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Test conditions for machining centres —

Part 10: Evaluation of thermal distortions

Conditions d'essai des centres d'usinage —
Partie 10: Évaluation des déformations thermiques

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Foreword

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

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

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

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

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

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

This second edition cancels and replaces the first edition (ISO 10791-10:2007), which has been technically revised.

The main changes are as follows:

— thermal test T4 has been added;

— Annex A has been added.

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 programme. Most machining centres have facilities for automatically changing the direction in which the workpieces are presented to the tool.

The purpose of this document is to provide information on tests and checks which can be carried out for comparison, acceptance, maintenance or any other purpose.

Annex A presents three machining tests to evaluate thermal distortions of machining centres.

Test conditions for machining centres —

Part 10: Evaluation of thermal distortions

1 Scope

This document specifies, tests for the evaluation of thermal distortions of the machine tool structure and positioning system, for machining centres with vertical spindle, with numerically controlled linear axes of lengths up to 5 000 mm for the X-axis and up to 2 000 mm for the Y- and Z-axis. It also applies to machining centres with horizontal spindle with numerically controlled linear axes of lengths up to 5 000 mm for the X-axis, 3 200 mm for the Y-axis and 2 000 mm for the Z-axis.

This document specifies four tests:

— environmental temperature variation error;

— thermal distortion caused by a rotating spindle;

— thermal distortion caused by moving linear axes;

— thermal distortion caused by rotary motion of components.

This document is intended to be used with ISO 230-3.

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 230-3:2020, *Test code for machine tools — Part 3: Determination of thermal effects*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 230-1:2012 and ISO 230-3:2020 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 Measuring units

In this document, all linear dimensions and deviations are expressed in millimetres. All angular dimensions are expressed in degrees. Angular deviations are, in principle, expressed in ratios; however,

in some cases, microradians or arcseconds may be used for clarification purposes. The equivalent of the following expressions should always be kept in mind:

0,010/1 000 = 10 µrad ≈ 2″

The temperatures are expressed in degrees Celsius (°C).

4.2 Reference to ISO 230-3

For the application of this document, reference shall be made to ISO 230-3:2020, 4.4 for the installation of the machine tool before testing, and shall be made to ISO 230-3:2020, Clauses 5, 6, 7 and 8 for the description of measuring methods and presentation of the results.

4.3 Measuring instruments

The measuring instruments recommended in this document are given only by way of examples. Other measuring instruments capable of measuring the same quantities and having the same or a smaller measurement uncertainty may be used. See ISO 230-3:2020, 4.3.

4.4 Testing sequence

The tests given in this document may be used either singularly or in any combination. Before each test, the machine tool should be in equilibrium with the environment. Therefore, a sufficient cooling down period between tests, generally at least as long as the thermal test, where parts of the machine tool have been heated, shall be planned and respected.

4.5 Tests to be performed

When testing a machine tool, it is not always necessary or even possible to carry out all the tests given in this document. When the tests are required for acceptance purposes, it is at the option of the user to choose, in agreement with the manufacturer/supplier, those tests relating to the components and/or the properties of the machine tool that are of interest. These tests are to be clearly stated when ordering a machine tool. Mere reference to this document for the acceptance tests, without specification of the tests to be carried out, and without agreement on the relevant expenses, cannot be considered as binding for any contracting party.

Annex A presents three machining tests to evaluate thermal distortions of machining centres, which can be performed as additional tests to the thermal tests in Clause 5.

4.6 Diagrams

The diagrams shown in Tests T1 through T4 of this document illustrate only one test setup, for the reason of simplicity.

4.7 Tolerances

This document has no intention of assigning any numerical tolerances associated with the tests specified. Numerical tolerance for each parameter shall be agreed between manufacturer/supplier and user.

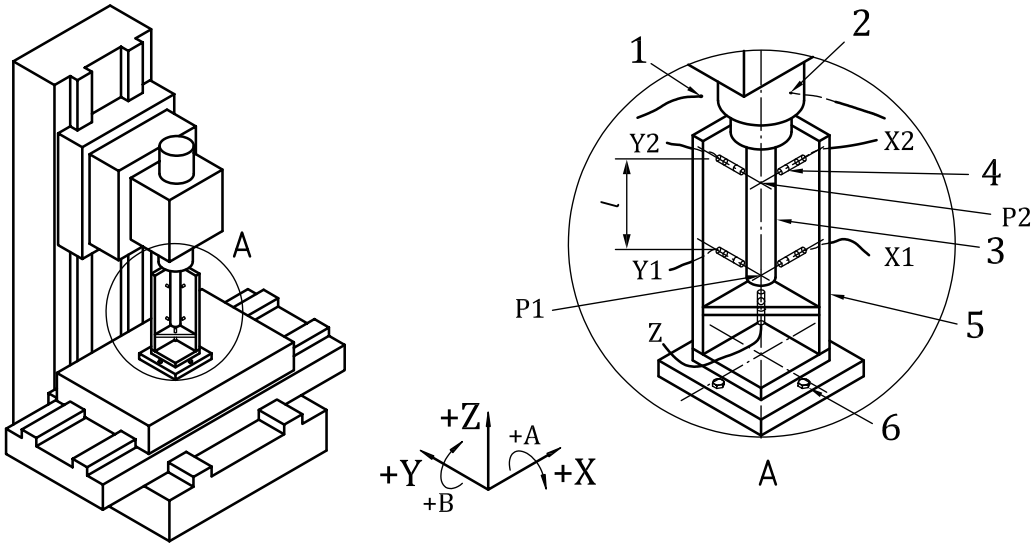
4.8 Software compensation

When software facilities are available for compensating some geometric errors, based on an agreement between the manufacturer/supplier and user, the relevant test can be carried out with these compensations. Some numerical thermal error compensations are based on temperature measurements on the machine tool structure, and others are based on operating conditions, e.g. the spindle rotation speed. Such a thermal compensation can be used, based on an agreement between the manufacturer/supplier and user. When any software compensation is used, this shall be stated in the test report.

5 Thermal tests

Object	**T1**
Checking of environmental temperature variation error (ETVE)	

Diagram



Key

1 ambient air temperature sensor
2 spindle bearing temperature sensor
3 test mandrel
4 linear displacement sensors
5 fixture
6 bolt for fixing the fixture
l distance between measuring positions P1 and P2
P1 measuring position 1
P2 measuring position 2
X1, X2, Y1, Y2, Z linear displacement sensors

Tolerance

Measured error

Parameter	Time	E_{TVE}(X)	E_{TVE}(Y)	E_{TVE}(Z)	E_{TVE}(A)	E_{TVE}(B)
	min	mm	mm	mm	mm/mm	mm/mm

Measuring instruments

temperature sensors, linear displacement sensors and test mandrel

Observations and references to ISO 230-3:2020, 5.2 and 5.3

ETVE tests are designed to reveal the effects of environmental temperature changes on the machine tool with respect to deflection or deformation of the machine tool or its parts. They shall not be used for machine comparison.

The manufacturer/supplier should provide guidelines regarding the kind of thermal environment that should be acceptable for the machine tool to perform with the specified accuracy. It shall be the responsibility of the user to provide an acceptable thermal environment for the operation. However, if the user follows the guidelines provided by the machine tool manufacturer/supplier, the responsibility for machine tool performance according to the specification reverts to the machine tool manufacturer/supplier.

End surface of test mandrel needs proper flatness and squareness to axis of mandrel as these deviations influence measurement uncertainty directly.

Axes might warm-up when the machine axes are in “HOLD” (servo-on) mode, especially if they are in vertical direction. In such cases, the ETVE test should be carried out with all controls in “OFF”. This shall be stated in the test report.

$E_{\mathrm{TVE}}(\mathrm{Z})$ is the maximum range of thermal distortion in the Z direction over the test period of time. $E_{\mathrm{TVE}}(\mathrm{Y})$ and $E_{\mathrm{TVE}}(\mathrm{X})$ can be determined in the same way for the two other directions. For $E_{\mathrm{TVE}}(\mathrm{A})$ and $E_{\mathrm{TVE}}(\mathrm{B})$, see ISO 230-3:2020.

In addition to numerical values of the measured errors, a graphical presentation of results should be provided in accordance with ISO 230-3:2020, 5.4.

The following information shall be recorded:

a) machine tool brand and model name;

b) year of construction of machine tool, if available;

c) machine tool serial number;

d) time and date of test;

e) location of the measurement setup;

f) location of temperature sensors;

g) type of sensors;

h) design and material of the test mandrel and fixture;

i) thermal compensation procedure;

j) any special test procedures;

k) machine preparation procedure prior to testing;

l) power ON or OFF;

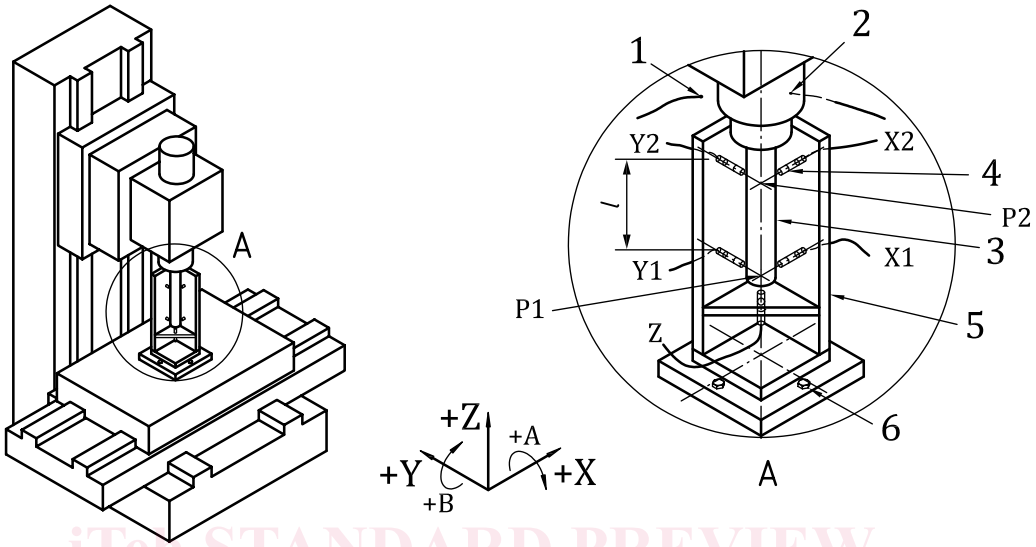
m) positive direction of thermal distortion (if different from coordinate system).

Object **T2**

Checking of thermal distortion caused by rotating spindles.

One test per spindle shall be carried out.

Diagram



Key

1 ambient air temperature sensor
2 spindle bearing temperature sensor
3 test mandrel
4 linear displacement sensors
5 fixture
6 bolt for fixing the fixture
l distance between measuring positions P1 and P2
P1 measuring position 1
P2 measuring position 2
X1, X2, Y1, Y2, Z linear displacement sensors

Tolerance

Measured error

	X1	**Y1**	**Z**	**A**	**B**
	mm	mm	mm	mm/mm	mm/mm
During first 60 min	$d(E_{X0(C)})_{P1,60}$ = …	$d(E_{Y0(C)})_{P1,60}$ = …	$d(E_{Z0(C)})_{60}$ = …	$d(E_{A0(C)})_{60}$ = …	$d(E_{B0(C)})_{60}$ = …
After end of period t = …	$d(E_{X0(C)})_{P1,t}$ = …	$d(E_{Y0(C)})_{P1,t}$ = …	$d(E_{Z0(C)})_{t}$ = …	$d(E_{A0(C)})_{t}$ = …	$d(E_{B0(C)})_{t}$ = …
Distance, l = …					

Measuring instruments

temperature sensors, linear displacement sensors and test mandrel

Observations and references to ISO 230-3:2020, 6.2

User and manufacturer/supplier shall agree as to whether a constant spindle speed or a variable speed spectrum is used. For the case of constant spindle speed, they also shall agree on the spindle speed to be used. For the variable speed spectrum, they shall agree on the spindle speeds and time interval durations.

NOTE A possible speed spectrum cycle is a percentage of the maximum spindle speed for set period of time, followed by a spindle stop for another fixed period of time (e.g. maximum spindle speed followed by a stop). This cycle is then repeated for the complete test. The exact details of the speed spectrum can be discussed between the user and manufacturer/supplier.

The test shall last for 4 h plus 1 h with the spindle stopped.

In addition to numerical values of the measured errors, a graphical presentation of results should be provided in accordance with ISO 230-3:2020, 6.4.

The following information shall be recorded:

a) machine tool brand and model name;

b) year of construction of machine tool, if available;

c) machine tool serial number;

d) time and date of test;

e) location of the measurement setup;

f) location of temperature sensors;

g) type of sensors;

h) design and material of the test mandrel and fixture;

i) thermal compensation procedure;

j) any special test procedures;

k) machine preparation procedure prior to testing;

l) spindle speed regime, e.g. constant spindle speed or a variable speed spectrum (see ISO 230-3:2020, 6.2);

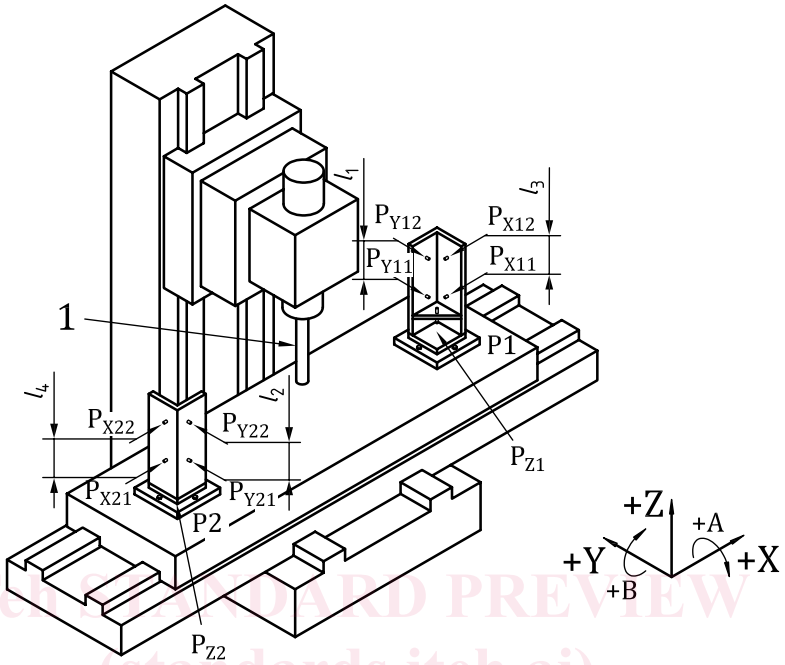
m) positive direction of thermal distortion (if different from coordinate system);

n) relative position of the spindle during measurement.

Object | **T3**

Checking of thermal distortion caused by the motion of linear axes

Diagram



Key

1	test mandrel
l_1, l_2, l_3, l_4	distances between sensors used to calculate angular distortions
$P_{X11}, P_{X12}, P_{Y11}, P_{Y12}, P_{Z1}$	linear displacement sensors at position P1
$P_{X21}, P_{X22}, P_{Y21}, P_{Y22}, P_{Z2}$	linear displacement sensors at position P2

Tolerance

Measured error

	$d(E_{XX})_{P1}$	$d(E_{YX})_{P1}$	$d(E_{ZX})_{P1}$	$d(E_{XX})_{P2}$	$d(E_{YX})_{P2}$	$d(E_{ZX})_{P2}$
	mm	mm	mm	mm	mm	mm
Measured values at t=...						
Measured values at t=...						

	$d(E_{BX})_{P1}$	$d(E_{AX})_{P1}$	$d(E_{BX})_{P2}$	$d(E_{AX})_{P2}$
	mm/mm	mm/mm	mm/mm	mm/mm
Measured values at t=...				
Measured values at t=...				

Measuring instruments
temperature sensors, linear displacement sensors, and special test mandrel
Observations and references to ISO 230-3:2020, 7.2 and 7.2.2
In practice, there should be different feed speeds for principal and for auxiliary axes.
EXAMPLE A feed speed set for principal axes at 50 %, and one for auxiliary axes set at 20 % of the maximum feed speed.
The test cycle shall be made up of two time periods: 4 h of warming up the axis and 1 h for cooling it down. The measurements may be interrupted when the distortion change noted during the last 60 min is less than 15 % of the distortion registered over the initial 60 min of the test.
For each axis of the machine tool, the following plots versus time should be presented (for the example setup shown in Diagram above): — two position plots of the target positions for the X-axis, one with $d(E_{XX})_{P1}$, $d(E_{YX})_{P1}$, $d(E_{ZX})_{P1}$, and the other with $d(E_{XX})_{P2}$, $d(E_{YX})_{P2}$, $d(E_{ZX})_{P2}$; — two rotation plots of the target positions, for the X-axis pitch plots, one with $d(E_{BX})_{P1}$, and the other with $d(E_{BX})_{P2}$; — two rotation plots of the target positions, for the X-axis roll plots, one with $d(E_{AX})_{P1}$, and the other with $d(E_{AX})_{P2}$; — temperature plots of environment and machine tool during tests versus time.
See ISO 230-3:2020, 7.2.2 for the calculation of the position and rotation plots from the readings of the linear displacement sensors.
It should be noted that the results are influenced by the positioning repeatability of the machine tool axis under tests and the machine tool axes moved to take the measurements.
The following information shall be recorded:

a) machine tool brand and model name;

b) year of construction of machine tool, if available;

c) machine tool serial number;

d) time and date of test;

e) location of measurement line;

f) location of temperature sensor;

g) feed speed;

h) dwell times;

i) start and end positions;

j) compensation capabilities and facilities;

k) instruments used;

l) coefficient of thermal expansion used;

m) warm-up procedures;

n) temperature of the measured objects (for example, position transducer, slideway, bed, table, spindle head, and test mandrel. See ISO 230-3, 7.2.4);

o) positive direction of thermal distortion in position and rotation (if different from coordinate system);

p) design and material of the test mandrel and fixture;

q) if relevant, conditions of any supply systems, e.g. lubrication, hydraulics, air supply, chillers.