7.7**
Checking of $E_{A(0Y)C'}$ squareness of the C'-axis (table rotation) to the Y-axis motion. NOTE This test is performed on the built-in table of the machine or on any pallet clamped in position.	
Diagram  **Key** l measurement distance	
Tolerance 0,030/1 000 (= 0,015/500, or 30 µrad or 6")	
Measured error	
Measuring instruments Gauge block and dial gauge.	
Observations and references to ISO 230-1 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 C'-axis (table rotation) by 180° and move the Y-axis until the stylus again touches the gauge block. The dial gauge reading, divided by the measurement distance l in the Y direction, is the error to be reported. The value of angle α, being less than, equal to or greater than 90°, shall be noted. The measured error $E_{A(0Y)C'}$ is positive when $\alpha > 90°$ and is negative when $\alpha < 90°$. This test can be influenced by the E_{ZY} vertical straightness error of the Y-axis. The squareness error obtained with this test can be cross checked with the results of tests G5.8 and G7.5 a). As an alternative, this squareness can be evaluated by test BK2 b) from ISO 10791-6:2014.	

Object	**G7.8**
Checking of coaxiality of the C'-axis (table rotation) and the spindle axis (C) at a predefined position of the X- and Y-axes: offsets a) $E_{Y(0(C))C'}$ in the vertical YZ plane, b) $E_{X(0(C))C'}$ in the vertical ZX plane, and parallelism a) $E_{A(0(C))C'}$ in the vertical YZ plane, b) $E_{B(0(C))C'}$ in the vertical ZX plane.	
Diagram  **Key** *l* measurement distance	
Tolerance Offset in both planes a) and b): 0,015 Parallelism in both planes a) and b): 0,040/1 000 (= 0,020/500, or 40 µrad or 8")	
Measured error Offset a) b) Parallelism a) b)	
Measuring instruments Cylindrical square with flange base and dial gauge.	

Observations and references to ISO 230-1

Step 1) Move the X-axis and the Y-axis to the theoretical position where the C'-axis (table rotation) and the spindle axis should coincide.

Step 2) Fix the cylindrical square on the table and the dial gauge in the spindle with the stylus square to the spindle axis in radial direction.

Step 3) With the dial gauge stylus oriented in the Y-axis direction for a) and in the X-axis direction for b), touch the cylindrical square, close to the bottom, and find the maximum dial gauge reading by small movements along the X-axis for a) and along the Y-axis for b). Zero the dial gauge.

Step 4) Turn both the table and the spindle by 180°.

Step 5) Find the maximum dial gauge reading as in step 3.

In both planes a) and b) half of the new reading on the dial gauge represents the offset between the two axes of rotation at the bottom of the cylindrical square.

Step 6) Without moving the Z-axis (see NOTE), repeat the measurements close to the top of the cylindrical square.

In both planes a) and b) half of the new reading on the dial gauge represents the offset between the two axes of rotation at the top of the cylindrical square.

The coaxiality error contains both offset and parallelism errors.

In both planes a) and b) the offset error is the one measured at the bottom of the cylindrical square, and the parallelism error is the difference between the two offsets at the bottom and at the top, divided by the measurement distance l in the Z direction.

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

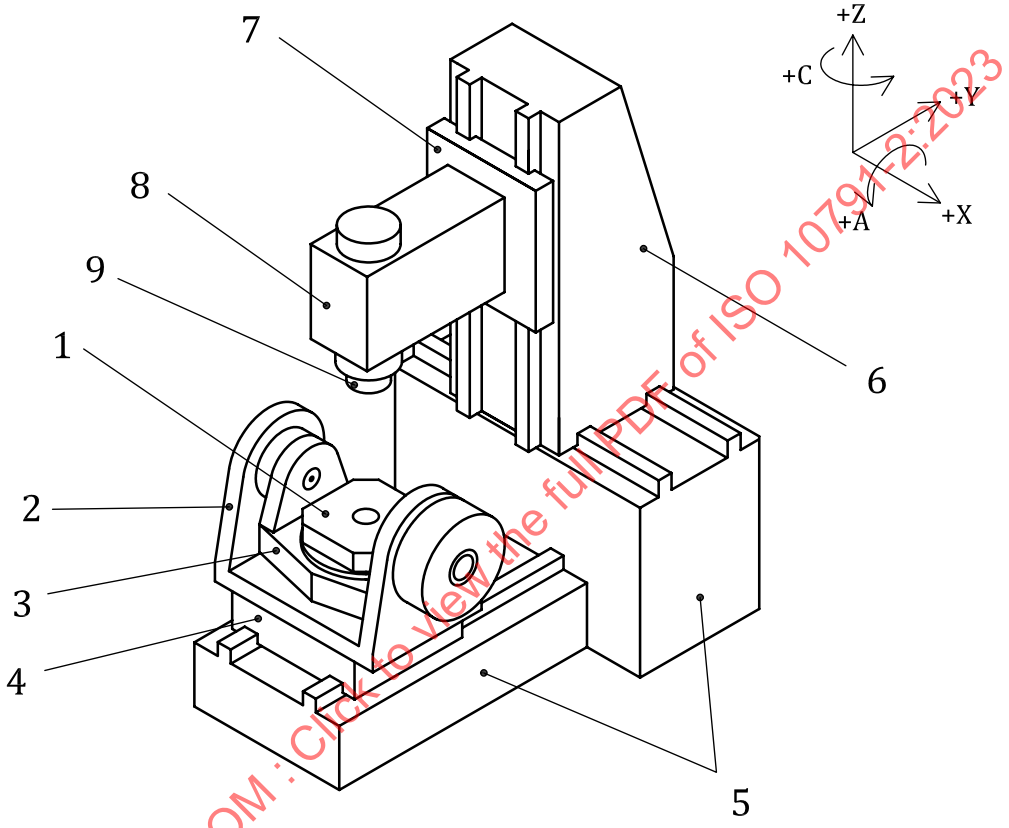
NOTE If this test were carried out in different positions of the Z-axis it would be affected by the parallelism errors between the spindle axis (C) and the Z-axis and between the C'-axis (table rotation) and the Z-axis, in both YZ and ZX planes.

In both planes, the arrow between the C'-axis and the spindle axis (C) shows the positive direction of the parallelism error.

8 Tables rotating around a vertical C'-axis and tilting around a horizontal A'-axis

8.1 General

Figure 4 shows an example of a machining centre with vertical spindle and a table rotating around a C'-axis and tilting around a horizontal A'-axis.



Key

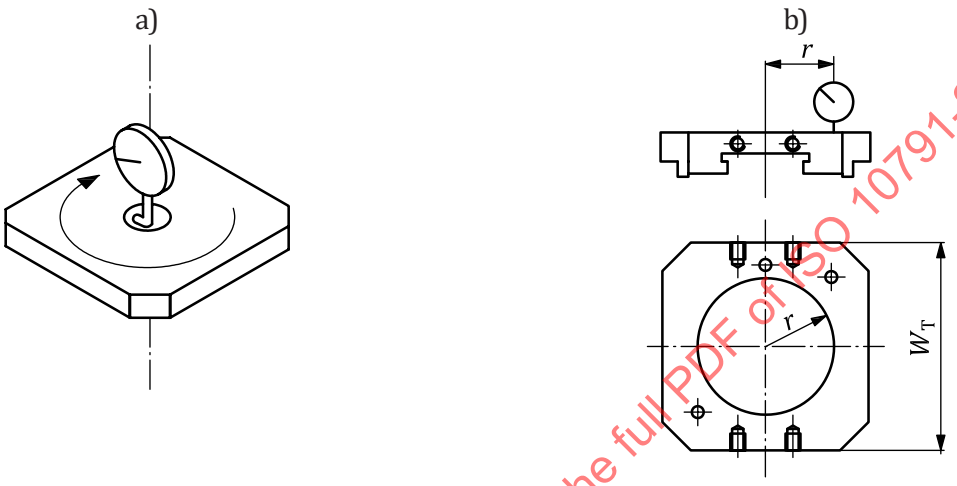
1	rotary table (C'-axis)	6	column (X-axis)
2	trunnion	7	spindle head slide (Z-axis)
3	tilting cradle (A'-axis)	8	spindle head
4	table saddle (Y'-axis)	9	spindle [(C)]
5	bed (b)		

Figure 4 — Example of vertical five-axis machining centre with a table rotating around a vertical C'-axis and tilting around a horizontal A'-axis — Machining centre ISO 10791-2 V [w C' A' Y' b X Z (C) t]

8.2 Tests for rotary tables tilting around the A'-axis

Object	**G8.1**
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 table surface. NOTE This test is performed on the built-in table of the machine or on one representative pallet clamped in position.	

Diagram



Key

W_T length of the shorter side of the table or pallet r measurement radius

Tolerance

a)					0,025
b)			W_T	≤	500 0,030
	500	<	W_T	≤	800 0,040

For W_T greater than 800 mm, the tolerance shall be agreed between user and supplier/manufacturer.

Measured error

For W_T = and r =

a) b)

Measuring instruments

a) Dial gauge. b) Gauge blocks and dial gauge.

Observations and references to ISO 230-1:2012, 9.1 and ISO 230-7:2015, 5.3 and 5.4

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.

For b) the radius r shall be as large as possible.

Test b) may 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 AR2 in Annex A and BR1 in Annex B for radial, axial and tilt error motion tests, especially if the rotary table is foreseen for turning operations.

Object	**G8.2**

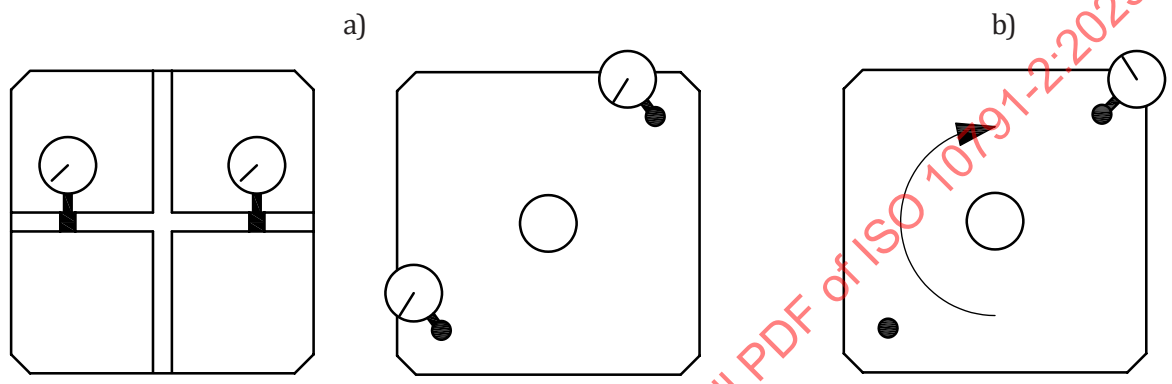
Checking of:

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 C'-axis (table rotation),

b) equidistance of the alignment holes with the C'-axis (table rotation).

NOTE This test is performed on the built-in table of the machine or on one representative pallet clamped in position.

Diagram



Tolerance

For a) and b): 0,030

Measured error

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 C'-axis in order to have the T-slot parallel to the X-axis (or Y-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 C'-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 error read in a).

Object	**G8.3**

Checking of parallelism of a representative line T of the table surface to the X-axis motion, in all the possible angular positions of the A'-axis (cradle tilting) among those listed hereunder and shown in the diagram:

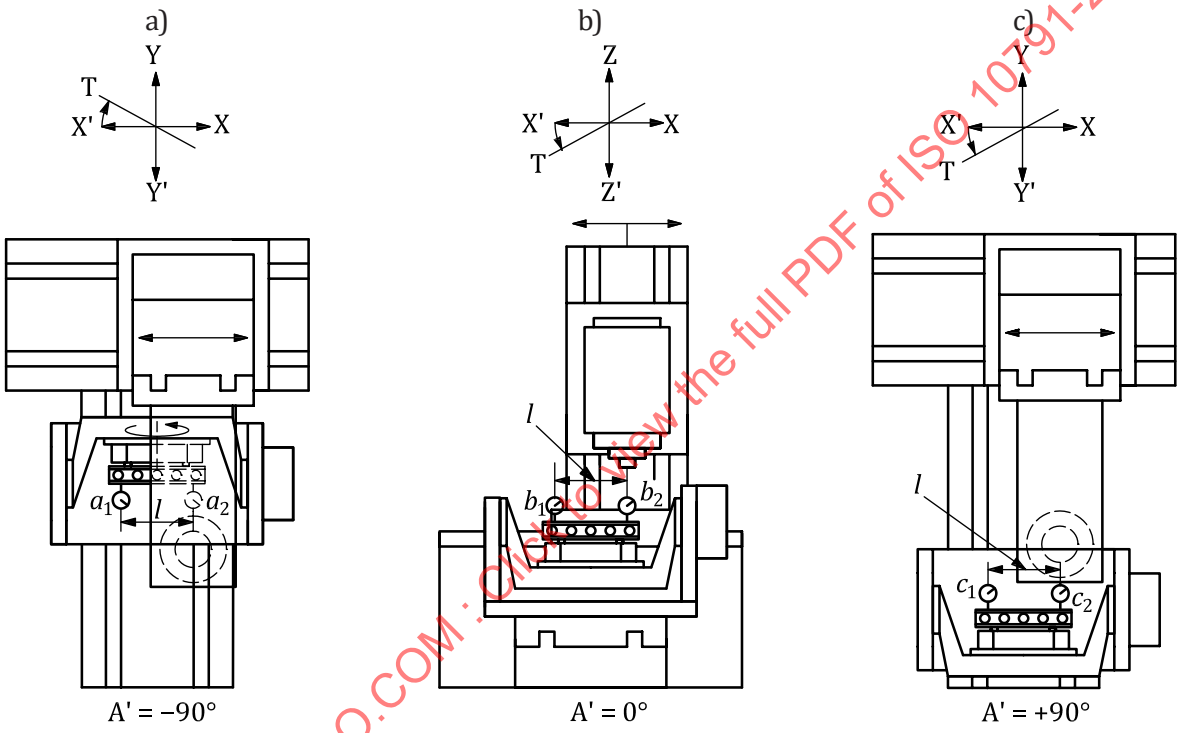
a) with the table in vertical position at A' = –90°, $E_{C(0X)T,\ A'=-90}$,

b) with the table in horizontal position at A' = 0°, $E_{B(0X)T,\ A'=0}$,

c) with the table in vertical position at A' = +90°, $E_{C(0X)T,\ A'=+90}$.

NOTE This test is performed on the built-in table of the machine or on one representative pallet clamped in position.

Diagram



Key

a_1, a_2, b_1, b_2, c_1, c_2 readings l measurement distance

Tolerance

For a), b) and c):	l	≤	500	0,020	over a measuring length of 500
	500 <	l	≤ 800	0,025	over a measuring length of 500

For l greater than 800 mm the tolerance shall be agreed between supplier/manufacturer and user.

Measured error

For l = ...

a) $(a_2 - a_1)$ = b) $(b_2 - b_1)$ = c) $(c_2 - c_1)$

Measuring instruments

Straightedge, gauge blocks and dial gauge.

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

The test shall be carried out in the angular positions a), b) and c), if possible, of the A'-axis.

For a) and c), Y-axis to be locked, if possible. For b), Z-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.

The stylus of the dial gauge shall be placed approximately in the working position of the tool.

The measurement may be made on a straightedge laid parallel to the table surface.

If the table is newly ground, the dial gauge stylus may directly touch the table surface. If a straightedge is used, it shall be safely fixed to the table, in order to allow the readings to be taken in all the possible angular positions of the A'-axis.

The algebraic sign of the readings shall be carefully noted.

The algebraic sign of the results $\Delta a = (a_2 - a_1)$, $\Delta b = (b_2 - b_1)$ and $\Delta c = (c_2 - c_1)$ is positive when the reading in point 2 is greater than in point 1, i.e. when the straightedge in point 2 is closer to the dial gauge than in point 1.

Note the readings and the distance l between the two readings.

The results Δa, Δb and Δc, with their algebraic signs, are the errors to be reported.

For all angular positions of the A'-axis the arrow between the table representative line T and the X-axis shows the positive direction of the error.

The setup of G8.3 can be used for tests G8.13 to G8.18.

Object	**G8.4**

Checking of parallelism of the reference line L, represented by:

— the longitudinal median or reference T-slot (if existing), or

— the longitudinal edge locator of the table

to the X-axis motion, in all the possible angular positions of the A'-axis (cradle tilting) among those listed hereunder and shown in the diagram:

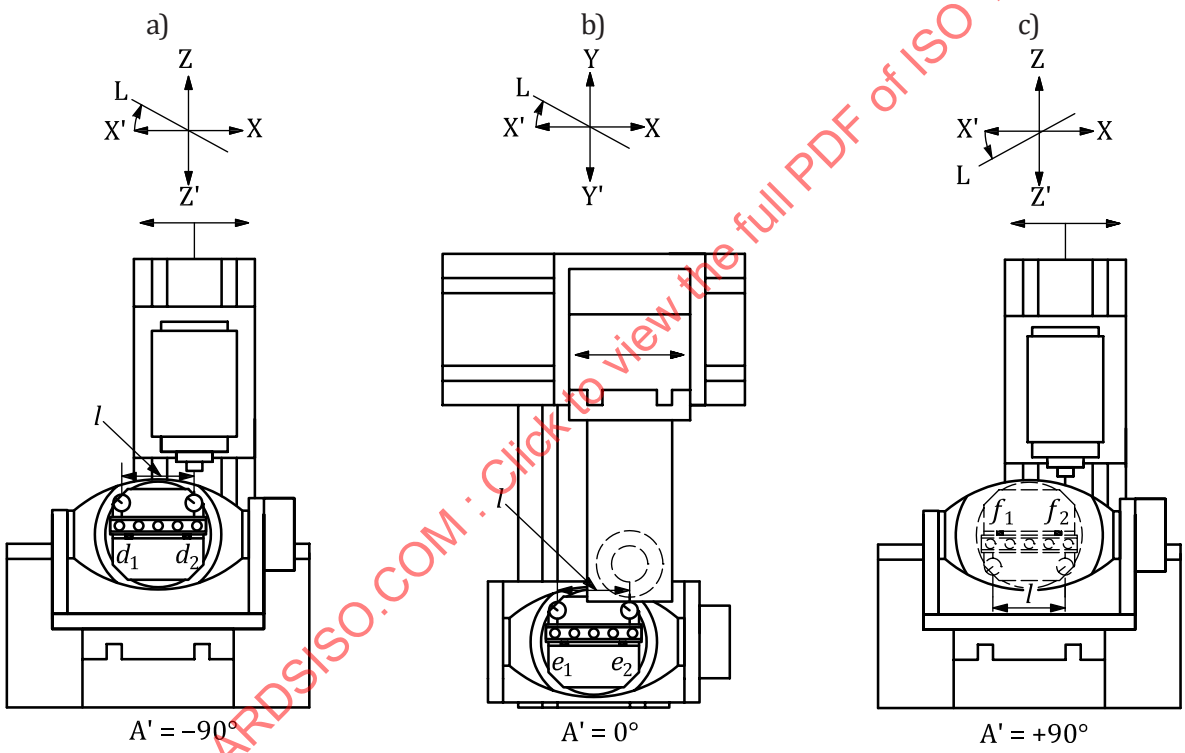
a) with the table in vertical position at A' = –90°, $E_{B(0X)L,\ A' = -90}$,

b) with the table in horizontal position at A' = 0°, $E_{C(0X)L,\ A' = 0}$,

c) with the table in vertical position at A' = +90°, $E_{B(0X)L,\ A' = +90}$.

NOTE This test is performed on the built-in table of the machine or on one representative pallet clamped in position.

Diagram



Key

d_1, d_2, e_1, e_2, f_1, f_2 readings — l measurement distance

Tolerance

For all angular positions of the A'-axis: 0,025 over a measuring length of 500

Measured error

For l = ...

a) $-(d_2 - d_1)$ = b) $-(e_2 - e_1)$ = c) $-(f_2 - f_1)$ =

Measuring instruments

Straightedge, or gauge blocks, and dial gauge.

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

The test shall be carried out in the angular positions a), b) and c), if possible, of the A'-axis.

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

For b), 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.

The stylus of the dial gauge shall be placed approximately in the working position of the tool.

When a reference T-slot or a tenon slot is provided, insert two gauge blocks in the slot at a distance l from each other.

The measurement may also be made on a straightedge laid parallel to the reference T-slot, or longitudinal edge locator.

If a straightedge is used, it shall be safely fixed to the table, in order to allow the readings to be taken in all the possible angular positions of the A'-axis.

For the measurement $(d_2 - d_1)$, the dial gauge shall be oriented downward, and for measurement $(f_2 - f_1)$ the dial gauge shall be oriented upward, in order to touch the same side of the straightedge or gauge blocks.

If it is difficult or unsafe for a machine operator to read the dial gauge when A' = +90°, an instrument with remote reading should be used, or G8.15 should be applied as an alternative.

The algebraic sign of the readings shall be carefully noted.

The algebraic sign of the results $\Delta d = (d_2 - d_1)$, $\Delta e = (e_2 - e_1)$ and $\Delta f = (f_2 - f_1)$ is positive when the reading in point 2 is greater than in point 1, i.e. when the straightedge in point 2 is closer to the dial gauge than in point 1.

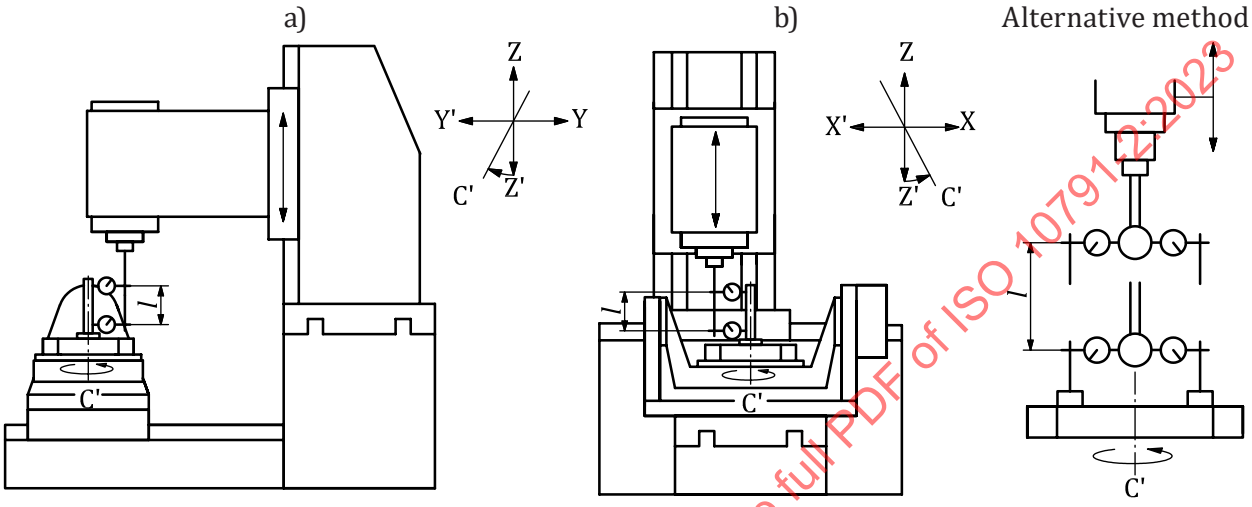
Note the readings and the distance l between the two readings.

The results Δd, Δe and Δf, with their algebraic signs, are the errors to be reported.

For all the angular positions of the A'-axis the arrow between the reference line L and the X-axis shows the positive direction of the error.

The setup of G8.4 can be used for tests G8.12 and G8.15 to G8.18.

NOTE The result of this test includes the possible $E_{CC'}$ positioning error of the C'-axis at 0°, the tilt error motion $E_{CA'}$ of the A'-axis at 0° and the tilt error motion $E_{BA'}$ of the A'-axis at −90°/+90°.

Object	**G8.5**
Checking of parallelism of the C'-axis (table rotation), with the table in the horizontal position (A' = 0°), to the Z-axis motion: a) $E_{A(0Z)C'}$ in the vertical YZ plane, b) $E_{B(0Z)C'}$ in the vertical ZX plane.	
Diagram  	
Key *l* measurement distance	
Tolerance For a) and b): 0,040/1 000 (= 0,020/500, or 40 µrad or 8")	
Measured error a) b)	
Measuring instruments Cylindrical square with flange base, or test sphere as an alternative, and dial gauge, or optical instruments.	

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 0°.

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

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

Step 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).

Step 3) Touch the cylindrical 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 the Y-axis for b). Zero the dial gauge.

Step 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 the Y-axis for b) and note the new reading.

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

Step 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 measurement distance l in the Z-direction, is the error to be reported.

In both planes the arrow between the C'-axis and the Z-axis shows the positive direction of the error.

As an alternative, a test sphere shall be mounted on the spindle head of the machine and the dial gauge shall be mounted on the table.

The test sphere shall be centred with respect to the C'-axis average line by moving X and Y-axes, while rotating the C'-axis.

The Z-axis shall then be moved to another location.

The dial gauge is re-positioned to read against the test sphere at this new location.

The error in the centre position shall be recorded as half the difference of the readings of the dial gauge at opposite points on the sphere, divided by the measurement distance l in the Z-direction.

This alternative method can be used when it is possible to touch a complete horizontal circumference of the sphere.

Object	**G8.6**

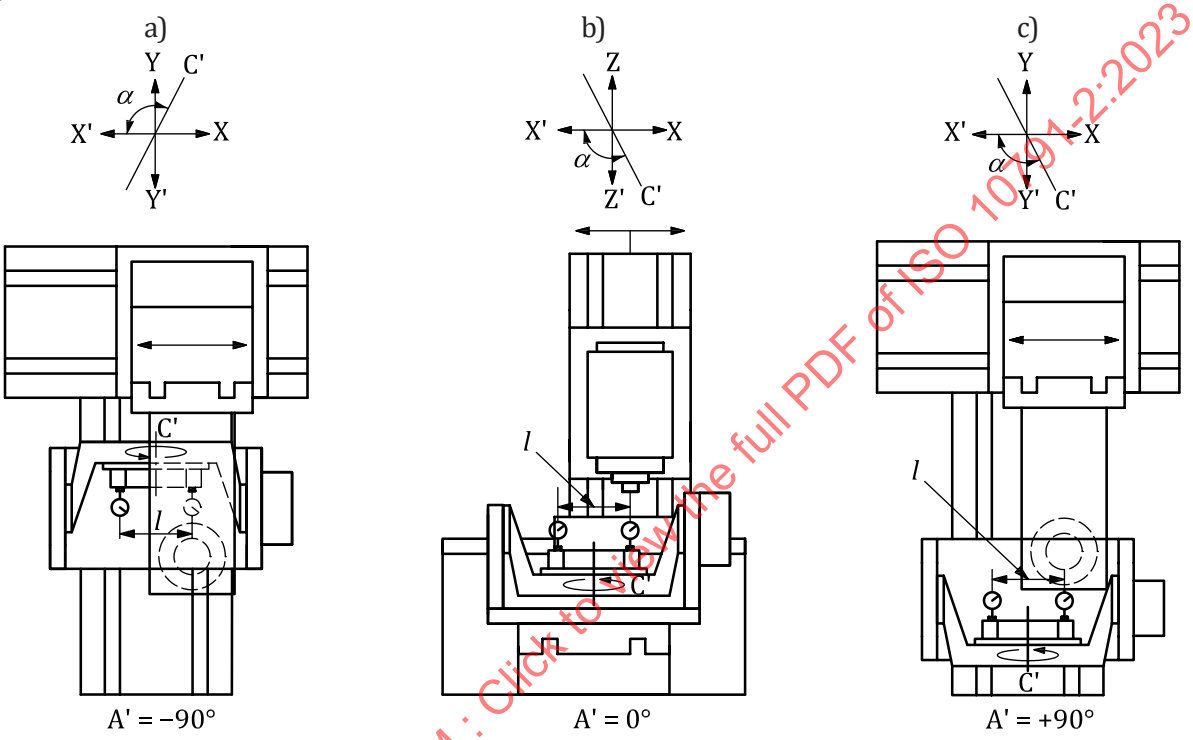
Checking of squareness of C'-axis (table rotation) to the X-axis motion, in all the possible angular positions of the A'-axis (cradle tilting) among those listed hereunder and shown in the diagram:

a) with the table in the vertical position at A' = –90° $E_{C(0X)C', A' = -90}$,

b) with the table in the horizontal position at A' = 0° $E_{B(0X)C', A' = 0}$,

c) with the table in the vertical position at A' = +90° $E_{C(0X)C', A' = +90}$;

Diagram



Key

l measurement distance

Tolerance

For a), b) and c): 0,040/1 000 (= 0,020/500, or 40 µrad or 8")

Measured error

a) b) c)

Measuring instruments

Gauge block and dial gauge.

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

The test shall be carried out in the angular positions a), b) and c), if possible, of the A'-axis.

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

For 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 C'-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 C'-axis (table rotation) 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 measurement distance l in the X-direction, is the error to be reported.

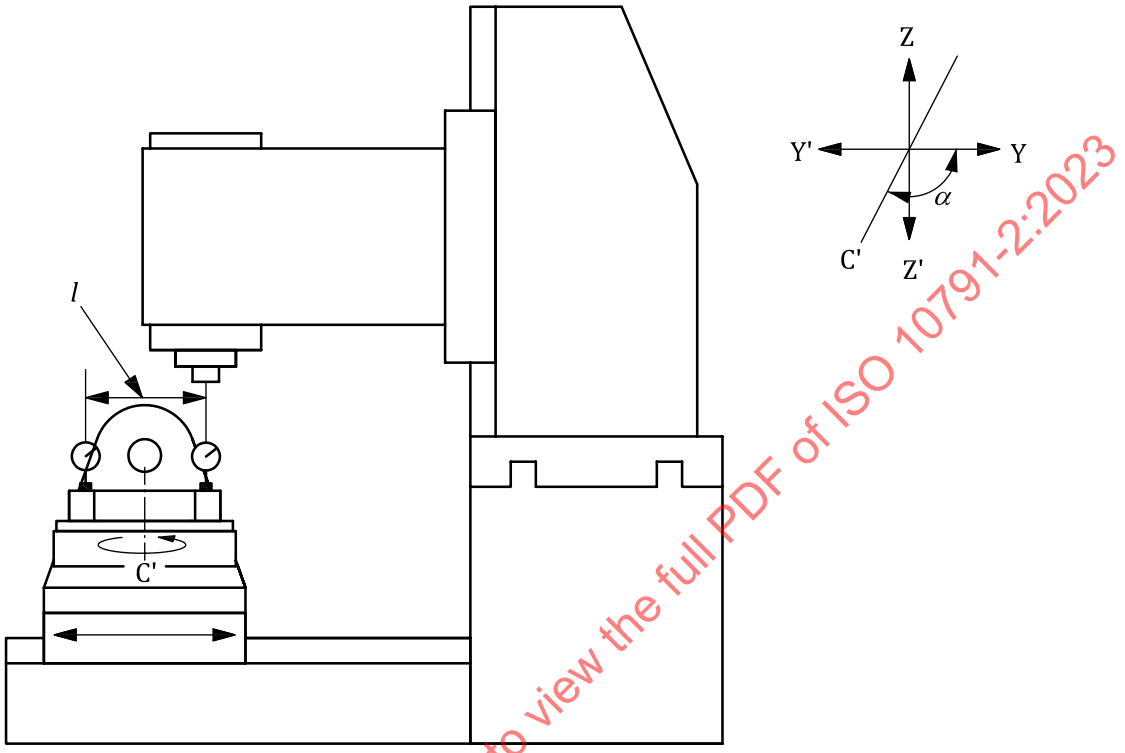
If it is difficult or unsafe for a machine operator to read the dial gauge when A' = +90°, an instrument with remote reading should be used, or G8.15 should be applied as an alternative.

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

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

In all possible angular positions of the A'-axis the measured error is positive when $\alpha > 90°$ and is negative when $\alpha < 90°$.

As an alternative, this squareness can be evaluated by test BK 2 b) from ISO 10791-6:2014.

Object	**G8.7**
Checking of $E_{A(0Y)C', A' = 0}$ squareness of the C'-axis (table rotation), with the table in the horizontal position (A' = 0°), to the Y-axis motion.	
Diagram  **Key** *l* measurement distance	
Tolerance 0,040/1 000 (= 0,020/500, or 40 µrad or 8")	
Measured error	
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 C'-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 C'-axis (table rotation) 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 measurement distance l in the Y-direction, is the error to be reported.

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

The measured error $E_{A(0Y)C', A' = 0}$ is positive when $\alpha > 90°$ and is negative when $\alpha < 90°$.

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

This test can be influenced by the E_{ZY} vertical straightness error of the Y-axis.

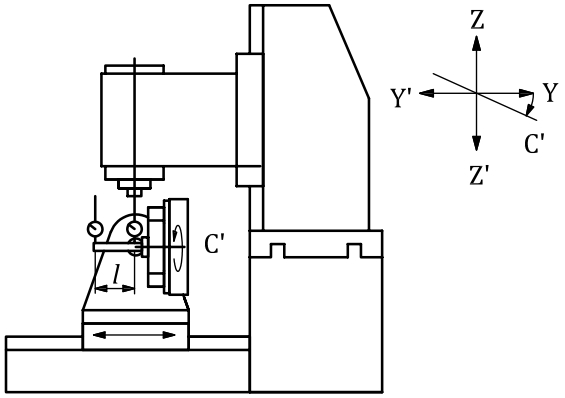
As an alternative, this squareness can be evaluated by test BK 2 b) from ISO 10791-6:2014.

Object	**G8.8**
Checking of parallelism of the C'-axis (table rotation) to the Y-axis motion, in the possible vertical positions of the table (depending on the machine configuration):	
a) with the table in the vertical position at A' = –90°	b) with the table in the vertical position at A' = +90°
1) in the vertical YZ plane $E_{A(0Y)C',\ A'=-90}$,	1) in the vertical YZ plane $E_{A(0Y)C',\ A'=+90}$,
2) in the horizontal XY plane $E_{C(0Y)C',\ A'=-90}$,	2) in the horizontal XY plane $E_{C(0Y)C',\ A'=+90}$;

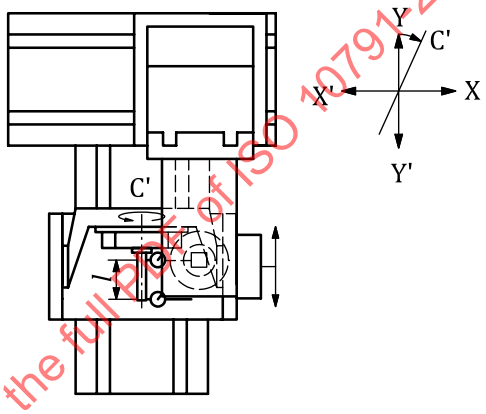
Diagram

a) A' = –90°

1) YZ plane

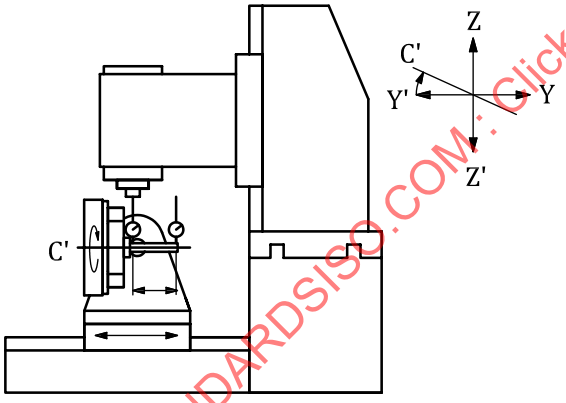


2) XY plane

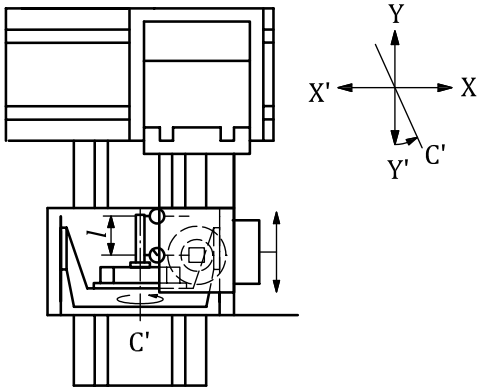


b) A' = +90°

1) YZ plane



2) XY plane



Key

l measurement distance

Tolerance

For a) and b): 0,050/1 000 (= 0,025/500, or 50 µrad or 10")

Measured error

a1) b1)

a2) b2)

Measuring instruments

Cylindrical square with flange base and dial gauge or optical instruments.

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

For a1) and b1) Z-axis to be locked, if possible. The result of tests a1) and b1) include the possible $E_{AA'}$ positioning error of the A'-axis at –90° or +90°.

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

The following steps shall be followed.

Step 1) Fix a cylindrical square with a flange base on the table and centre it approximately on the C'-axis of rotation.

Step 2) Fix the dial gauge on the spindle, if it can be locked, or on the spindle head, with the stylus oriented in the Z-axis direction for a1) and b1) and X-axis direction for a2) and b2).

Step 3) Touch the cylindrical square by the stylus, close to the cylinder bottom, and find the maximum dial gauge reading by small movements along the X-axis for a1) and b1) and along the Z-axis for a2) and b2). Zero the dial gauge.

Step 4) Move the head apart from the table along the Y-axis, and touch again the cylinder close to its top. Note the Y-axis travel length. Find the maximum dial gauge reading by small movements along the X-axis for a1) and b1) and along the Z-axis for a2) and b2), and note the new dial gauge reading.

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

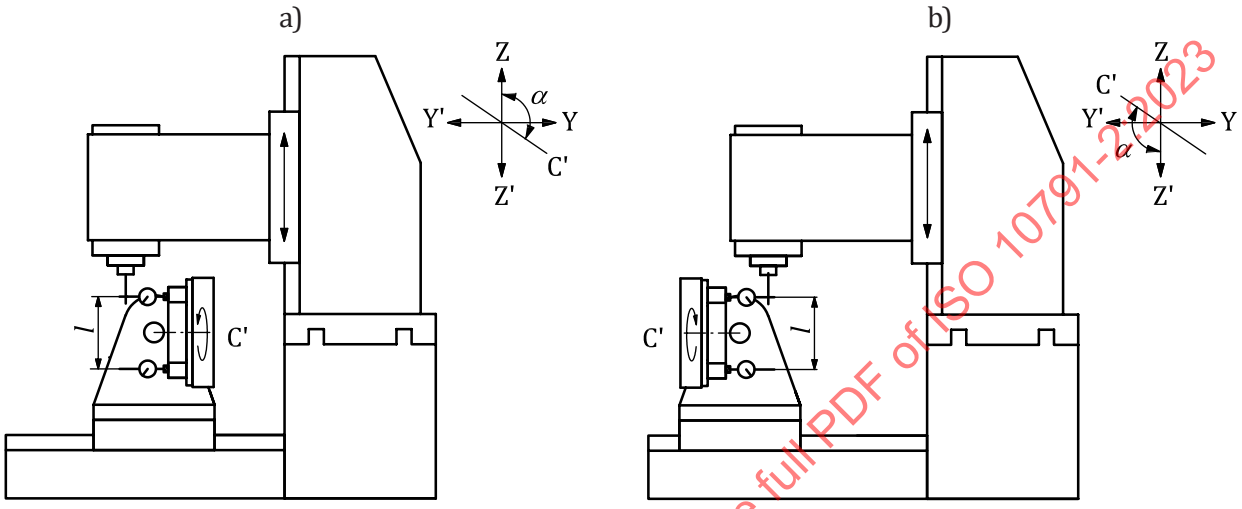
If it is difficult or unsafe for a machine operator to read the dial gauge when A' = +90°, an instrument with remote reading should be used, or G8.15 should be applied as an alternative.

For all measurements, the average value (half the algebraic sum) of the two dial gauge readings on top of the cylinder, divided by the measurement distance l in the Y direction, is the error to be reported.

For all angular positions of the A'-axis, the arrow between the C'-axis and the Y-axis shows the positive direction of the error.

Object	**G8.9**
Checking of squareness of the C'-axis (table rotation) to the Z-axis motion in the possible vertical positions of the table (depending on the machine configuration): a) A' = –90° ($E_{A(0Z)C',A'=-90}$), b) A' = +90° ($E_{A(0Z)C',A'=+90}$).	

Diagram



Key

l measurement distance

Tolerance

For a) and b): 0,040/1 000 (= 0,020/500, or 40 µrad or 8")

Measured error

a) b)

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 C'; 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 C'-axis (table rotation) 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 measurement distance *l* in the Z-direction, is the error to be reported.

If it is difficult or unsafe for a machine operator to read the dial gauge when A' = +90°, an instrument with remote reading should be used.

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

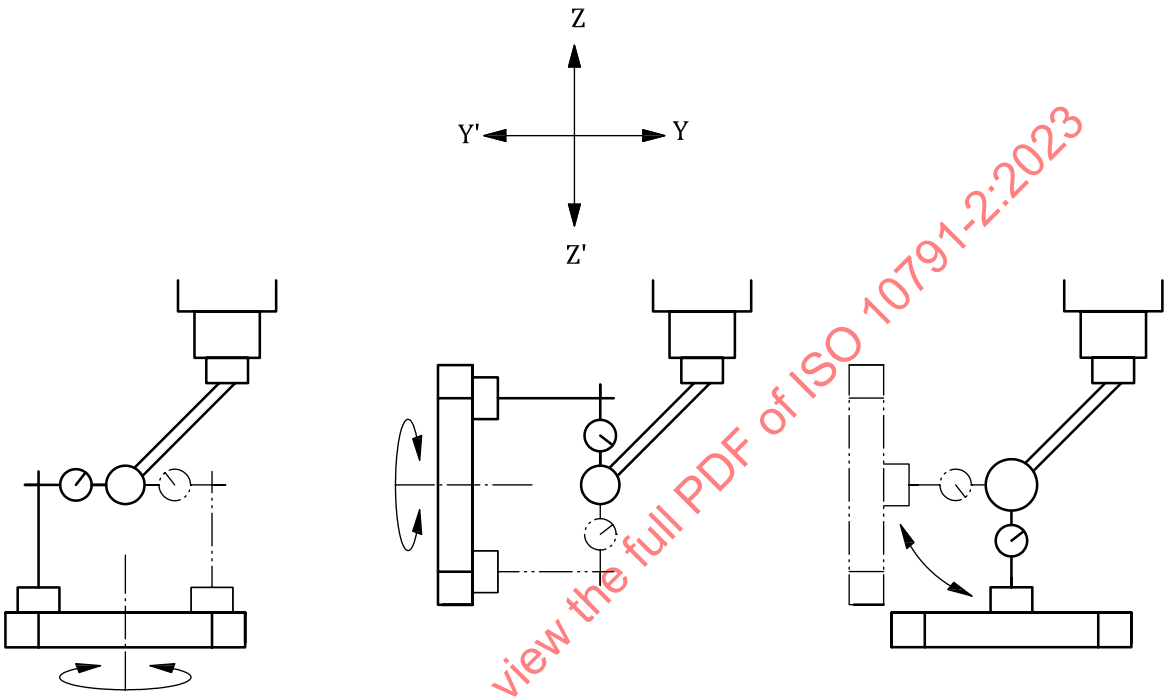
In both angular positions of the A'-axis the measured error $E_{A(0Z)C'}$ is positive when $\alpha > 90°$ and is negative when $\alpha < 90°$.

The result of this test includes the possible $E_{AA'}$ positioning error of the A'-axis at –90° or +90°.

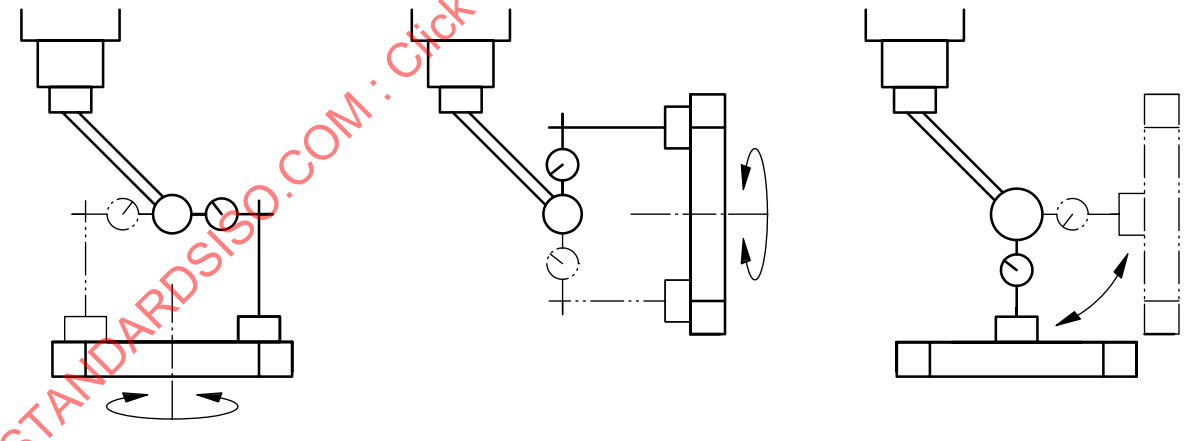
This test can be influenced by the straightness error of the Z-axis in the YZ-plane, E_{YZ}.

Object	**G8.10**
Checking of intersection of the C'-axis (table rotation) with the A'-axis (cradle tilting) for table surfaces lower than the A'-axis, $E_{Y(0A')C',\,A'=0}$ (only for machines with nominally zero offset between A' and C'-axis and without compensation facilities for any offset error)	

Diagram



2) A' = 0° 4) A' = +90° 7) A' = 0° to +90°



2) A' = 0° 4) A' = −90° 7) A' = 0° to −90°

NOTE The sketch shows steps 2), 4) and 7) of the test procedure specified in the observations.

Tolerance

0,030

Measured error

Measuring instruments

Test sphere and dial gauge.

Observations and references to ISO 230-1:2012, 10.4.3	
Step 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.
Step 2)	With the table in horizontal position (A' = 0°), align the C'-axis (table rotation) on the sphere centre, by means of rotations around the C'-axis and adjustments along the X- and Y-axes.
Step 3)	Lock the X- and Y-axes, if possible.
Step 4)	Turn the table to the vertical position (A' = −90°, or A' = +90°, depending on the machine configuration) and again align the C'-axis (table rotation) on the sphere centre, by means of rotations around the C'-axis and adjustments along the Z-axis.
Step 5)	Lock the Z-axis, if possible.
Step 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.
Step 7)	Turn the table to the vertical position (A' = −90°, or A' = +90°, depending on the machine configuration) 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 to prevent any possible reading errors due to its opposite and/or changing deflections in the different measurement positions.	

Object **G8.11**

Checking of coaxiality of the C'-axis (table rotation) to the spindle axis (C) at a predefined position of the X- and Y-axes, with the table in the horizontal position (A' = 0°):

offsets

a) $E_{Y(0(C))C',\,A'=0}$ in the vertical YZ plane,

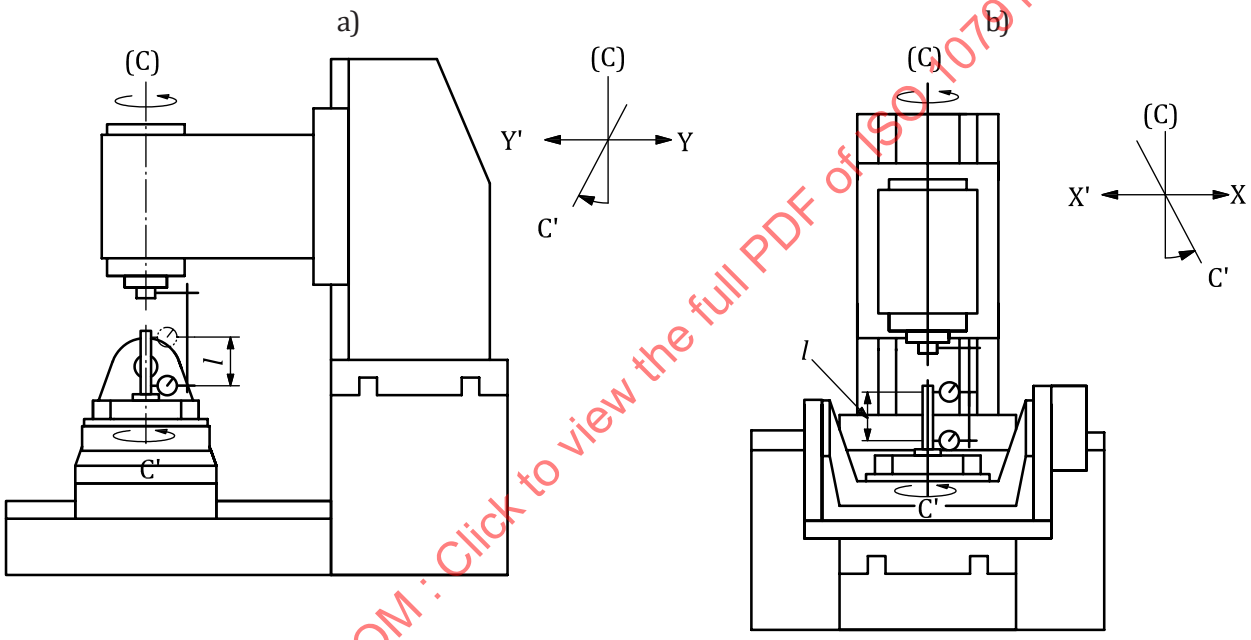
b) $E_{X(0(C))C',\,A'=0}$ in the vertical ZX plane,

and parallelism

a) $E_{A(0(C))C',\,A'=0}$ in the vertical YZ plane,

b) $E_{B(0(C))C',\,A'=0}$ in the vertical ZX plane.

Diagram



Key

l measurement distance

Tolerance

Offset in both planes a) and b):	0,015
Parallelism in both planes a) and b):	0,040/1 000 (= 0,020/500, or 40 µrad or 8")

Measured error

Offset

a) b)

Parallelism

a) b)

Measuring instruments

Cylindrical square with flange base and dial gauge.

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

Step 1) Adjust the A'-axis (cradle tilting) until the C'-axis (table rotation) is parallel to the Z-axis in the YZ plane.

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

Step 3) Fix the cylindrical square on the table, and the dial gauge in the spindle with the stylus square to the spindle axis in radial direction.

Step 4) With the dial gauge stylus oriented in the Y-axis direction for a) and in the X-axis direction for b), touch the cylindrical square, close to the bottom, and find the maximum dial gauge reading by small movements along the X-axis for a) and along the Y-axis for b). Zero the dial gauge.

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

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

In both planes a) and b), half of the new reading on the dial gauge represents the offset between the two axes of rotation at the bottom of the cylindrical square.

Step 7) Without moving the Z-axis (see NOTE), repeat the measurements close to the top of the cylindrical square.

In both planes a) and b), half of the new reading on the dial gauge represents the offset between the two axes of rotation at the top of the cylindrical square.

The coaxiality error contains both offset and parallelism errors.

In both planes a) and b), the offset error is the one measured at the bottom of the cylindrical square, and the parallelism error is the difference between the two offsets at the bottom and at the top, divided by the measurement distance l in the Z-direction.

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

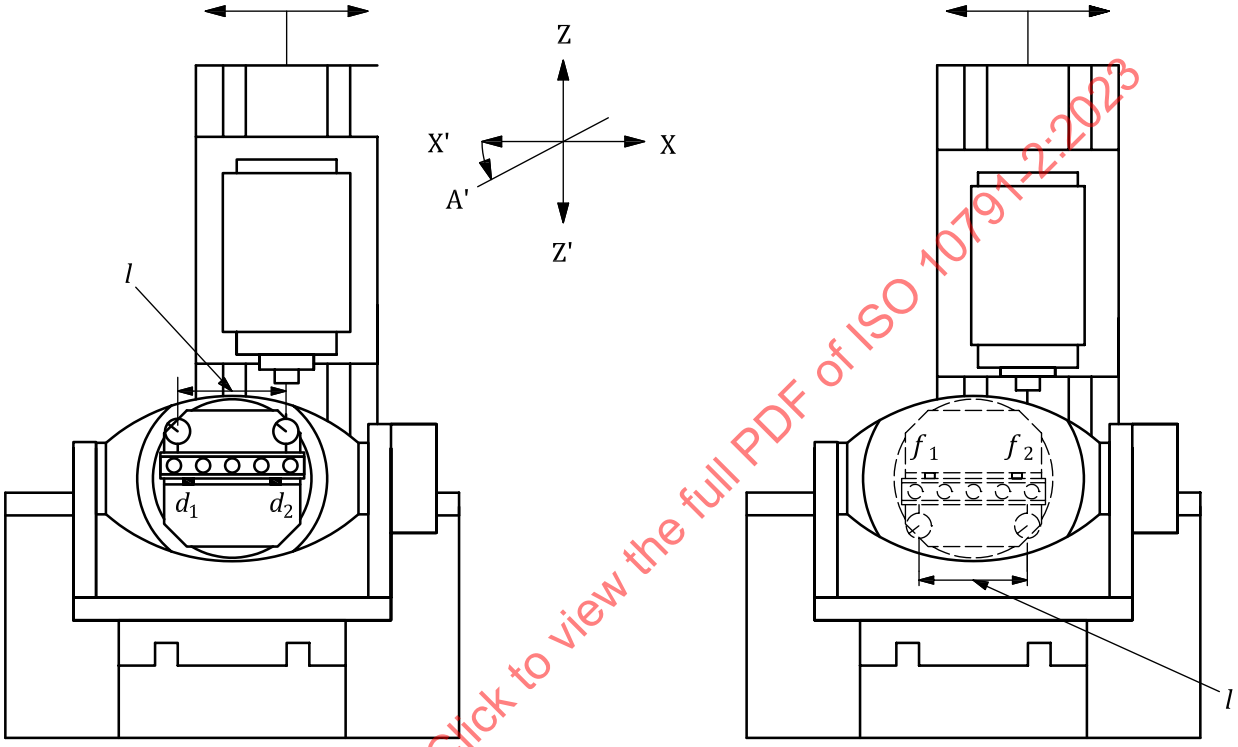
In both planes, the arrow between the C'-axis and the spindle axis (C) shows the positive direction of the error.

NOTE If this test were carried out in different positions of the Z-axis it would be affected by the parallelism errors between the spindle axis (C) and the Z-axis and between the C'-axis (table rotation) and the Z-axis, in both YZ and ZX planes.

8.3 Tests for the A'-axis tilting from –90° to +90°

Object	**G8.12**
Checking of parallelism of the A'-axis (cradle rotation) to the X-axis motion in the vertical ZX plane, $E_{B(0X)A'}$	

Diagram



Key

d_1, d_2, f_1, f_2 readings — l measurement distance

Tolerance

0,050/1 000 (= 0,025/500, or 50 µrad or 10")

Measured error

Measuring instruments

Straightedge or gauge blocks, and dial gauge.

Observations and references to ISO 230-1

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. The stylus of the dial gauge shall be placed approximately in the working position of the tool.

With the same setup used for G8.4, when a reference T-slot or a tenon slot is provided, insert two gauge blocks in the slot, at a distance l from each other. The measurement may also be made on a straightedge laid parallel to the reference T-slot, or longitudinal edge locator.

When neither the reference T-slot, nor edge locators are present, a straightedge shall be aligned approximately parallel to the X-axis. If a straightedge is used, it shall be safely fixed to the table, in order to allow the readings to be taken in both angular positions of the A'-axis.

For the measurement $(d_2 - d_1)$, the dial gauge shall be oriented downward, and for measurement $(f_2 - f_1)$ the dial gauge shall be oriented upward, in order to touch the same side of the straightedge or gauge blocks.

If it is difficult or unsafe for a machine operator to read the dial gauge when A' = +90°, an instrument with remote reading should be used, or G8.15 should be applied as an alternative. Note the readings and the distance l between the two readings. The algebraic sign of the readings shall be carefully noted.

The error to be reported is $E_{B(0X)A'} = 1/2(\Delta d - \Delta f)/l = 1/2[(d_2 - d_1) - (f_2 - f_1)]/l$.

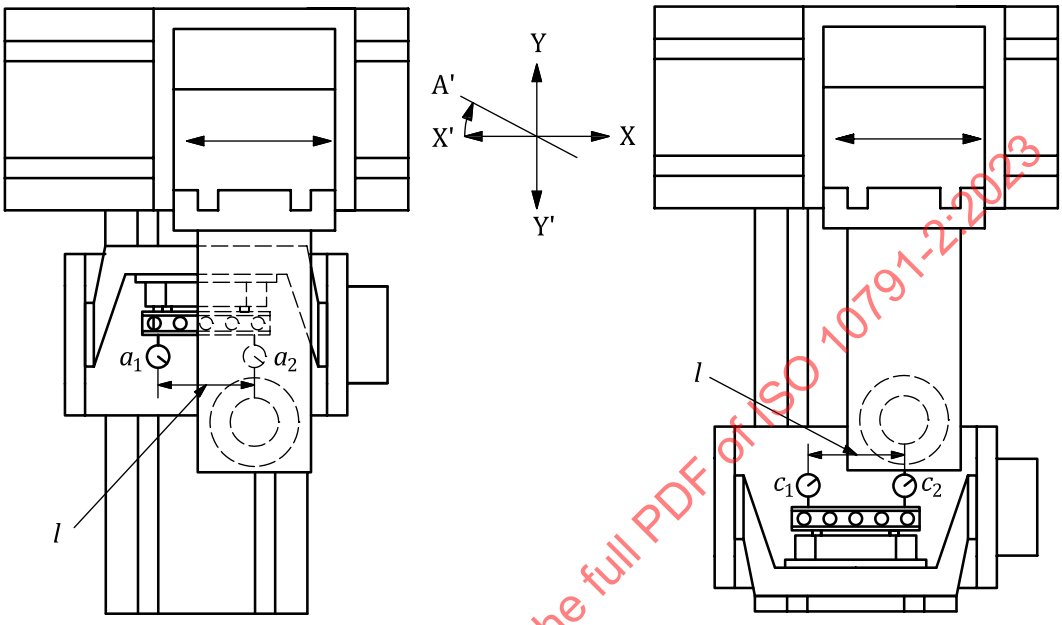
The algebraic sign of the results $\Delta d = (d_2 - d_1)$ and $\Delta f = (f_2 - f_1)$ is positive when the reading in point 2 is greater than in point 1, i.e. when the straightedge in point 2 is closer to the dial gauge than in point 1.

The arrow between the A'-axis and the X-axis shows the positive direction of the $E_{B(0X)A'}$ error.

NOTE Half sum of the two readings "Δf" and "Δd", i.e. their algebraic average, out from the object of this test, shows the opposite of the parallelism error of the reference line L (represented by the straightedge, or T-slot) to the A'-axis, which affects the readings in G8.4.

Object	**G8.13**
Checking of parallelism of the A'-axis (cradle rotation) to the X-axis motion in the horizontal XY plane, $E_{C(0X)A'}$.	

Diagram



Key

a_1, a_2, c_1, c_2 readings — l measurement distance

Tolerance

0,050/1 000 (= 0,025/500, or 50 µrad or 10")

Measured error

Measuring instruments

Straightedge or gauge blocks and dial gauge.

Observations and references to ISO 230-1

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.

The stylus of the dial gauge shall be placed approximately in the working position of the tool.

With the same setup used for G8.3, place a straightedge on the table, approximately parallel to the table surface, safely fixed to the table, in order to allow the readings to be taken in both angular positions of the A'-axis.

If the table is newly ground, the dial gauge stylus may directly touch the table surface.

If it is difficult or unsafe for a machine operator to read the dial gauge when A' = +90°, an instrument with remote reading should be used, or G8.15 should be applied as an alternative.

Note the readings and the distance l between the two readings. The algebraic sign of the readings shall be carefully noted.

The error to be reported is $E_{C(0X)A'} = 1/2(\Delta a - \Delta c)/l = 1/2[(a_2 - a_1) - (c_2 - c_1)]/l$.

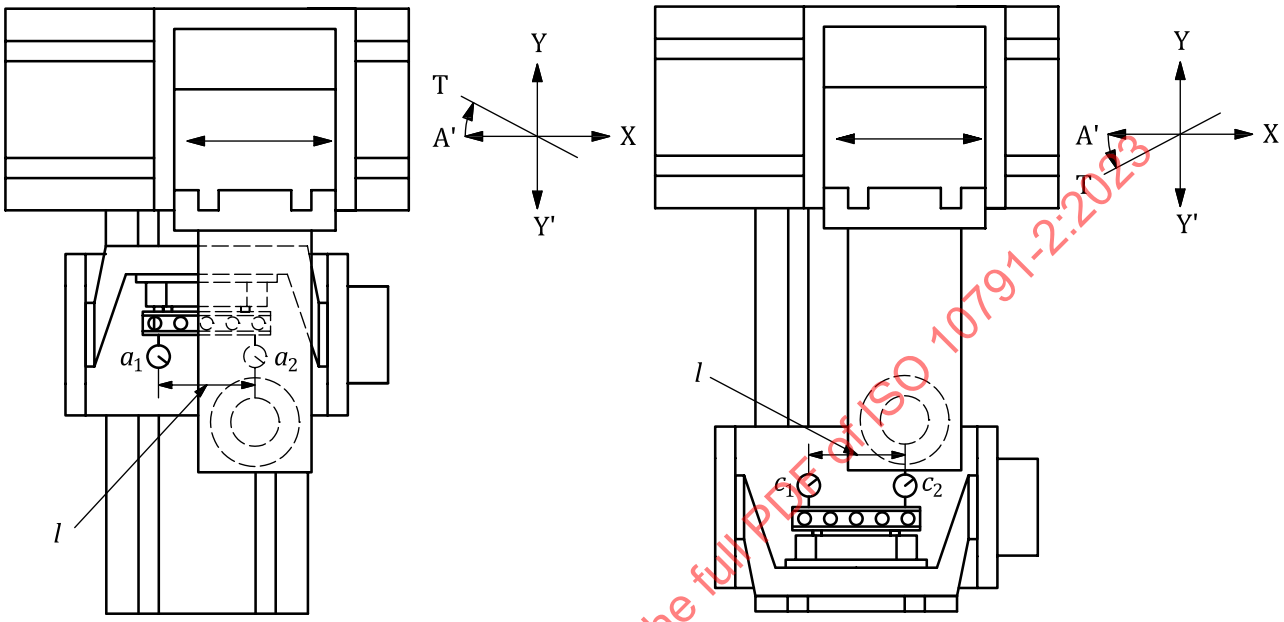
The algebraic sign of the results $\Delta a = (a_2 - a_1)$ and $\Delta c = (c_2 - c_1)$ is positive when the reading in point 2 is greater than in point 1, i.e. when the straightedge in point 2 is closer to the dial gauge than in point 1.

The arrow between the A'-axis and the X-axis shows the positive direction of the $E_{C(0X)A'}$ error.

NOTE The half sum of the two readings "Δa" and "Δc", i.e. their algebraic average, out from the object of this test, shows the parallelism error of the table representative line T to the A'-axis, which is the object of G8.14.

Object	**G8.14**
Checking of parallelism of a representative line T of the table surface to the A'-axis (cradle rotation), $E_{B(0A')T}$.	

Diagram



Key

a_1, a_2, c_1, c_2 readings

l measurement distance

Tolerance

0,025 over a measuring length of 500.

Measured error

Measuring instruments

Straightedge or gauge blocks and dial gauge.

Observations and references to ISO 230-1

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.

The stylus of the dial gauge shall be placed approximately in the working position of the tool.

With the same setup used for G8.3, place a straightedge on the table, approximately parallel to the table surface, safely fixed to the table, in order to allow the readings to be taken in both angular positions of the A'-axis.

If the table is newly ground, the dial gauge stylus may directly touch the table surface.

If it is difficult or unsafe for a machine operator to read the dial gauge when A' = +90°, an instrument with remote reading should be used, or G8.16 should be applied as an alternative.

Note the readings and the distance l between the two readings.

The algebraic sign of the readings shall be carefully noted.

The error to be reported is $E_{B(OA')T} = 1/2(\Delta a + \Delta c) = 1/2[(a_2 - a_1) + (c_2 - c_1)]$.

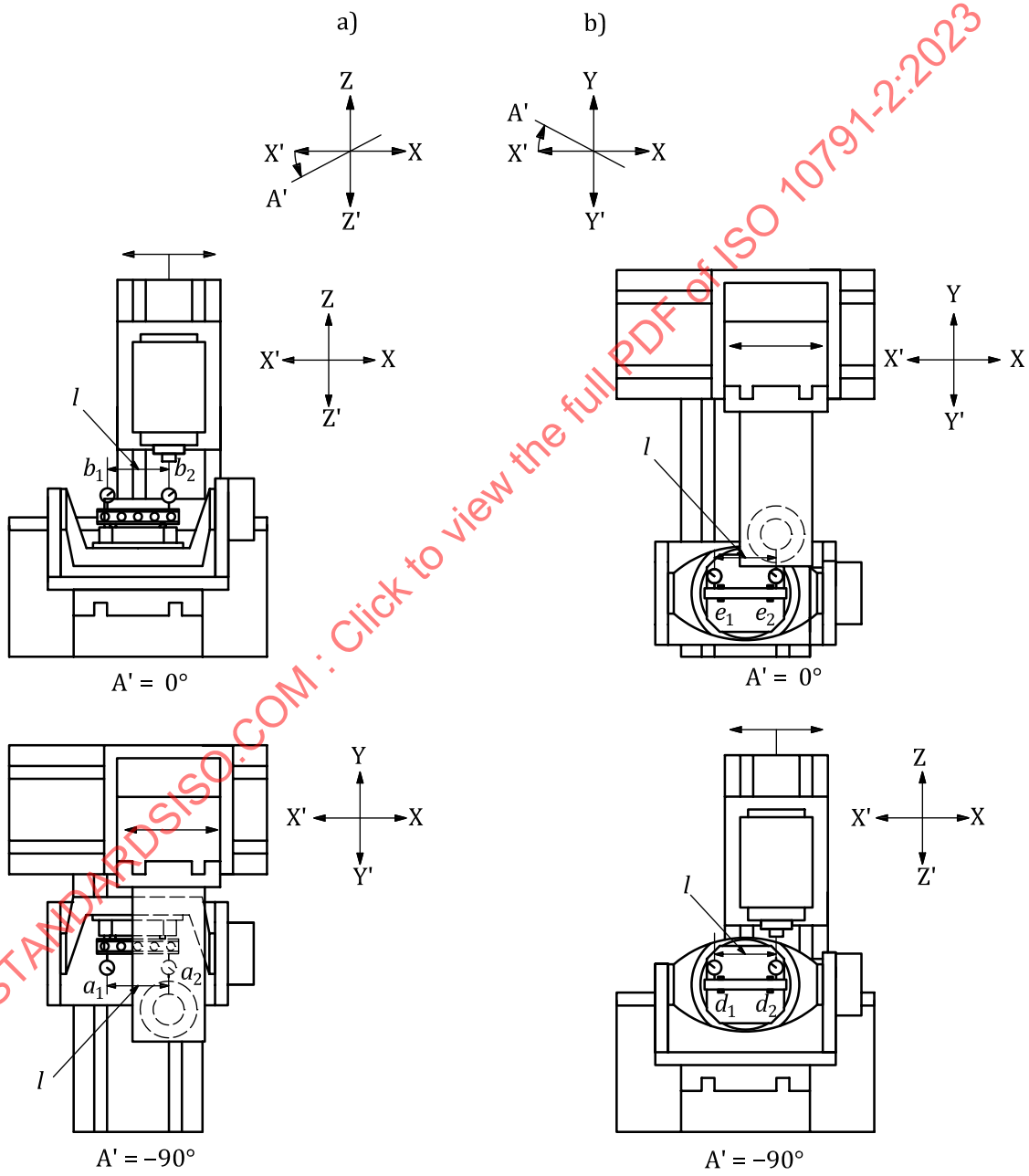
The algebraic sign of the results $\Delta a = (a_2 - a_1)$ and $\Delta c = (c_2 - c_1)$ is positive when the reading in point 2 is greater than in point 1, i.e. when the straightedge in point 2 is closer to the dial gauge than in point 1.

The arrow between the table representative line T and the A'-axis shows the positive direction of the $E_{B(0A')T}$ error.

8.4 Tests for the A'-axis tilting from –90° to 0°

Object	**G8.15**
Checking of parallelism of the A'-axis (cradle rotation) to the X-axis motion: a) $E_{B(0X)A'}$ in the vertical ZX plane, b) $E_{C(0X)A'}$ in the horizontal XY plane.	

Diagram



Key

a_1, a_2, b_1, b_2, d_1, d_2, e_1, e_2 readings

l measurement distance

Tolerance

For a) and b): 0,050/1 000 (= 0,025/500, or 50 µrad or 10”)

Measured error

a) b)

Measuring instruments

Straightedge or gauge blocks and dial gauge.

Observations and references to ISO 230-1

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.

The stylus of the dial gauge shall be placed approximately in the working position of the tool.

For measurements $(a_2 - a_1)$ and $(b_2 - b_1)$ with the same procedure used for G8.3 (without moving A’ to +90°, which is not possible), place a straightedge on the table, approximately parallel to the table surface, safely fixed to the table, in order to allow the readings to be taken in both angular positions of the A’-axis.

If the table is newly ground, the dial gauge stylus may directly touch the table surface.

Take the results $\Delta a = (a_2 - a_1)$ and $\Delta b = (b_2 - b_1)$.

For measurements $(d_2 - d_1)$ and $(e_2 - e_1)$ with the same procedure used for G8.4 (without moving A’ to +90°, which is not possible), when a reference T-slot or a tenon slot is provided, insert two gauge blocks in the slot, at a distance l from each other.

The measurement may also be made on a straightedge laid parallel to the reference T-slot, or longitudinal edge locator.

When neither the reference T-slot, nor edge locators are present, a straightedge shall be aligned approximately parallel to the X-axis. If a straightedge is used, it shall be safely fixed to the table, in order to allow the readings to be taken in both angular positions of the A’-axis.

Take the results $\Delta d = (d_2 - d_1)$ and $\Delta e = (e_2 - e_1)$.

The algebraic sign of the readings shall be carefully noted.

The measurement distance l shall be the same for all readings.

In both planes the arrow between the A’-axis and the X-axis shows the positive direction of the error.

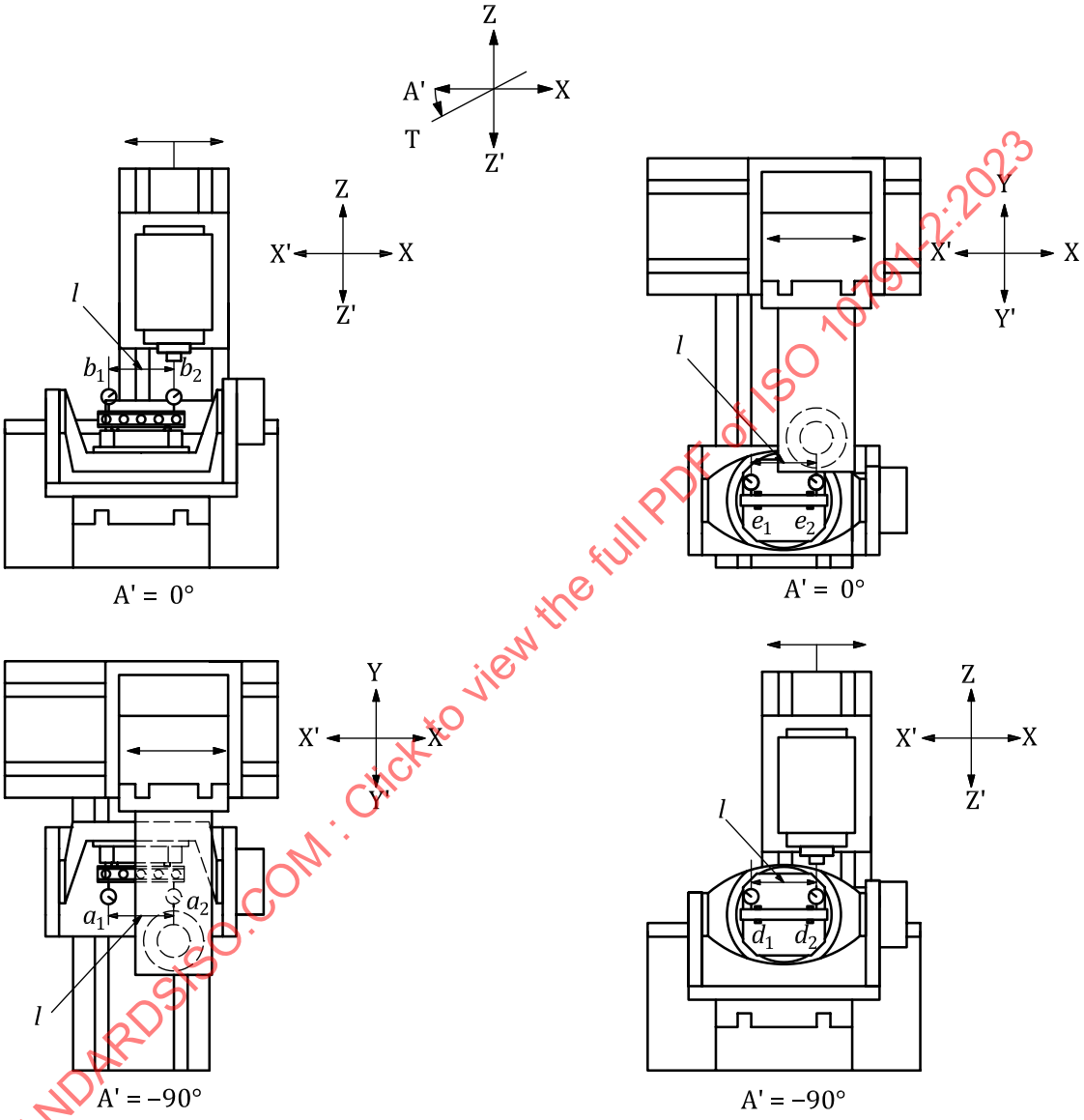
a) The parallelism error in the vertical ZX plane is: $E_{B(OX)A'} = 1/2\ (-\Delta a + \Delta b + \Delta d - \Delta e)/l$.

b) The parallelism error in the horizontal XY plane is: $E_{C(OX)A'} = 1/2\ (\Delta a - \Delta b + \Delta d - \Delta e)/l$.

The results of tests G8.15 and G8.16 are determined separately by the formulae shown in each test.

Object	**G8.16**
Checking of parallelism of a representative line T of the table surface to the A'-axis (cradle rotation) $E_{B(0A')T}$.	

Diagram



Key

a_1, a_2, b_1, b_2, d_1, d_2, e_1, e_2 readings — l measurement distance

Tolerance
0,025 over a measuring length of 500
Measured error
Measuring instruments
Straightedge or gauge blocks and dial gauge.

Observations and references to ISO 230-1

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.

The stylus of the dial gauge shall be placed approximately in the working position of the tool.

The straightedge shall be placed on the table, approximately parallel to the table surface, safely fixed to the table, in order to allow the readings to be taken in both angular positions of the A'-axis.

For this test, setup and test procedure of G8.15 shall be used (without moving A' to +90°, which is not possible).

Take the results $\Delta a = (a_2 - a_1)$ and $\Delta b = (b_2 - b_1)$.

Take the results $\Delta d = (d_2 - d_1)$ and $\Delta e = (e_2 - e_1)$.

The algebraic sign of the readings shall be carefully noted.

The measurement distance l shall be the same for all readings.

The parallelism error of the table representative line T to the A'-axis is:
$E_{B(0A')T} = 1/2\ (\Delta a + \Delta b - \Delta d + \Delta e)$.

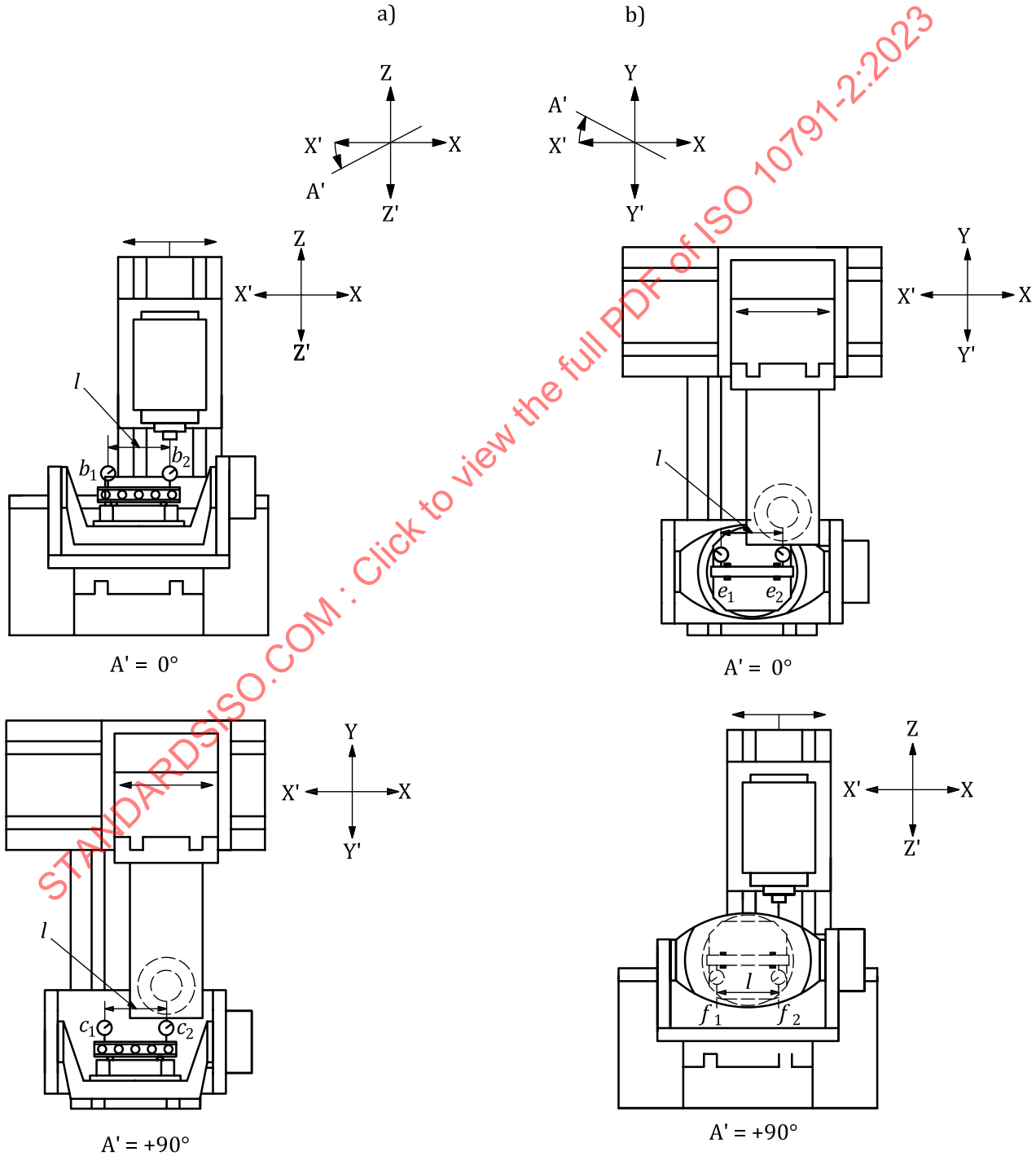
The arrow between the table representative line T and the A'-axis shows the positive direction of the $E_{B(0A')T}$ error.

The results of tests G8.15 and G8.16 are determined separately by the formulae shown in each test.

8.5 Tests for the A'-axis tilting from 0° to +90°

Object	**G8.17**
Checking of parallelism of the A'-axis (cradle rotation) to the X-axis motion: a) $E_{B(0X)A'}$ in the vertical ZX plane, b) $E_{C(0X)A'}$ in the horizontal XY plane.	

Diagram



Key

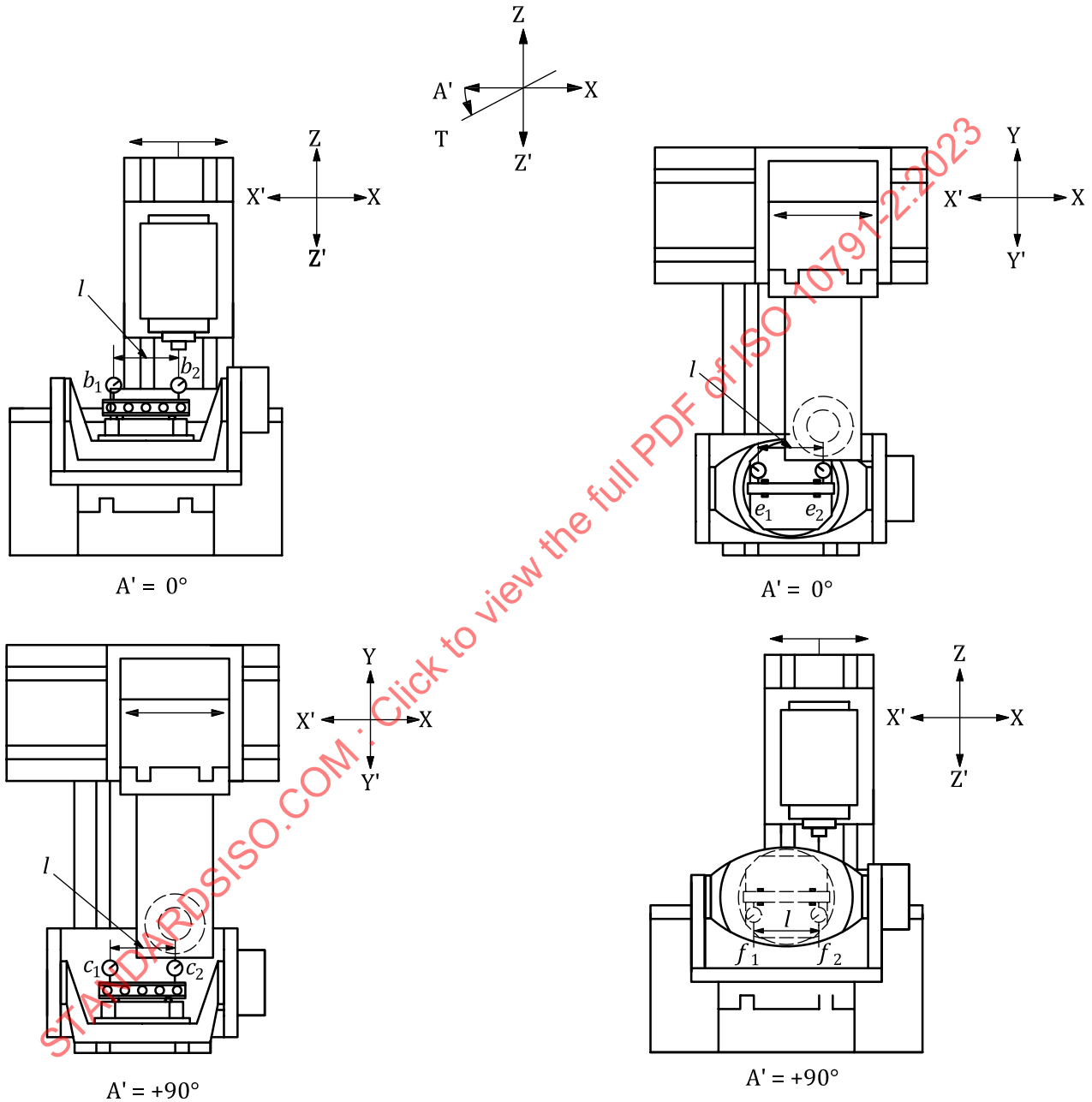
$b_1, b_2, c_1, c_2, e_1, e_2, f_1, f_2$ readings

l measurement distance

Tolerance
For a) and b): 0,050/1 000 (= 0,025/500, or 50 µrad or 10”)
Measured error
a) b)
Measuring instruments
Straightedge or gauge blocks and dial gauge.
Observations and references to ISO 230-1
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.
The stylus of the dial gauge shall be placed approximately in the working position of the tool.
For measurements ($b_2 - b_1$) and ($c_2 - c_1$) with the same procedure used for G8.3 (without moving A’ to −90°, which is not possible), place a straightedge on the table, approximately parallel to the table surface, safely fixed to the table, in order to allow the readings to be taken in both angular positions of the A’-axis.
If the table is newly ground, the dial gauge stylus may directly touch the table surface.
Take the results $\Delta b = (b_2 - b_1)$ and $\Delta c = (c_2 - c_1)$.
For measurements ($e_2 - e_1$) and ($f_2 - f_1$) with the same procedure used for G8.4 (without moving A’ to −90°, which is not possible), when a reference T-slot or a tenon slot is provided, insert two gauge blocks in the slot, at a distance l from each other.
The measurement may also be made on a straightedge laid parallel to the reference T-slot or longitudinal edge locator.
When neither the reference T-slot, nor edge locators are present, a straightedge shall be aligned approximately parallel to the X-axis. If a straightedge is used, it shall be safely fixed to the table, in order to allow the readings to be taken in both angular positions of the A’-axis.
For the measurement ($f_2 - f_1$), the dial gauge shall be oriented upward, in order to touch the bottom side of the straightedge or gauge blocks.
If it is difficult or unsafe for a machine operator to read the dial gauge when A’ = +90°, an instrument with remote reading should be used, or G8.15 should be applied as an alternative.
Take the results $\Delta e = (e_2 - e_1)$ and $\Delta f = (f_2 - f_1)$.
The algebraic sign of the readings shall be carefully noted.
The measurement distance l shall be the same for all readings.
In both planes the arrow between the A’-axis and the X-axis shows the positive direction of the error.
a) The parallelism error in the vertical ZX plane is: $E_{B(OX)A'} = 1/2\ (\Delta b - \Delta c + \Delta e - \Delta f)/l$.
b) The parallelism error in the horizontal XY plane is: $E_{C(OX)A'} = 1/2\ (\Delta b - \Delta c - \Delta e + \Delta f)/l$.
The results of tests G8.17 and G8.18 are determined separately by the formulae shown in each test.

Object	**G8.18**
Checking of parallelism of a representative line T of the table surface to the A'-axis (cradle rotation), $E_{B(0A')T}$.	

Diagram



Key

$b_1, b_2, c_1, c_2, e_1, e_2, f_1, f_2$ readings — l measurement distance

Tolerance
0,025 over a measuring length of 500.
Measured error
Measuring instruments
Straightedge or gauge blocks and dial gauge.

Observations and references to ISO 230-1

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.

The stylus of the dial gauge shall be placed approximately in the working position of the tool.

For this test, setup and test procedure of G8.17 shall be used (without moving A' to −90°, which is not possible).

For the measurement $(f_2 - f_1)$, the dial gauge shall be oriented upward, in order to touch the bottom side of the straightedge or gauge blocks.

If it is difficult or unsafe for a machine operator to read the dial gauge when A' = +90°, an instrument with remote reading should be used, or G8.15 should be applied as an alternative.

Take the results $\Delta b = (b_2 - b_1)$ and $\Delta c = (c_2 - c_1)$.

Take the results $\Delta e = (e_2 - e_1)$ and $\Delta f = (f_2 - f_1)$.

The algebraic sign of the readings shall be carefully noted.

The measurement distance l shall be the same for all readings.

The parallelism error of the table representative line T to the A'-axis is:
$E_{B(OA)T,A'} = 1/2\ (\Delta b + \Delta c - \Delta e + \Delta f)$.

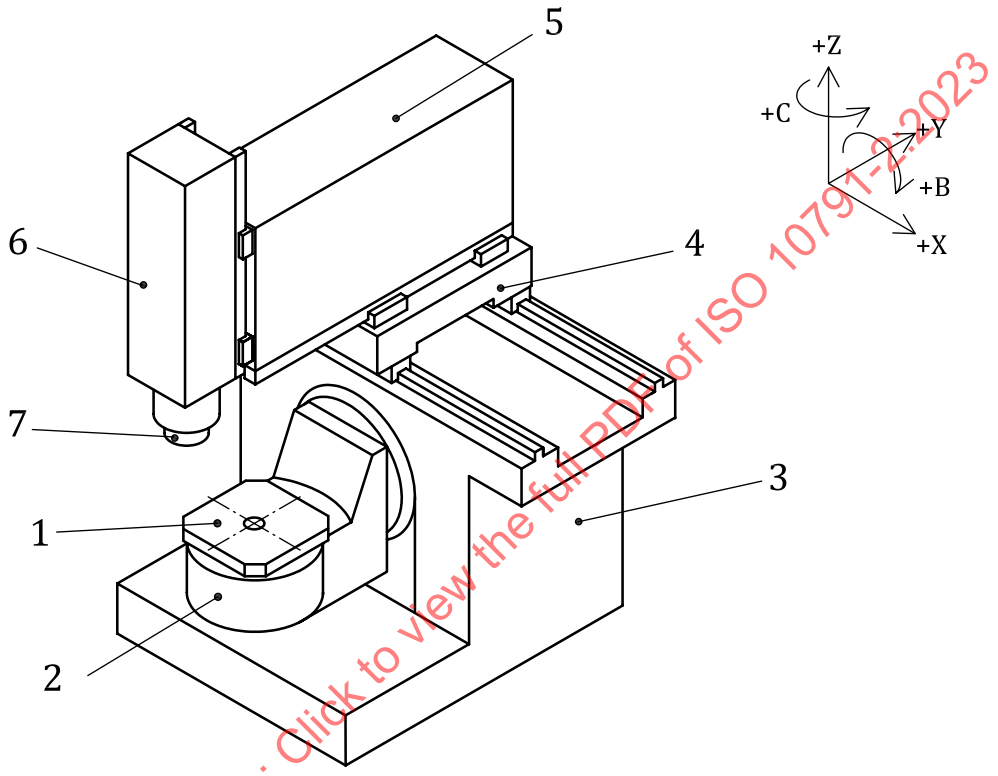
The arrow between the table representative line T and the A'-axis shows the positive direction of the $E_{B(0A')T}$ error.

The results of tests G8.17 and G8.18 are determined separately by the formulae shown in each test.

9 Tables rotating around a vertical C'-axis and tilting around a horizontal B'-axis

9.1 General

Figure 5 shows an example of a machining centre with vertical spindle and a horizontal table, rotating around a vertical C'-axis and tilting around a horizontal B'-axis.

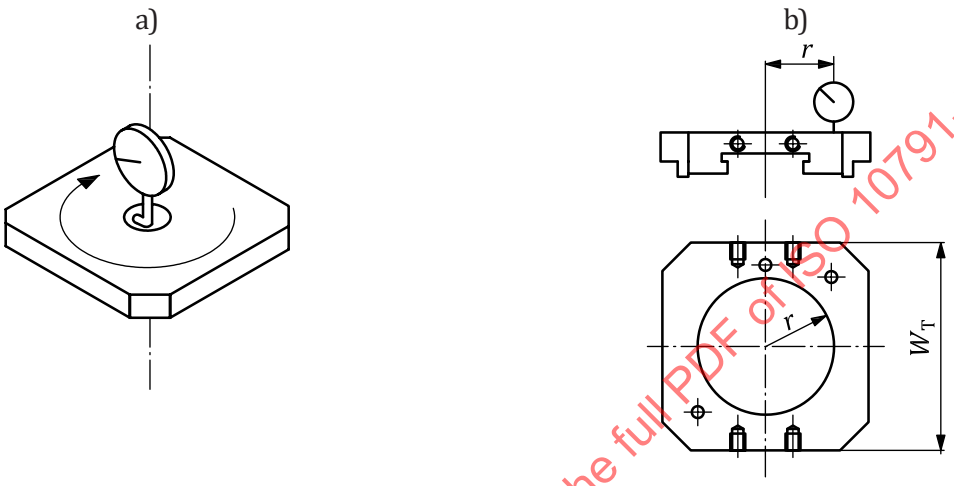


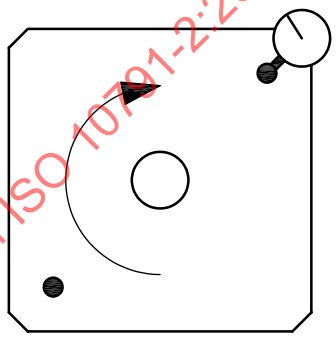
Key

1	rotary table (C'-axis)	5	cross slide (Y-axis)
2	tilting cradle (B'-axis)	6	spindle head (Z-axis)
3	bed (b)	7	spindle [(C)]
4	longitudinal slide (X-axis)		

Figure 5 — Example of vertical five-axis machining centre with a table rotating around a vertical C'-axis and tilting around a horizontal B'-axis — Machining centre ISO 10791-2 V [w C' B' b X Y Z (C) t]

9.2 Tests for rotary tables tilting around the B'-axis

Object	**G9.1**
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 table surface. NOTE This test is performed on the built-in table of the machine or on one representative pallet clamped in position.	
Diagram  	
Key W_T length of the shorter side of the table or pallet r measurement radius	
Tolerance a): 0,025 b): $W_T \leq$ 500 0,030 500 < $W_T \leq$ 800 0,040 For W_T greater than 800 mm, the tolerance shall be agreed between user and supplier/manufacturer.	
Measured error For W_T = and r = a) b)	
Measuring instruments a) Dial gauge. b) Gauge blocks and dial gauge.	
Observations and references to ISO 230-1:2012, 9.1 and ISO 230-7:2015, 5.3 and 5.4 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. For b) the radius r shall be as large as possible. Test b) may 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 AR2 in Annex A and CR1 in Annex C for radial, axial and tilt error motion tests, especially if the rotary table is foreseen for turning operations.	

Object	**G9.2**
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 C'-axis (table rotation), b) equidistance of the alignment holes with the C'-axis (table rotation). NOTE This test is performed on the built-in table of the machine or on one representative pallet clamped in position.	
Diagram a) Missing image: \\csgva.iso.ch\shares\Stand-Data\Draw\Eps\sup>\sup>-2_ed-2figG9_2a.EPS b) 	
Tolerance For a) and b): 0,030	
Measured error 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 C'-axis in order to have the T-slot parallel to the X-axis (or Y-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 C'-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 error read in a).	

Object **G9.3**

Checking of $E_{A(0Y)T}$ parallelism of a representative line T of the table surface to the Y-axis motion, in all the possible angular positions of the B'-axis (cradle tilting) among those listed hereunder and shown in the diagram:

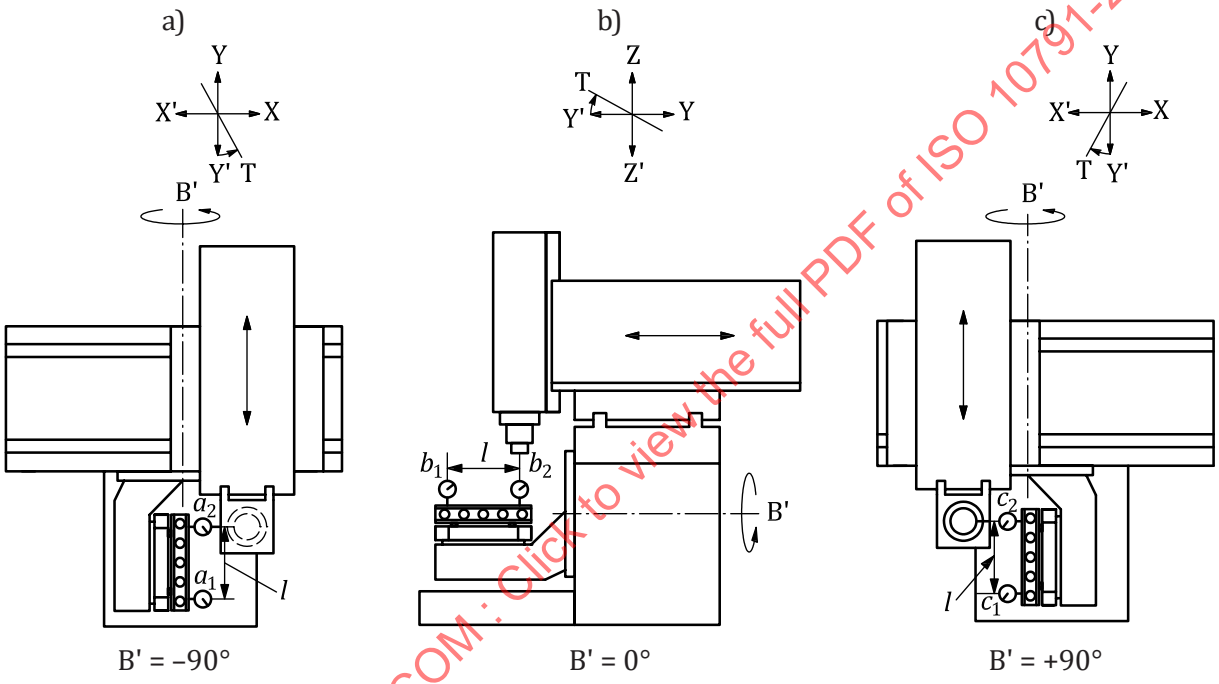
a) with the table in vertical position at B' = –90°, $E_{C(0Y)T,\ B' = -90,}$

b) with the table in horizontal position at B' = 0°, $E_{A(0Y)T,\ B' = 0,}$

c) with the table in vertical position at B' = +90°, $E_{C(0Y)T,\ B' = +90;}$

NOTE This test is performed on the built-in table of the machine or on one representative pallet clamped in position.

Diagram



Key

a_1, a_2, b_1, b_2, c_1, c_2 readings l measurement distance

Tolerance

For a), b) and c):

	l	≤	500	0,020	over a measuring length of 500
500	< l	≤	800	0,025	over a measuring length of 500

For l greater than 800 mm the tolerance shall be agreed between supplier/manufacturer and user.

Measured error

For l = ...

a) $-(a_2 - a_1)$ = b) $-(b_2 - b_1)$ = c) $-(c_2 - c_1)$ =

Measuring instruments

Straightedge, gauge blocks, and dial gauge.

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

The test shall be carried out in the angular positions a), b) and c), if possible, of the B'-axis.

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

For b), Z-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.

The stylus of the dial gauge shall be placed approximately in the working position of the tool. The measurement may be made on a straightedge laid parallel to the table surface.

If the table is newly ground, the dial gauge stylus may directly touch the table surface.

If a straightedge is used, it shall be safely fixed to the table, in order to allow the readings to be taken in all the possible angular positions of the B'-axis.

The algebraic sign of the readings shall be carefully noted.

The algebraic sign of the results $\Delta a = (a_2 - a_1)$, $\Delta b = (b_2 - b_1)$ and $\Delta c = (c_2 - c_1)$ is positive when the reading in point 2 is greater than in point 1, i.e. when the straightedge in point 2 is closer to the dial gauge than in point 1.

Note the readings and the distance l between the two readings.

The results Δa, Δb and Δc, with their algebraic signs, are the errors to be reported.

In all angular positions of the B'-axis, the arrow between the table representative line T and the X-axis shows the positive direction of the $E_{A(0Y)T}$ error.

The setup of G9.3 can be used for tests G9.13 to G9.18.

Object **G9.4**

Checking of parallelism of the reference line L, represented by:

— the transverse median or reference T-slot (if existing), or

— the transverse edge locator of the table

to the Y-axis motion, in all the possible angular positions of the B'-axis (cradle tilting) among those listed hereunder and shown in the diagram:

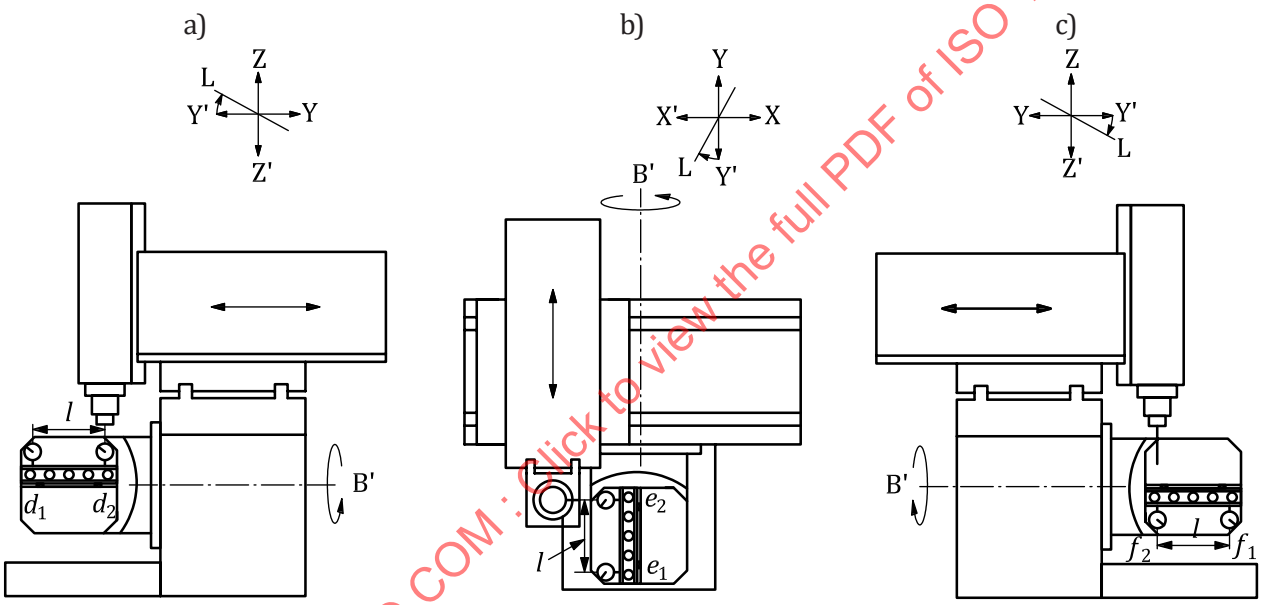
a) with the table in vertical position at B' = −90°, $E_{A(0Y)L,\ B'=-90}$,

b) with the table in horizontal position position at B' = 0°, $E_{C(0Y)L,\ B'=0}$, and

c) with the table in vertical position at B' = +90°, $E_{A(0Y)L,\ B'=+90}$.

NOTE This test is performed on the built-in table of the machine or on one representative pallet clamped in position.

Diagram



B' = −90° B' = 0° B' = +90°

Key

$d_1, d_2, e_1, e_2, f_1, f_2$ readings l measurement distance

Tolerance

For all angular positions of the B'-axis: 0,025 over a measuring length of 500.

Measured error

For l = ...

a) $-(d_2 - d_1)$ = b) $-(e_2 - e_1)$ = c) $-(f_2 - f_1)$ =

Measuring instruments

Straightedge, or gauge blocks, and dial gauge.

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

The test shall be carried out in the angular positions a), b) and c), if possible, of the B'-axis.

For d) and f), Z-axis to be locked, if possible.

For e), X-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.

The stylus of the dial gauge shall be placed approximately in the working position of the tool.

When a reference T-slot or a tenon slot is provided, insert two gauge blocks in the slot, at a distance l from each other.

The measurement may also be made on a straightedge laid parallel to the reference T-slot, or transverse edge locator.

If a straightedge is used, it shall be safely fixed to the table, in order to allow the readings to be taken in all the possible angular positions of the B'-axis.

For the measurement $(d_2 - d_1)$ the dial gauge shall be oriented downward, and for measurement $(f_2 - f_1)$ the dial gauge shall be oriented upward, in order to touch the same side of the straightedge or gauge blocks.

The algebraic sign of the readings shall be carefully noted.

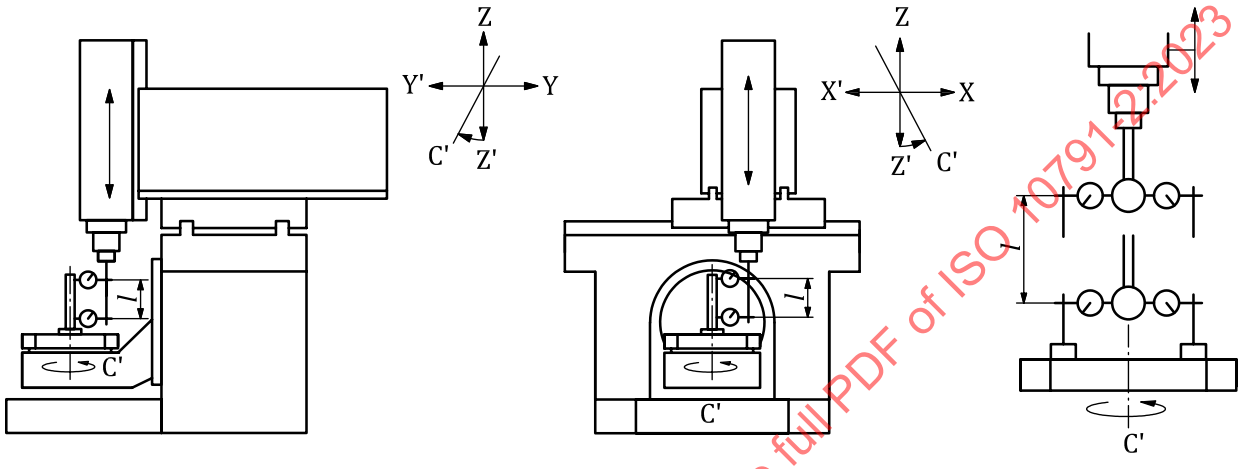
The algebraic sign of the results $\Delta d = (d_2 - d_1)$, $\Delta e = (e_2 - e_1)$, $\Delta f = (f_2 - f_1)$ is positive when the reading in point 2 is greater than in point 1, i.e. when the straightedge in point 2 is closer to the dial gauge than in point 1.

Note the readings and the distance l between the two readings.

The results Δd, Δe and Δf, with their algebraic signs, are the errors to be reported.

For all angular positions of the B'-axis the arrow between the reference line L and the Y-axis shows the positive direction of the error. The setup of G9.4 can be used for tests G9.12 and G9.15 to G9.18.

NOTE The result of this test includes the possible E_{CC} positioning error of the C'-axis at 0°, the tilt error motion $E_{CB'}$ of the B'-axis at 0° and the tilt error motion $E_{AB'}$ of the B'-axis at −90°/+90°.

Object	**G9.5**
Checking of parallelism of the C'-axis (table rotation), with the table in the horizontal position (B' = 0°), to the Z-axis motion: a) $E_{A(0Z)C'}$ in the vertical YZ plane, b) $E_{B(0Z)C'}$ in the vertical ZX plane.	
Diagram a) b) Alternative method  	
Key l measurement distance	
Tolerance For a) and b): 0,040/1 000 (= 0,020/500, or 40 µrad or 8")	
Measured error a) b)	
Measuring instruments Cylindrical square with flange base, or test sphere as an alternative, and dial gauge, or optical instruments.	
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 error of the B'-axis at 0°. Step 1) Fix a cylindrical square with a flange base on the table and centre it on approximately on the axis of rotation. Step 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). Step 3) Touch the cylindrical 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 the Y-axis for b). Zero the dial gauge. Step 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 reading. Step 5) Turn the table by 180°, and repeat steps 3) and 4). Step 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 measurement distance l in the Z direction, is the error to be reported.	

In both planes the arrow between the C'-axis and the Z-axis shows the positive direction of the error.

As an alternative, a test test sphere shall be mounted on the spindle head of the machine and the dial gauge shall be mounted on the table.

The test sphere shall be centred with respect to the C'-axis average line by moving X and Y-axes, while rotating the C'-axis.

The Z-axis shall then be moved to another location.

The dial gauge is re-positioned to read against the test sphere at this new location.

The error in the centre position shall be recorded as half the difference of the readings of the dial gauge at opposite points on the sphere, divided by the measurement distance *l* in the Z direction.

This alternative method can be used when it is possible to touch a complete horizontal circumference of the sphere.

Object	**G9.6**

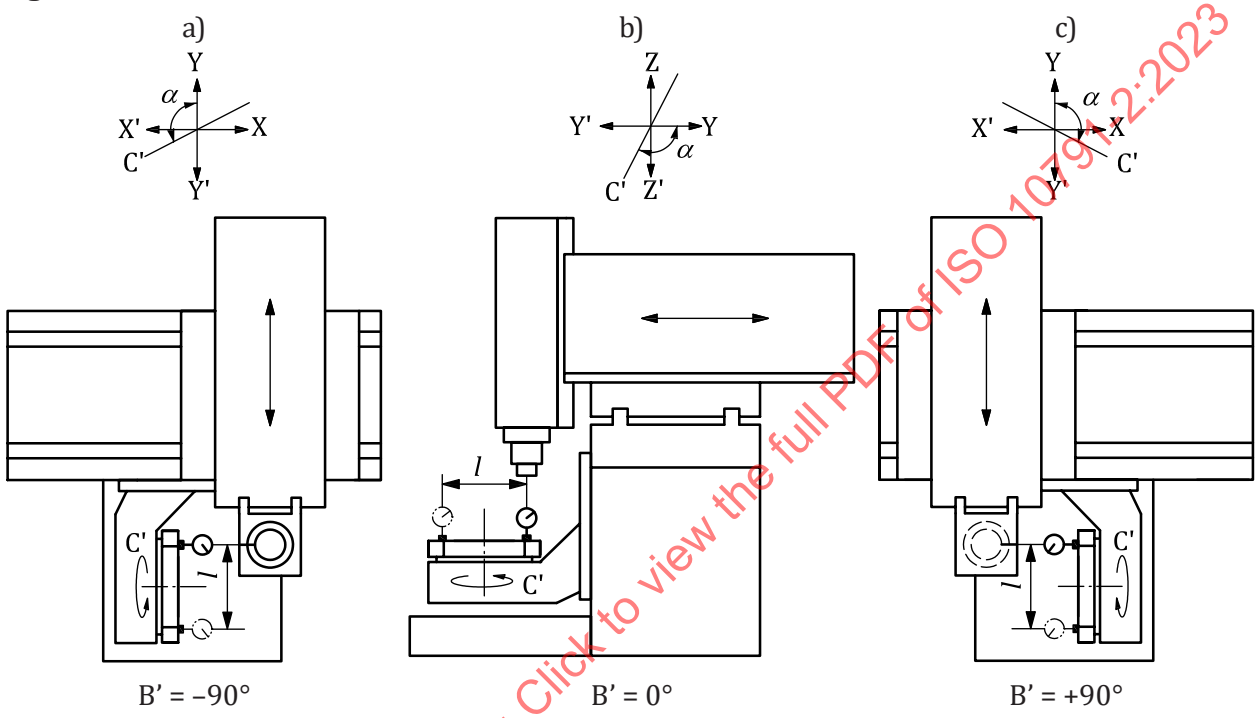
Checking of squareness of the C'-axis (table rotation) to the Y-axis motion, in all the possible angular positions of the B'-axis (cradle tilting) among those listed hereunder and shown in the diagram:

a) with the table in the vertical position at B' = –90° $E_{C(0Y)C', B' = -90}$,

b) with the table in the horizontal position at B' = 0° $E_{A(0Y)C', B' = 0}$,

c) with the table in the vertical position at B' = +90° $E_{C(0Y)C', B' = +90}$.

Diagram



Key

l measurement distance

Tolerance

For a), b) and c): 0,040/1 000 (= 0,020/500, or 40 µrad or 8")

Measured error

a) b) c)

Measuring instruments

Gauge block and dial gauge.

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

The test shall be carried out in the angular positions a), b) and c), if possible, of the B'-axis.

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

For 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 C'-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 C'-axis (table rotation) by 180° and move the Y-axis until the stylus again touches the gauge block in the same point.

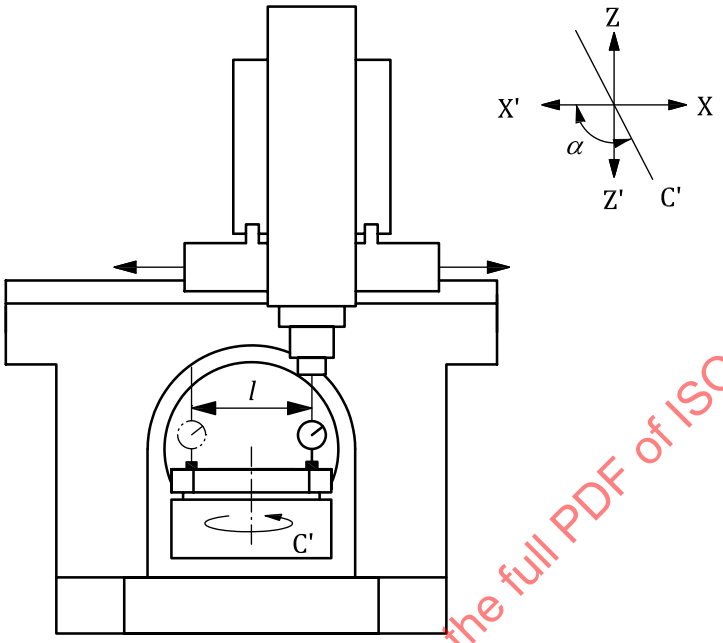
The dial gauge reading, divided by the measurement distance l in the Y-direction, is the error to be reported.

Tests a) and c) can be influenced by the E_{XY} horizontal straightness error of the Y-axis, and test b) by the E_{ZY} vertical straightness error of the Y-axis.

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

In all possible angular positions of the B'-axis the measured error is positive when $\alpha > 90°$ and is negative when $\alpha < 90°$.

As an alternative, this squareness can be evaluated by test BK 2 b) from ISO 10791-6:2014.

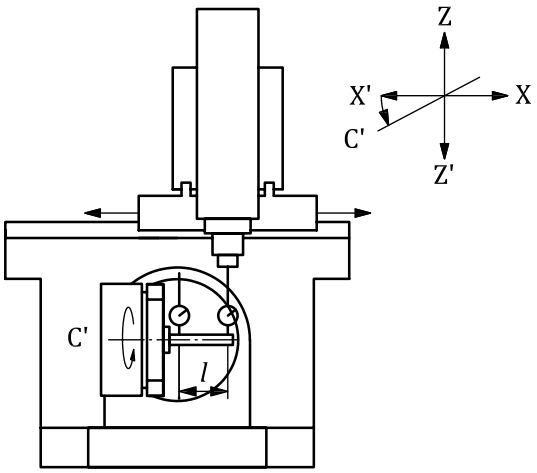
Object	**G9.7**
Checking of $E_{B(0X)C',\,B'=0}$ squareness of the C'-axis (table rotation), with the table in the horizontal position (B' = 0°), to the X-axis motion.	
Diagram  **Key** l measurement distance	
Tolerance 0,040/1 000 (= 0,020/500, or 40 µrad or 8")	
Measured error	
Measuring instruments 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 X-direction apart from the C'-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 C'-axis (table rotation) 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 measurement distance l in the X-direction, is the error to be reported. The value of angle α, being less than, equal to or greater than 90°, shall be noted. The measured error $E_{B(0X)C',\,B'=0}$ is positive when $\alpha > 90°$ and is negative when $\alpha < 90°$. The result of this test includes the possible $E_{BB'}$ positioning error of the B'-axis at 0°. This test can be influenced by the E_{ZX} vertical straightness error of the X-axis. As an alternative, this squareness can be evaluated by test BK 2 b) from ISO 10791-6:2014.	

Object	**G9.8**
Checking of parallelism of the C'-axis (table rotation) to the X-axis motion, in the possible vertical positions of the table (depending on the machine configuration):	
a) with the table in the vertical position at B' = –90°	b) with the table in the vertical position at B' = +90°
1) in the vertical ZX plane $E_{B(0X)C',\ B'=-90,}$	1) in the vertical ZX plane $E_{B(0X)C',\ B'=+90,}$
2) in the horizontal XY plane $E_{C(0X)C',\ B'=-90,}$	2) in the horizontal XY plane $E_{C(0X)C',\ B'=+90;}$

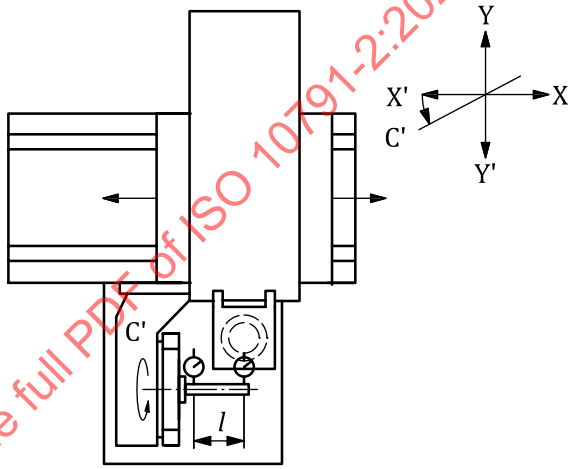
Diagram

a) B' = –90°

1) ZX plane

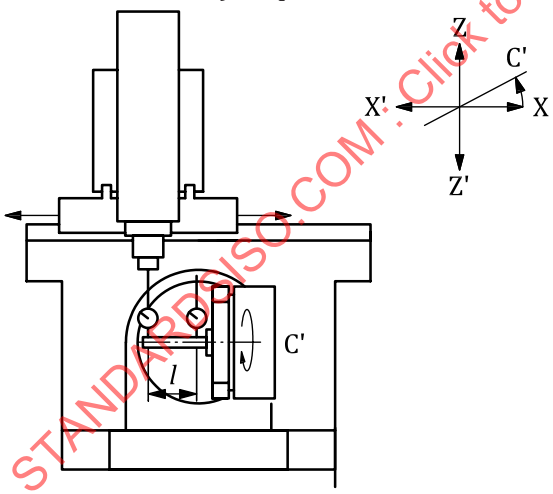


2) XY plane

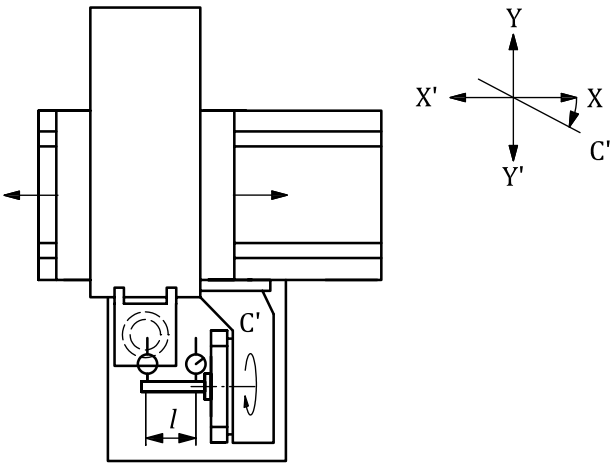


b) B' = +90°

1) ZX plane



2) XY plane



Key

l measurement distance

Tolerance

For a) and b): 0,050/1 000 (= 0,025/500, or 50 µrad or 10")

Measured error

a1) b1)

a2) b2)

Measuring instruments

Cylindrical square with flange base and dial gauge or optical instruments.

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

For a1) and b1) Z-axis to be locked, if possible. The result of tests a1) and b1) include the possible $E_{BB'}$ positioning error of the B'-axis at – 90° or +90°.

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

The following steps shall be followed.

Step 1) Fix a cylindrical square with a flange base on the table and centre it approximately on the C'-axis of rotation.

Step 2) Fix the dial gauge on the spindle, if it can be locked, or on the spindle head, with the stylus oriented in the Z-axis direction for a1) and b1) and Y-axis direction for a2) and b2).

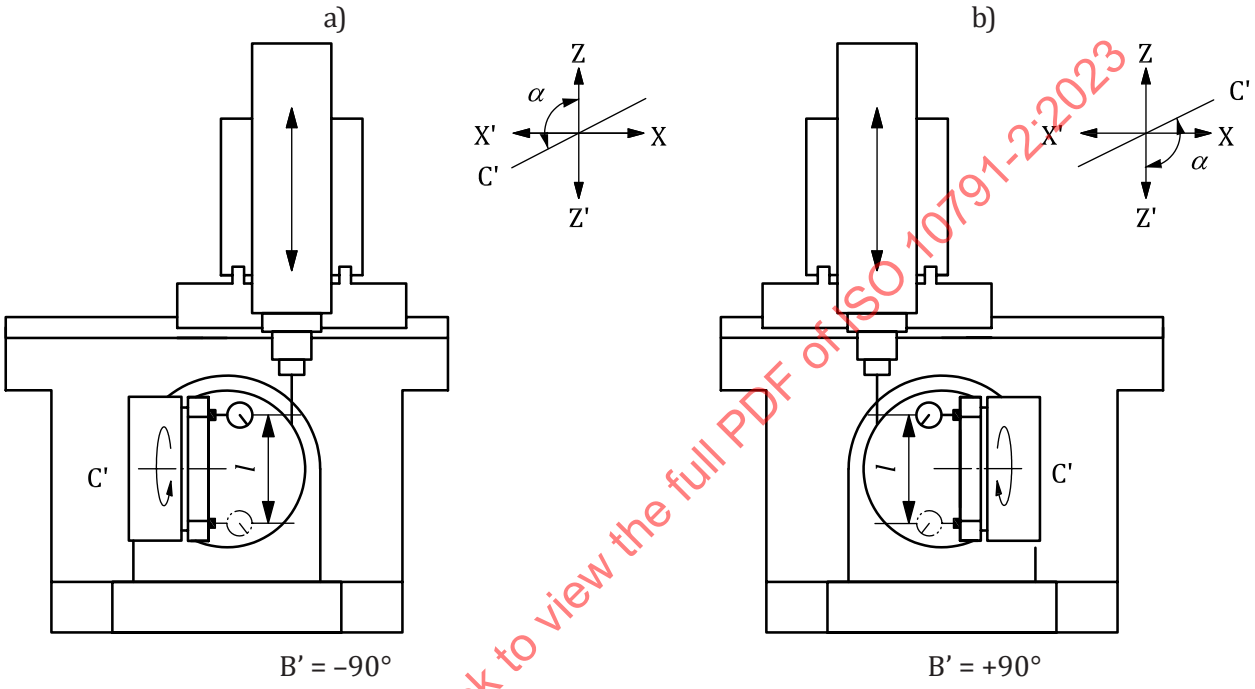
Step 3) Touch the cylindrical square by the stylus, close to the cylinder bottom, and find the maximum dial gauge reading by small movements along the Y-axis for for a1) and b1) and along Z-axis for a2) and b2). Zero the dial gauge.

Step 4) Move the head apart from the table along the X-axis, and touch again the cylinder close to its top. Note the X-axis travel length. Find the maximum dial gauge reading by small movements along the Y-axis for for a1) and b1) and along the Z-axis for a2) and b2), and note the new dial gauge reading.

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

For all measurements, the average value (half the algebraic sum) of the two dial gauge readings on top of the cylinder, divided by the measurement distance l in the X direction, is the error to be reported.

For all angular positions of the B'-axis, the arrow between the C'-axis and the X-axis shows the positive direction of the error.

Object	**G9.9**
Checking of squareness of the C'-axis (table rotation) to the Z-axis motion in the possible vertical positions of the table (depending on the machine configuration): a) B' = –90° ($E_{B(0Z)C',B'=-90}$), b) B' = +90° ($E_{B(0Z)C',B'=+90}$).	
Diagram  	
Key *l* measurement distance	
Tolerance For a) and b): 0,040/1 000 (= 0,020/500, or 40 µrad or 8")	
Measured error a) b)	
Measuring instruments Gauge block and dial gauge.	

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

X-axis locked, if possible.

Place a gauge block on one edge of the table, in the Z direction apart from the axis of rotation C'; 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 C'-axis (table rotation) 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 measurement distance l in the Z-direction, is the error to be reported.

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

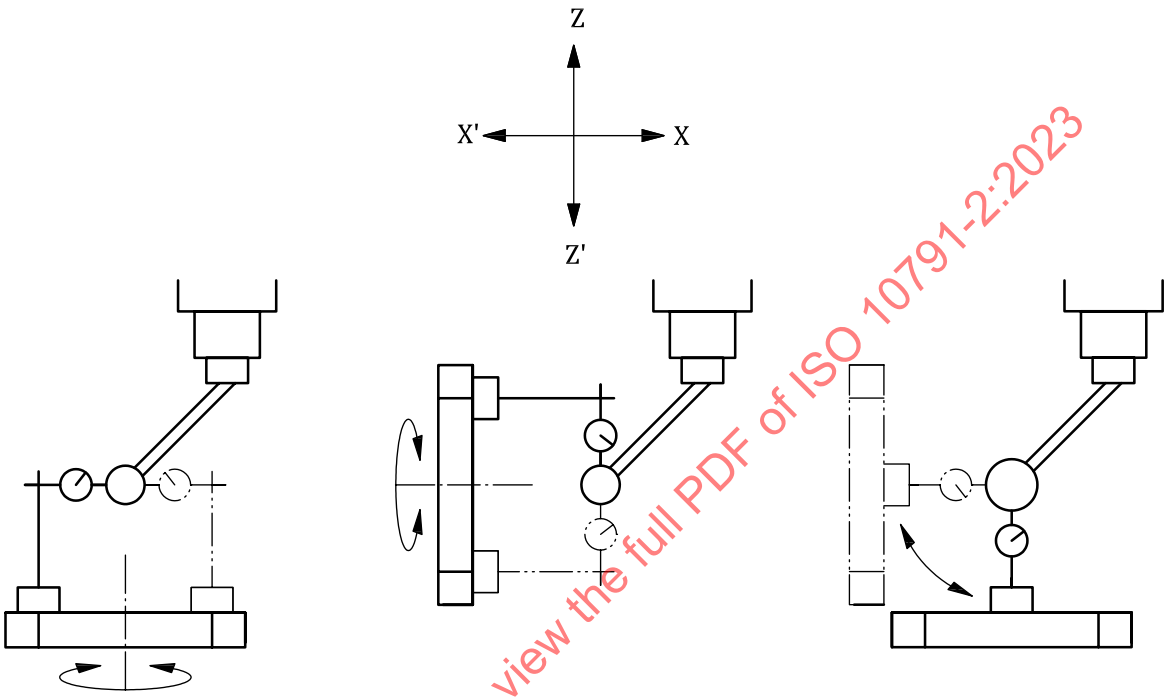
In both angular positions of the B'-axis, the measured error $E_{B(0Z)C'}$ is positive when $\alpha > 90°$ and is negative when $\alpha < 90°$.

The result of this test includes the possible $E_{BB'}$ positioning error of the B'-axis at –90° or +90°.

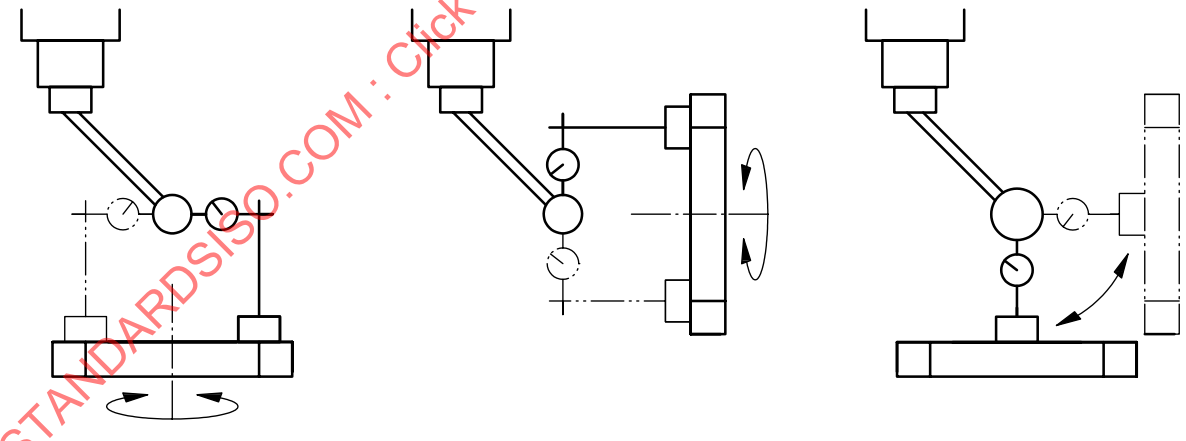
This test can be influenced by the straightness error of the Z-axis in the ZX-plane, E_{XZ}.

Object	**G9.10**
Checking of intersection of the C'-axis (table rotation) with the B'-axis (cradle tilting) for table surfaces lower than the B'-axis, $E_{X(0B')C', B'=0}$ (only for machines with nominally zero offset between B' and C'-axis and without compensation facilities for any offset error).	

Diagram



2) B' = 0° 4) B' = –90° 7) B' = 0° to –90°



2) B' = 0° 4) B' = +90° 7) B' = 0° to +90°

NOTE The sketch shows steps 2), 4) and 7) of the test procedure specified in the observations.

Tolerance

0,030

Measured error

Measuring instruments

Test sphere and dial gauge.

Observations and references to ISO 230-1:2012, 10.4.3	
Step 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.
Step 2)	With the table in horizontal position (B' = 0°), align the C'-axis (table rotation) on the sphere centre, by means of rotations around the C'-axis and adjustments along the X- and Y-axes.
Step 3)	Lock the X- and Y-axes, if possible.
Step 4)	Turn the table to the vertical position (B' = –90°, or B' = +90°, depending on the machine configuration) and again align the C'-axis (table rotation) on the sphere centre, by means of rotations around the C'-axis and adjustments along the Z-axis.
Step 5)	Lock the Z-axis, if possible.
Step 6)	With the table in horizontal position (B' = 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.
Step 7)	Turn the table to the vertical position (B' = –90°, or B' = +90°, depending on the machine configuration) 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 to prevent any possible reading errors due to its opposite and/or changing deflections in the different measurement positions.	

Object **G9.11**

Checking of coaxiality of the C'-axis (table rotation) and the spindle axis (C) at a predefined position of the X- and Y-axes, with the table in the horizontal position (B' = 0°):

offsets

a) $E_{Y(0(C))C',\,B'=0}$ in the vertical YZ plane,

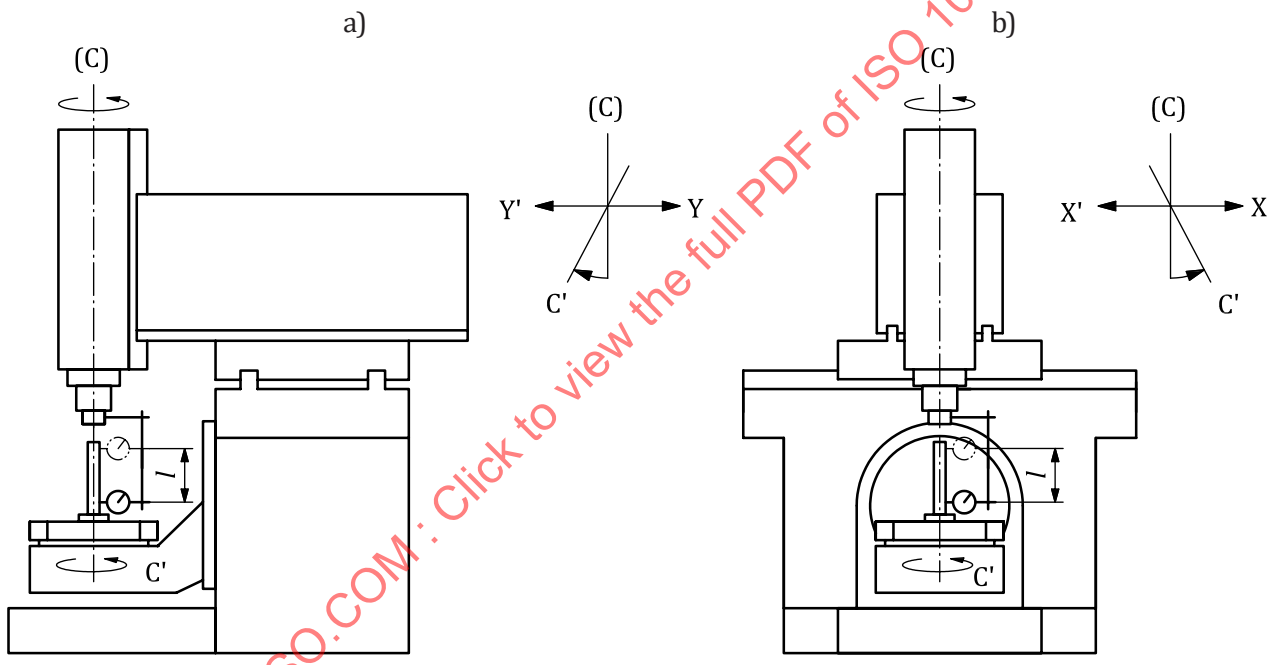
b) $E_{X(0(C))C',\,B'=0}$ in the vertical ZX plane,

and parallelism

a) $E_{A(0(C))C',\,B'=0}$ in the vertical YZ plane,

b) $E_{B(0(C))C',\,B'=0}$ in the vertical ZX plane.

Diagram



Key

l measurement distance

Tolerance

Offset in both planes a) and b):	0,015
Parallelism in both planes a) and b):	0,040/1 000 (= 0,020/500, or 40 µrad or 8")

Measured error

Offset

a) b)

Parallelism

a) b)

Measuring instruments

Cylindrical square with flange base and dial gauge.

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

Step 1) Adjust the B'-axis (cradle tilting) until the C'-axis (table rotation) is parallel to the Z-axis in the ZX-plane.

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

Step 3) Fix the cylindrical square on the table, and the dial gauge in the spindle with the stylus square to the spindle axis in radial direction.

Step 4) With the dial gauge stylus oriented in the Y-axis direction for a) and in the X-axis direction for b), touch the cylindrical square, close to the bottom, and find the maximum dial gauge reading by small movements along the X-axis for a) and along the Y-axis for b). Zero the dial gauge.

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

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

In both planes a) and b) half of the new reading on the dial gauge represents the offset between the two axes of rotation at the bottom of the cylindrical square.

Step 7) Without moving the Z-axis (see NOTE), repeat the measurements close to the top of the cylindrical square.

In both planes a) and b) half of the new reading on the dial gauge represents the offset between the two axes of rotation at the top of the cylindrical square.

The coaxiality error contains both offset and parallelism errors.

In both planes a) and b) the offset error is the one measured at the bottom of the cylindrical square, and the parallelism error is the difference between the two offsets at the bottom and at the top, divided by the measurement distance l in the Z-direction.

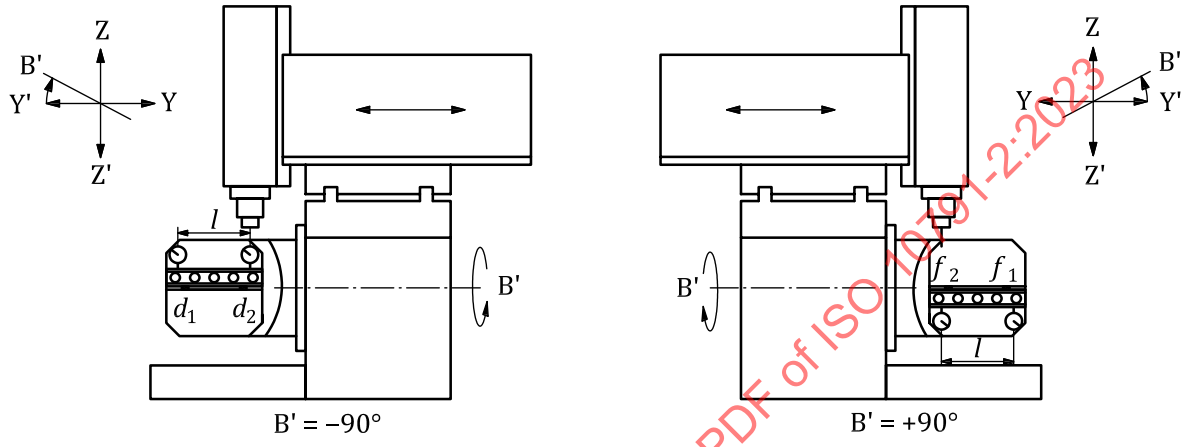
The dial gauge arm shall be stiff enough to prevent any possible reading errors due to its opposite and/or changing deflections in the different measurement positions.

In both planes the arrow between the C'-axis and the spindle axis (C) shows the positive direction of the error.

NOTE If this test were carried out in different positions of the Z-axis it would be affected by the parallelism errors between the spindle axis (C) and the Z-axis and between the C'-axis (table rotation) and the Z-axis, in both YZ and ZX planes.

9.3 Tests for the B'-axis tilting from –90° to +90°

Object	**G9.12**
Checking of parallelism of the B'-axis (cradle rotation) to the Y-axis motion in the vertical YZ plane, $E_{A(0Y)B'}$.	
Diagram	



Key

d_1, d_2, f_1, f_2 readings

l measurement distance

Tolerance

0,050/1 000 (= 0,025/500, or 50 µrad or 10")

Measured error

Measuring instruments

Straightedge or gauge blocks, and dial gauge.

Observations and references to ISO 230-1

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. The stylus of the dial gauge shall be placed approximately in the working position of the tool.

With the same setup used for G9.4, when a reference T-slot or a tenon slot is provided, insert two gauge blocks in the slot, at a distance l from each other. The measurement may also be made on a straightedge laid parallel to the reference T-slot, or transverse edge locator.

When neither the reference T-slot, nor edge locators are present, a straightedge shall be aligned approximately parallel to the Y-axis. If a straightedge is used, it shall be safely fixed to the table, in order to allow the readings to be taken in both angular positions of the B'-axis.

For the measurement $(d_2 - d_1)$, the dial gauge shall be oriented downward, and for measurement $(f_2 - f_1)$ the dial gauge shall be oriented upward, in order to touch the same side of the straightedge or gauge blocks.

Note the readings and the distance l between the two readings. The algebraic sign of the readings shall be carefully noted.

The error to be reported is $E_{A(0Y)B'} = 1/2\ (\Delta f - \Delta d)/l = 1/2[(f_2 - f_1)\ - (d_2 - d_1)]/l$.

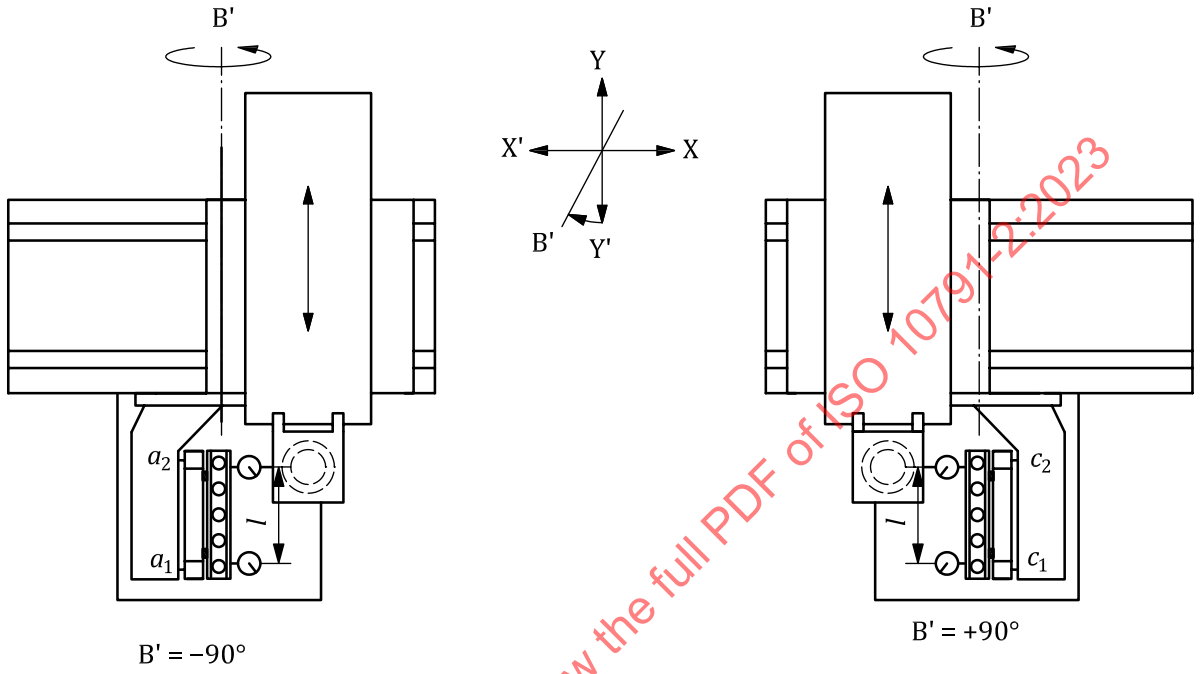
The algebraic sign of the results $\Delta d = (d_2 - d_1)$ and $\Delta f = (f_2 - f_1)$ is positive when the reading in point 2 is greater than in point 1, i.e. when the straightedge in point 2 is closer to the dial gauge than in point 1.

The arrow between the B'-axis and the Y-axis shows the positive direction of the $E_{A(0Y)B'}$ error.

NOTE Half sum of the two readings "Δf" and "Δd", i.e. their algebraic average, out from the object of this test, shows the opposite of the parallelism error of the reference line L (represented by the straightedge, or T-slot) from the B'-axis, which affects the readings in G9.4.

Object	**G9.13**
Checking of parallelism of the B'-axis (cradle rotation) to the Y-axis motion in the horizontal XY plane, $E_{C(0Y)B'}$.	

Diagram



Key

a_1, a_2, c_1, c_2 readings — l measurement distance

Tolerance

0,050/1 000 (= 0,025/500, or 50 µrad or 10")

Measured error

a) b)

Measuring instruments

Straightedge or gauge blocks and dial gauge.