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:

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

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

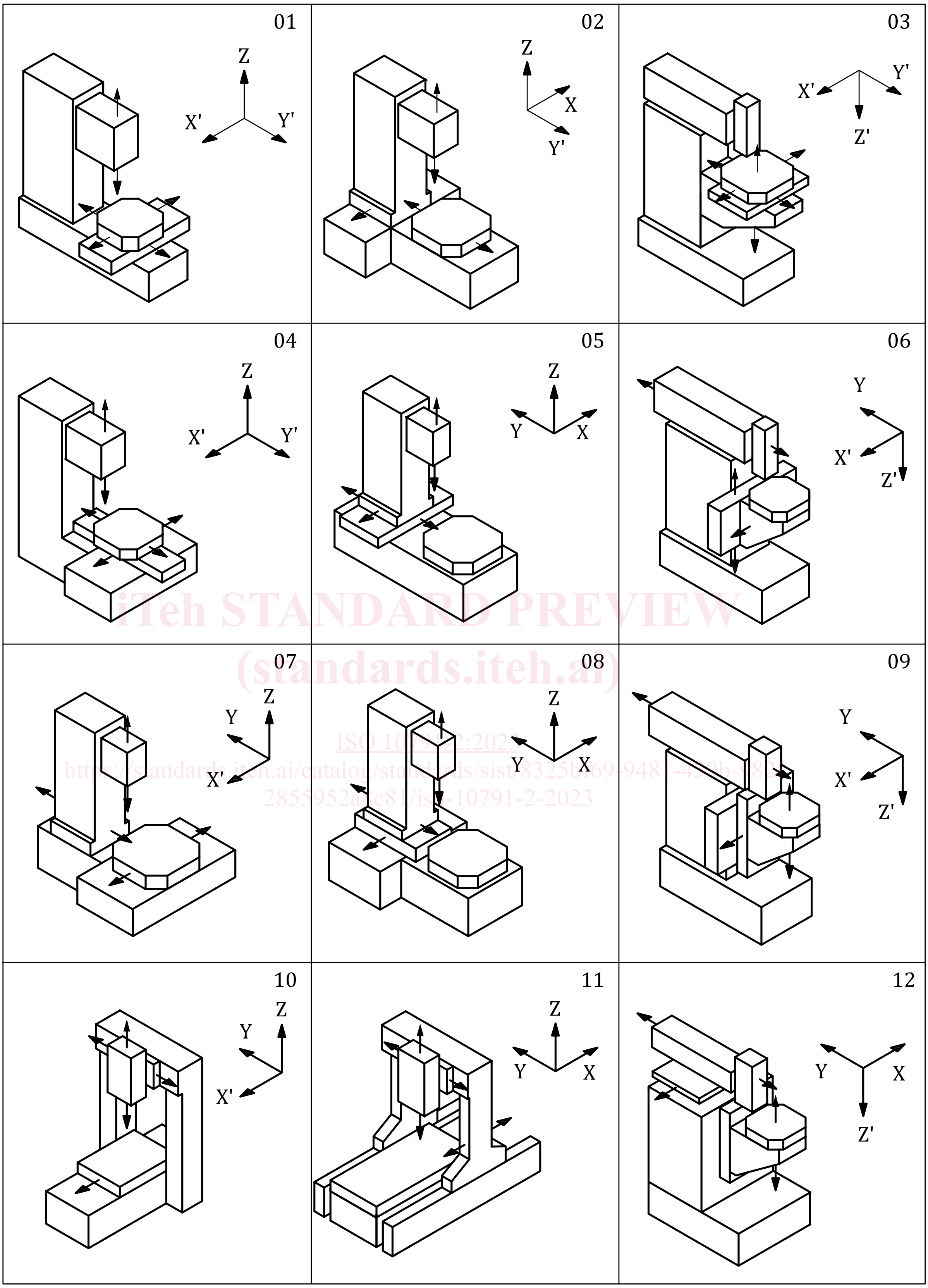
— the kinematic chain of moving axes is described in square brackets,

— 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