INTERNATIONAL STANDARD

ISO 13041-5

First edition
2006-12-01

Test conditions for numerically controlled turning machines and turning centres —

Part 5: Accuracy of feeds, speeds and interpolations

Conditions d'essai des tours à commande numérique et des centres de tournage —

Partie 5: Exactitude des vitesses, avances et interpolations

Reference number
ISO 13041-5:2006(E)

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Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

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Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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.

ISO 13041-5 was prepared by Technical Committee ISO/TC 39, *Machine tools*, Subcommittee SC 2, *Test conditions for metal cutting machine tools*.

ISO 13041 consists of the following parts, under the general title *Test conditions for numerically controlled turning machines and turning centres*:

— *Part 1: Geometric tests for machines with a horizontal workholding spindle*

— *Part 2: Geometric tests for machines with a vertical workholding spindle*

— *Part 3: Geometric tests for machines with an inverted vertical workholding spindle*

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

— *Part 5: Accuracy of feeds, speeds and interpolations*

— *Part 6: Accuracy of a finished test piece*

— *Part 7: Evaluation of contouring performance in the coordinate planes*

— *Part 8: Evaluation of thermal distortions*

Introduction

A numerically controlled turning machine is a machine tool in which the principal motion is the rotation of the workpiece against the stationary cutting tool(s) and where cutting energy is brought by the workpiece and not by the tool. This machine is controlled by a numerical control (NC) providing automatic function according to ISO 13041-1:2004, 3.3, and can be of single- or multi-spindle type.

A turning centre is an NC turning machine equipped with power driven tool(s) and the capacity to orientate the work holding spindle around its axis.

The object of ISO 13041 is to supply information as wide and comprehensive as possible on geometric, positional, contouring, thermal and machining tests, which can be carried out for comparison, acceptance, maintenance or any other purpose.

ISO 13041 specifies, with reference to the relevant parts of ISO 230, *Test code for machine tools,* tests for turning centres and numerically controlled turning machines with or without tailstocks standing alone or integrated in flexible manufacturing systems. ISO 13041 also establishes the tolerances or maximum acceptable values for the test results corresponding to general purpose and normal accuracy turning centres, and numerically controlled turning machines.

Test conditions for numerically controlled turning machines and turning centres —

Part 5: Accuracy of feeds, speeds and interpolations

1 Scope

This part of ISO 13041 specifies, with reference to ISO 230-1, certain kinematic tests for numerically controlled (NC) turning machines and turning centres, concerning the spindle speeds, the feeds of the individual NC linear axes and the accuracy of the paths described by the simultaneous movement of two or more NC linear and/or rotary axes.

2 Normative references

The following referenced documents are indispensable for the application 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 230-1:1996, *Test code for machine tools — Part 1: Geometric accuracy of machines operating under no-load or finishing conditions*

ISO 230-4:2005, *Test code for machine tools — Part 4: Circular tests for numerically controlled machine tools*

3 Preliminary remarks

3.1 Measuring units

In this part of ISO 13041, all linear dimensions, deviations and corresponding tolerances are expressed in millimetres, angular dimensions are expressed in degrees, and angular deviations and the corresponding tolerances are expressed in ratios, but in some cases microradians or arcseconds may be used for clarification purposes. The equivalence of the following expressions should always be kept in mind:

$$0{,}010/1\,000 = 10 \times 10^{-6} = 10\ \mu\text{rad} \approx 2\ \text{arcsec}$$

3.2 Reference to ISO 230-1

For application of this part of ISO 13041, reference shall be made to ISO 230-1, especially for the installation of the machine before testing, warming-up of spindles and other moving parts, the description of measuring methods, and recommended accuracy of testing equipment.

3.3 Testing sequence

The sequence in which the kinematic tests are given in no way defines the practical order of testing. In order to make the mounting of instruments or gauging easier, tests may be performed in any order.

3.4 Tests to be performed

When testing a machine, it is not always necessary or possible to carry out all the tests given in this part of ISO 13041. When the tests are required for acceptance purposes, the choice of tests relating to the components and/or the properties of the machine of interest is at the discretion of the user, in agreement with the supplier/manufacturer. The tests to be used are to be clearly stated when ordering a machine. The mere reference to this part of ISO 13041 for the acceptance tests, without specifying the tests to be carried out, and without agreement on the relevant expenses, cannot be considered as binding for any contracting party.

3.5 Measuring instruments

The measuring instruments indicated in relation to the tests given in Clause 4 are examples only. Other instruments measuring the same quantities and having at least the same measurement uncertainty and the same resolution may be used.

Due to the requirement of graphical representation of the results (e.g. detection of spikes at reversal points or repeatability of the circular paths) in tests K3 to K6, measuring instruments shall have a resolution of 0,001 mm or better.

3.6 Diagrams

For reasons of simplification, the figures in this part of ISO 13041 illustrate only certain types of machines.

4 Kinematic tests

4.1 Speeds (K1) and feeds (K2)

The purpose of these tests is to check the overall accuracy of all the electric, electronic and kinematic chain in the control system between the command values given by the controller.

4.2 Linear interpolations (K3)

The purpose of this test is to check the mutual behaviour of two linear axes while they are moving at the same feed rate (45° angle) and to check the behaviour of each one of them at very low feed rate (small angles), with the stick-slip motion possible.

4.3 Circular interpolations (K4)

The purpose of this test is to check the mutual behaviour of two linear axes (generally X and Z) at variable feed rates, including points in which the feed of one axis slows down to zero and the direction of movement is reversed.

4.4 Radial interpolations (K5)

This test is an alternative to K4, in cases where the machine under test does not have a measurement sweep of 360° or if K4 is otherwise not relevant. The purpose of this test is to check the mutual behaviour of two linear axes (generally X and Z) at variable feed rates, including points in which the feed of one axis slows down to zero and the direction of movement is reversed.

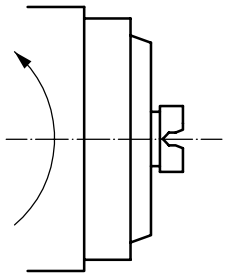
4.5 Interpolations between X, Y and C axes (K 6)

The purpose of this test is to check the interpolation between the X, Y and C axes of a turning centre for clockwise and anticlockwise (counter-clockwise) contouring motions.

Object **K1**

Checking of deviations in the spindle speed at 50 % and 100 % of the maximum speed of each range, in the clockwise and anticlockwise (counter-clockwise) directions of rotation.

Diagram



Tolerance

$\pm$ 5 %

Measured deviation

Speed range	Direction of rotation	Programmed speed	Actual speed	% deviation
	Anticlockwise			
	Clockwise			
	Anticlockwise			
	Clockwise			
	Anticlockwise			
	Clockwise			
	Anticlockwise			
	Clockwise			

Measuring instruments

Revolutions counter, stroboscope or others

Observations and references to ISO 230-1

If the instantaneous speed is read, five readings shall be taken and the average calculated.

Readings shall be taken at constant speed, avoiding the acceleration/deceleration at start and stop.

The override control shall be set at 100 %.

The spindle speed deviation shall be calculated using the following formula:

$$\% \text{ deviation} = \frac{\text{actual speed} - \text{programmed speed}}{\text{programmed speed}} \times 100$$

NOTE This test is applicable to all main spindles and all tool spindles.

Object **K2**

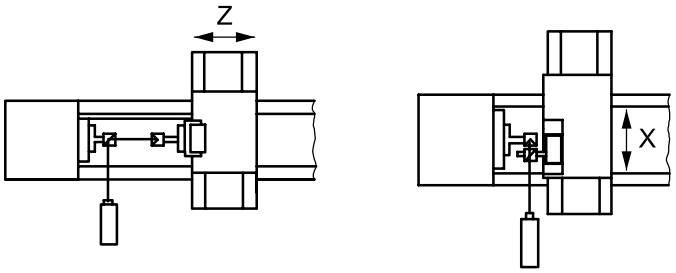
Checking of accuracy of the feed rate of the linear axes at the following feed rates:

a) 100 mm/min;

b) 1 000 mm/min;

c) maximum feed rate.

Diagram



Tolerance

± 5 %

Measured deviation

Programmed feed rate	Axis	X		Y		Z	
	Direction	Actual feedrate	% deviation	Actual feedrate	% deviation	Actual feedrate	% devation
100 mm/min	Positive						
	Negative						
1 000 mm/min	Positive						
	Negative						
Maximum feed rate ..... mm/min	Positive						
	Negative						

Measuring instruments

Laser interferometer, grid encoder or stop watch

Observations and references to ISO 230-1:1996 **5.231.3 and 5.232.2**

If an interferometer is used which reads the instantaneous velocity, five readings shall be taken along the travel and the average calculated.

Caution should be adopted when using this test over a short measurement range due to the effects of acceleration and deceleration.

If a stopwatch is used, the time shall be measured over a measuring length shorter than the programmed travel, in order to avoid the acceleration/deceleration at both ends.

The override control shall be set at 100 %.

The feed rate deviation shall be calculated using the following formula:

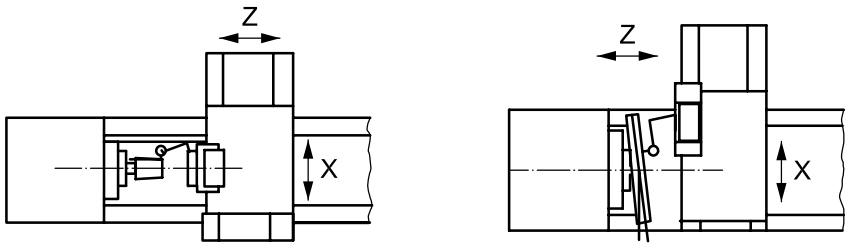
$$\%\ \text{deviation} = \frac{\text{actual feedrate} - \text{programmed feedrate}}{\text{programmed feedrate}} \times 100$$

Object **K3**

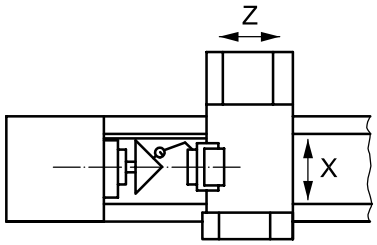
Checking of straightness of the path described by linear interpolation of two linear axes, over a maximum measuring length of 300 mm with a measurement angle of:

1 a) 3° to Z axis motion;
1 b) 3° to X axis motion;
2) 45° to X-Z axes motion.

Diagram



1 a) **1 b)**



2)

Tolerance	**Measured deviations**
0,020 for any length of 100	1 a) direction of Z travel (±):
	1 b) direction of Z travel (±):
	2) direction of Z travel (±):

Measuring instruments

Straightedge or sine bar and linear displacement sensor; electronic probe with graphic recorder; special cone mandrels; cross grid plate

Observations and references to ISO 230-1:1996 **5.211.1; 5.212; A2; A3; A7.2**

For tests using special cone mandrels [see 1 a) and 2)], clamp the cone mandrel in the workholding spindle chuck or collet. Attach a linear displacement sensor to the tool slide with the stylus contacting the tapered surface of the cone.

For tests using the straightedge [see 1 b)], attach the straightedge to the workholding spindle faceplate or four-jaw chuck with gauging surface at approximately ± 3° to the X-axis travel. Lock the workholding spindle rotation. Attach a linear displacement sensor to the tool slide with the stylus contacting the gauging surface of the straightedge.

For all straightness tests, establish a common linear displacement sensor zero at two locations on the gauging surface of the artefact, conveniently spaced at the required measuring length with an additional allowance for axis acceleration and deceleration. Record the coordinate locations of the X and Z axes of the selected points. Program a bi-directional move at 250 mm/min between the two locations and record the straightness data. Analyse the recorded data separately in each direction (as per ISO 230-1) excluding an allowance for acceleration and deceleration. The larger deviation and its direction shall be recorded as the result of the test.

Object **K4**

Checking the circular deviation, G, of the path generated by circular interpolation of two linear axes (generally in the XZ plane) according to ISO 230-4, over 360°, at one of the following diameters and at two feed rates:

1) 50 mm diameter	2) 100 mm diameter	3) 200 mm diameter	4) 300 mm diameter
a) 100 mm/min	a) 140 mm/min	a) 200 mm/min	a) 250 mm/min
b) 250 mm/min	b) 350 mm/min	b) 500 mm/min	b) 600 mm/min

The circular deviation, G, shall be checked for clockwise and anticlockwise (counter-clockwise) contouring motion.

Diagram

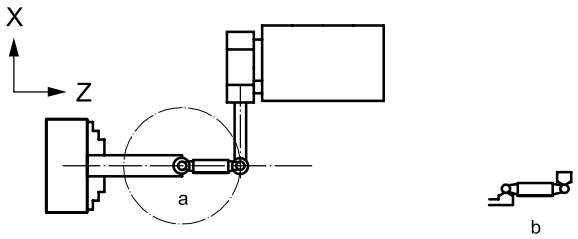


Figure 1

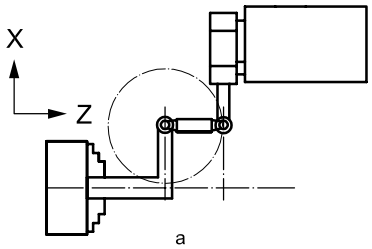


Figure 2

a Plan view.
b Side view.

Tolerance

a) G_{XZ} = 0,03 mm b) G_{XZ} = 0,05 mm
G_{ZX} = 0,03 mm G_{ZX} = 0,05 mm

Measured deviation

a) Feed rate = ...
G_{XZ} = ...
G_{XZ} = ...

b) Feed rate = ...
G_{XZ} = ...
G_{XZ} = ...

Diameter of nominal path .....
Location of measuring instrument
— centre of circle (X/Y/Z) .....
— offset to tool reference (X/Y/Z) .....
— offset to workpiece reference (X/Y/Z) .....
Data acquisition method
— starting point .....
— number of measuring points .....
— data smoothing process .....
Compensation used .....
Positions of axes not under test .....

Measuring instruments

Test mandrel, special rotary fixture and electronic probe, or circular master piece and bi-dimensional probe, or telescopic ball bar or grid encoder

Observations and references to ISO 230-1:1996 **6.63**

This test may be carried out according to Figure 1 or 2, depending on the nominal tool lengths used in practice. If 360° is not possible, see K5.

Diameters could differ from the above values by a maximum of 25 %. In such cases, the feed rate shall be adjusted according to ISO 230-4:2005, Annex C. Zero the axes in a position in which the test mandrel is on the axis of rotation of the rotary fixture or the bi-dimensional probe is in the centre of the master piece or in the centre of the socket on the workholding side of the telescopic ball bar.

Start the interpolation in one of the four quadrants — if possible, not in one of the four reversal points, in order to avoid missing the performance of the machine at those points.

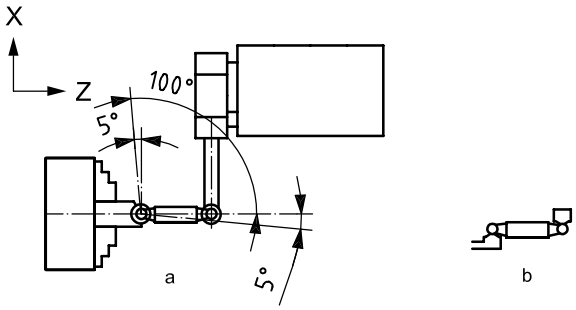
Object **K5**

Checking the radial deviation, F, of the path generated by circular interpolation of two linear axes (generally in the XZ plane) according to ISO 230-4, over 100°, at one of the following diameters and at two feed rates:

1) 50 mm diameter	2) 100 mm diameter	3) 200 mm diameter	4) 300 mm diameter
a) 100 mm/min	a) 140 mm/min	a) 200 mm/min	a) 250 mm/min
b) 250 mm/min	b) 350 mm/min	b) 500 mm/min	b) 600 mm/min

The radial deviation, F, shall be checked for clockwise and anticlockwise (counter-clockwise) contouring motion.

Diagram



a Plan view.
b Side view.

Tolerance

a)		b)	
F_{XZ} max. =	0,15 mm	F_{XZ} max. =	0,25 mm
F_{XZ} min. =	– 0,15 mm	F_{XZ} min. =	– 0,25 mm
F_{ZX} max. =	0,15 mm	F_{ZX} max. =	0,25 mm
F_{ZX} min. =	– 0,15 mm	F_{ZX} min. =	– 0,25 mm

Measured deviation

a) Feed rate = ...
F_{XZ} max. = ...
F_{XZ} min. = ...
F_{ZX} max. = ...
F_{ZX} min. = ...

b) Feed rate = ...
F_{XZ} max. = ...
F_{XZ} min. = ...
F_{ZX} max. = ...
F_{ZX} min. = ...

Diameter of nominal path .....
Location of measuring instrument
— centre of circle (X/Y/Z) .....
— offset to tool reference (X/Y/Z) .....
— offset to workpiece reference (X/Y/Z) .....
Data acquisition method
— starting point .....
— number of measuring points .....
— data smoothing process .....
Compensation used .....
Positions of axes not under test .....

Measuring instruments

Test mandrel, special rotary fixture and electronic probe, or circular masterpiece and bi-dimensional probe, or telescopic ball bar or grid encoder

Observations and references to ISO 230-1:1996 **6.63**

This test is an alternative to Test K4, in cases where the test machine cannot perform a 360° measurement sweep or the test is not relevant.

Diameters may differ from the above values by a maximum of 25 %. In such cases, the feed rate shall be adjusted according to ISO 230-4:2005, Annex C. Zero the axes in a position in which the test mandrel is on the axis of rotation of the rotary fixture, or the bi-dimensional probe is in the centre of the master piece or in the centre of the socket on the workholding side for the telescopic ball bar. For the grid encoder, take readings at the zero position of the axes.

Object **K6**

Checking the interpolation between the X, Y and C axes in the XY plane over 180° or 360° at a diameter 2/3 of the X-axis stroke.

Feedrate: 500 mm/min

The bi-directional circular deviation G(b) shall be evaluated in accordance with ISO 230-4.

Diagram

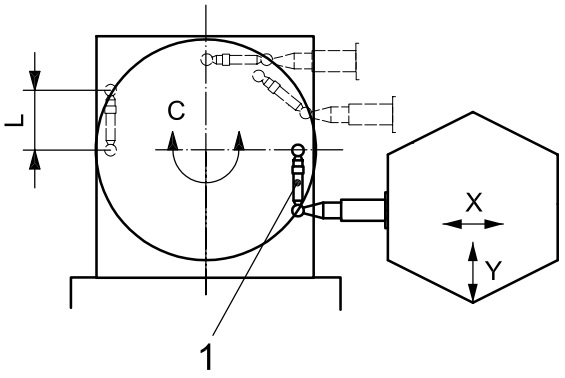


Figure 1

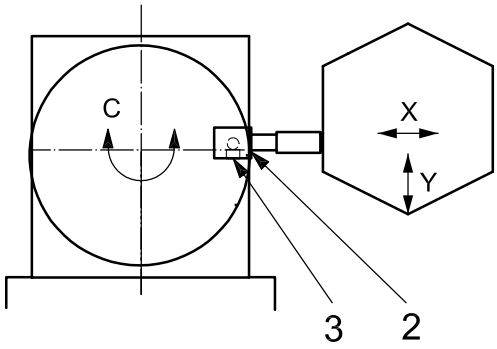


Figure 2

Key

1 ball bar
2 2-D probe
3 reference block

Tolerance

$G(b)_{XYC}$ = 0,080 mm

Measured deviation

$G(b)_{XYC}$ = ... mm

Diameter of nominal path.....

Angle of nominal path.....

Location of measuring instrument

— offset to tool reference (X/Y/Z).....

— offset in the Z axis.....

Data acquisition method

— starting point .....

— number of measuring points.....

— data smoothing process.....

Compensation used.....

Positions of axes not under test.....

Measuring instruments

Telescopic ball bar or 2D probe and reference surface

Observations and references to ISO 230-1:1996 **6.632**

The circular path of the NC programme shall be centred in the C axis. The telescoping ball bar (see Figure 1) should be as short as possible. The 2-D probe (see Figure 2) shall be deflected by the block centred radial to the circular path.

Bibliography

[1] ISO 13041-1:2004, *Test conditions for numerically controlled turning machines and turning centres — Part 1: Geometric tests for machines with a horizontal workholding spindle*

[2] ISO 13041-2, *Test conditions for numerically controlled turning machines and turning centres — Part 2: Geometric tests for machines with a vertical workholding spindle*

[3] ISO 13041-3, *Test conditions for numerically controlled turning machines and turning centres — Part 3: Geometric tests for machines with an inverted vertical workholding spindle*

[4] ISO/TR 16015:2003, *Geometrical product specifications (GPS) — Systematic errors and contributions to measurement uncertainty of length measurement due to thermal influences*

ICS 25.040.20

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