BS ISO 13041-5:2015

BSI Standards Publication

Test conditions for numerically controlled turning machines and turning centres

Part 5: Accuracy of speeds and interpolations

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National foreword

This British Standard is the UK implementation of ISO 13041-5:2015. It supersedes BS ISO 13041-5:2006 which is withdrawn.

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

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

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INTERNATIONAL STANDARD

ISO 13041-5

Second edition
2015-03-15

Test conditions for numerically controlled turning machines and turning centres —

Part 5: Accuracy of speeds and interpolations

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

Partie 5: Exactitude des vitesses et interpolations

Reference number
ISO 13041-5:2015(E)

Contents

Foreword

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

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

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

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

For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT), see the following URL: Foreword — Supplementary information.

The committee responsible for this document is ISO/TC 39, *Machine tools*, Subcommittee SC 2, *Test conditions for metal cutting machine tools*.

This second edition cancels and replaces the first edition (ISO 13041-5:2006), which has been technically revised.

ISO 13041 consists of the following part, 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 inverted vertical workholding spindles*

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

— *Part 5: Accuracy of 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 non-rotating cutting tool(s) and where cutting energy is provided by the motion of the workpiece which is driven by a spindle. 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 control orientation of the workholding and/or toolholding spindle by continuously rotating, indexing, and/or interpolating around their axes.

The objective of ISO 13041 (all parts) is to provide information as widely and as comprehensively as possible on geometric, positional, contouring, thermal, and machining tests, which can be carried out for comparison, acceptance, maintenance, or any other purpose deemed necessary by user or manufacturer.

ISO 13041 (all parts) specifies, with reference to the relevant parts of ISO 230, tests for turning centres and numerically controlled turning machines with/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.

Attention should be given to the tolerances in tests AK5, BK5, and CK5, which are reduced from ISO 13041-5 (Test K5) due to improved centring procedure or practical experience that proves that the closer tolerances can be met.

Test conditions for numerically controlled turning machines and turning centres —

Part 5: Accuracy of speeds and interpolations

1 Scope

This part of ISO 13041 specifies, with references to ISO 230-1 and ISO 230-4, certain kinematic tests for numerically controlled (NC) turning machines and turning centres, concerning the spindle speeds, the feed speeds 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.

NOTE This part of ISO 13041 applies to numerically-controlled turning machines and turning centres with horizontal, vertical, and inverted vertical type workholding spindle(s).

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

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

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

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

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

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

ISO/TR 16907[1]), *Machine tools — Numerical compensation of geometric errors*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
turning machine
machine tool in which the principle movement is on the rotation of the workpiece against the stationary cutting tool(s)

1) To be published.

3.2
manual control
mode of operation where each movement of the machine is individually initiated and controlled by the operator

3.1.3
numerical control
NC
computerized numerical control
CNC
automatic control of a process performed by a device that makes use of numerical data introduced while the operation is in progress

3.4
manually controlled turning machine
turning machine whose process steps for the machining are controlled or started by an operator without support by an NC-machining program

3.5
numerically controlled turning machine
NC turning machine
turning machine that operates under numerical control (NC) or computerized numerical control (CNC)

3.6
turning centre
NC turning machine equipped with power-driven tool(s) and the capacity to orientate the work-holding spindle around its axis

Note 1 to entry: It can include additional features such as automatic tool changing from a turret and/or magazine.

3.7
numerically controlled turning machine with horizontal workholding spindle(s)
numerically controlled turning machine where the workpiece is mounted on horizontal workholding spindle(s) against the stationary cutting tool(s) and where cutting energy is brought by the workpiece and not by the tool

Note 1 to entry: This machine is controlled by a numerical control (NC) providing automatic function.

3.8
turning centre with horizontal workholding spindle(s)
turning centre having horizontal workholding spindle(s) equipped with toolholding spindles and the capacity to orientate the workholding spindle around its axis

Note 1 to entry: This machine may include additional features such as automatic toolchanging from a magazine or Y-axis motion.

3.9
numerically controlled turning machine with vertical workholding spindle(s)
numerically controlled turning machine where the workpiece is mounted on vertical workholding spindle(s) against the stationary cutting tool(s) and where cutting energy is brought by the workpiece and not by the tool

Note 1 to entry: This machine is controlled by a numerical control (NC) providing automatic function.

3.10
turning centre with vertical workholding spindle(s)
turning centre having vertical workholding spindle(s) equipped with toolholding spindles and the capacity to orientate the workholding spindle around its axis

Note 1 to entry: This machine may include additional features such as automatic toolchanging from a magazine or Y-axis motion.

3.11
numerically controlled turning machine with inverted vertical workholding spindle(s)
NC turning machine where the workpiece is mounted on an inverted vertical workholding spindle equipped with a workholding device at the lower end of the workholding spindle

Note 1 to entry: For other types of vertical workholding spindle machine, see ISO 13041-2.

3.12
turning centre with inverted vertical workholding spindle(s)
turning centre having an inverted vertical workholding spindle equipped with a workholding device at the lower end of the vertical workholding spindle

Note 1 to entry: It can include additional features such as automatic tool changing from a magazine or Y-axis motion.

Note 2 to entry: For other types of vertical workholding spindle turning centre, see ISO 13041-2.

3.13
machine modes of operation
modes of operation of the numerically controlled or data entry devices where entries are interpreted as functions to be executed

3.14
manual mode of numerical control
non-automatic mode of numerical control of a machine in which the operator controls it without the use of pre-programmed numerical data

EXAMPLE By push button or joystick control.

3.15
manual data input mode
entry of programme data by hand at the numerical control

3.16
single block mode
mode of numerical control in which, at the initiation of the operator, only one block of control data are executed

3.17
automatic mode
mode of numerical control in which the machine operates in accordance with the programme data until stopped by the programme or the operator

4 Preliminary remarks

4.1 Measurement units

In this part of ISO 13041, all linear dimensions, deviations, and corresponding tolerances are expressed in millimetres.

4.2 Reference to ISO 230-1 and ISO 230-4

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. For tests of circular interpolation motion, reference shall be made to ISO 230-4.

4.3 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 can be performed in any order, including tests described in other parts of ISO 13041.

4.4 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.

4.5 Measuring instruments

The measuring instruments indicated in relation to the tests given in Annexes A to C are examples only. Other instruments measuring the same quantities and having at least the same measurement uncertainty and the same resolution can be used.

In some tests, it is recommended to present test results in a graphical form (see Annex D).

4.6 Software compensation

When built-in software facilities are available for compensating geometric, positioning, contouring, and/or thermal deviations, their use during these tests shall be based on agreement between manufacturer/supplier and user, with due consideration to the machine tool intended use.

When the software compensation is used, this shall be stated in the test reports. Using the definitions given in ISO/TR 16907, it shall be noted that when software compensation is used, axes shall not be locked for test purposes.

5 Tests described in Annexes A to C

Tests in Annex A refer to horizontal workholding spindle machines (ISO 13041-1, Type 1), tests in Annex B refer to vertical workholding spindle machines (ISO 13041-2, Type 2), and tests in Annex C refer to inverted vertical workholding spindle machines (ISO 13041-3, Type 3).

Annex A
(normative)

Kinematic tests for machines with a horizontal workholding spindle

A.1 Machine configuration and designation

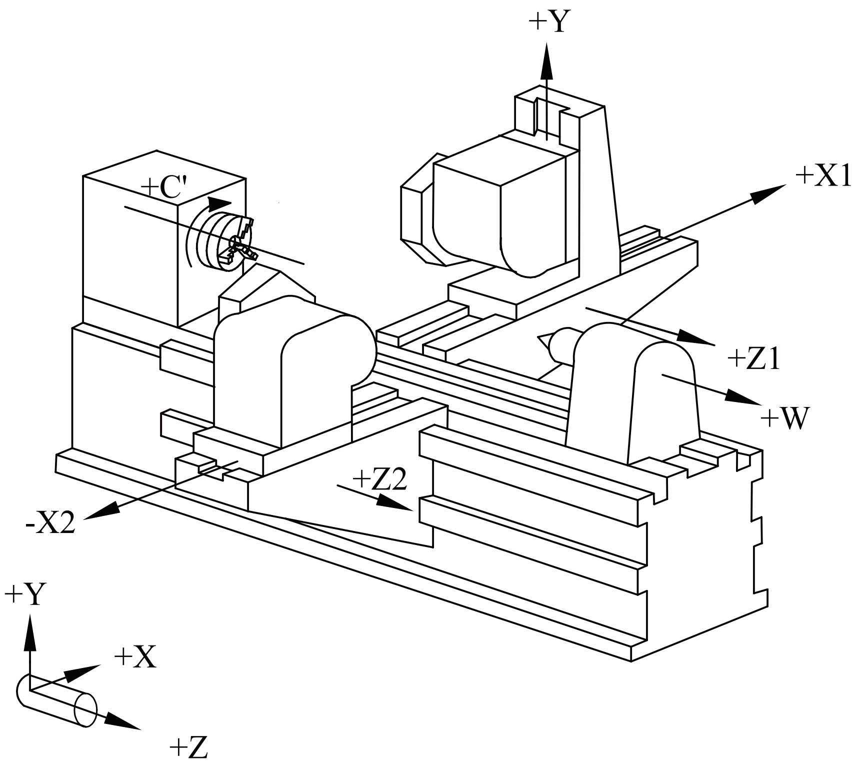


Figure A.1 — Typical example of a turning machine with a horizontal workholding spindle [[w (C') b Z X1 Y C_1 t] [w (C') b Z2 X2 C_2 t] [w (C') W {t,w}]]

Figure A.1 shows a typical example of a turning machine with a horizontal workholding spindle.

The structural configuration is described by using the structural codes to serially connect the motion axis from the workpiece side to the tool side, and vice versa. The name of axes of motion follows ISO 841. As an example, the structural code of the machine shown in Figure A.1 can be described as [[w (C') b Z X1 Y C_1 t] [w (C') b Z2 X2 C_2 t] [w (C') W {t,w}]] by connecting the motion axes from the workpiece side to the tool side. In this description, the workpiece side and the tool side are distinguished by naming the workpiece by "w", the tool by "t", and the bed by "b"; (C) stands for the spindle axis without numerical control for angular positioning. Multiple kinematic chains from the workpiece side and the tool side are all shown.

"{t,w}" in the third chain indicates that the tail stock (W or Z3) can be connected either to the workpiece or to a tool (e.g. a drill).

A.2 Kinematic tests

A.2.1 General

Tests specified in this Annex refer, for simplicity, to the example of machine configuration depicted in Figure A.1, but they are applicable to all configurations of turning machines and turning centres with a horizontal workholding spindle.

NOTE These tests might not be used directly to predict the actual workpiece errors resulting from cutting.

A.2.2 Spindle speeds (AK1) and feed speeds (AK2)

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 and the physical movement of the component.

A.2.3 Linear interpolations (AK3)

The purpose of these tests is to check the coordinated motion of two linear axes in the following two conditions:

— While these are moving either at the same speed (45°), or

— While one of these is moving at a significantly lower speed than the other (small angles).

A.2.4 Circular interpolations (AK4)

The purpose of circular interpolation motion tests is to check the coordinated motion of two linear axes along a circular path, including points in which the motion of one axis slows down to zero and the direction of movement is reversed. During these tests, axes move with variable speeds.

A.2.5 Radial interpolations (AK5)

These tests are alternative to AK4, in cases where the machine under test does not have a measurement sweep of 360° or if AK4 is otherwise not relevant. The purpose of these tests is to check the mutual behaviour of two linear axes (generally X and Z) at variable feed speeds, including points in which the feed of one axis slows down to zero and the direction of movement is reversed.

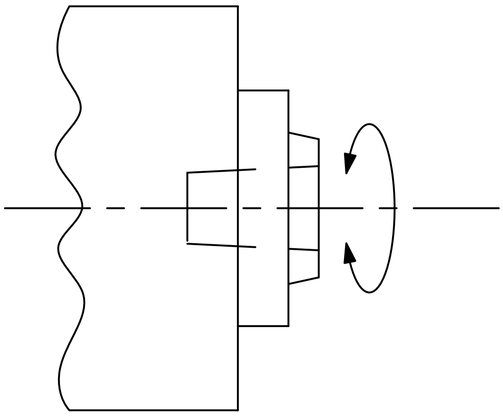
A.2.6 Circular interpolation motion by simultaneous three-axis control (X-, Y-, and C-axes) (AK6)

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

Spindle speeds

Object	**AK1**
Checking of deviations in the spindle speed at the mid-speed and the maximum speed of each range, in the clockwise and counter-clockwise (anticlockwise) directions of rotation.	

Diagram



Tolerance

±5 %

Measuring deviation

Speed range		Direction of rotation	Programmed speed	Measured speed	Deviation %
	Mid.	counter-clockwise (anticlockwise)			
		clockwise			
	Max.	counter-clockwise (anticlockwise)			
		clockwise			
	Mid.	counter-clockwise (anticlockwise)			
		clockwise			
	Max.	counter-clockwise (anticlockwise)			
		clockwise			

Measuring instruments

Revolution counter or stroboscope[a)]

a) Measuring instruments that are independent of numerical control shall be used.

Observations

Readings shall be taken at constant speed, avoiding the acceleration/deceleration at start and stop. When reading the speed instantaneously, at least five readings shall be taken and the average calculated. This test shall be done for both workholding and toolholding spindles.

The override control shall be set at 100 %.

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

$$D = \frac{A_S - P_S}{P_S} \times 100$$

where

D is the deviation in percentage;

A_S is the actual speed;

P_S is the programmed speed.

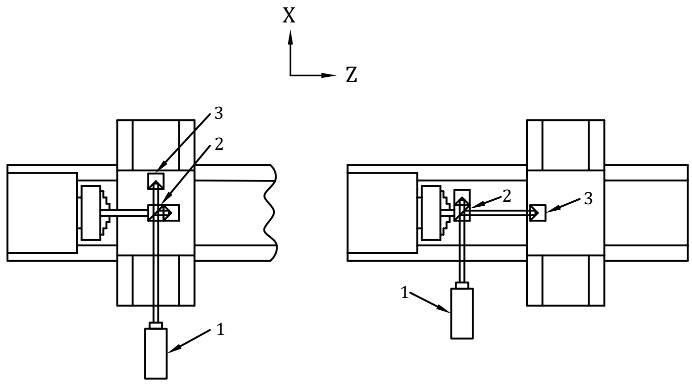
Linear axes feed speeds

Object	**AK2**

Checking of accuracy of the feed speed of the linear axes at the following feed speeds: 1 000 mm/min and maximum speed.

This test shall be performed for all linear axes. Caution should be taken when using this test over a short measurement range, due to the effects of acceleration and deceleration (typically for *y*-axis).

Diagram



For X-axis
For Z-axis

Key

1 laser head

2 interferometer

3 reflector

Tolerance

To be agreed between manufacturer/supplier and user.

Measuring deviation

Programmed feed speed	Axis	X		Y		Z	
	Direction	Measured average feed speed	% dev.	Measured average feed speed	% dev.	Measured average feed speed	% dev.
1 000 mm/min	positive						
	negative						
Maximum feed speed .... mm/min	positive						
	negative						

Measuring instruments

Laser interferometer

Observations

Align the laser interferometer (setup for positioning deviation) with the motion of the axis under test. Axis shall be commanded to execute a simple motion with two end points specified. Travel a distance of about half the axis travel range (or 500 mm, whichever is shorter) to allow the axis to accelerate, then move at constant speed, and then decelerate to stop shall be selected. Same travel distance shall be used for all feed speeds. The tests shall be carried out for both directions of travel (positive and negative). Speed data should be sampled with a minimum frequency of 100 Hz, no smoothing or averaging shall be allowed. The override control shall be set at 100 %. Reading shall be taken at constant speed, avoiding the acceleration/deceleration at start and stop. For each direction, calculate the average feed speed as the average of all measured constant feed speed values (minimum 1 000 sampled points) for a given test. This test can be carried out in conjunction with the linear positioning test.

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

$$D_f = \frac{A_f - P_f}{P_f} \times 100$$

Where

D_f is the deviation in percentage;

A_f is the measured average feed speed;

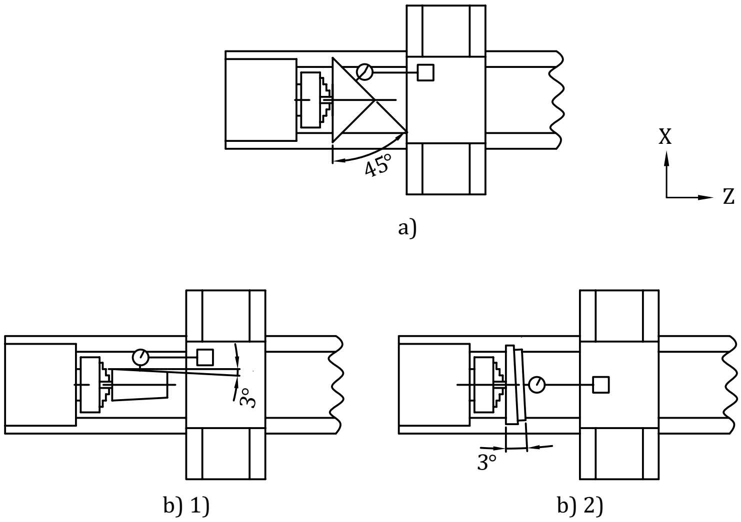
P_f is the programmed feed speed.

The measurement's sampling frequency shall be reported.

Linear interpolations

Object				**AK3**
Checking of straightness of the motion described by linear interpolation of two linear axes over a maximum measuring length of 300 mm with a measurement angle of approximately: a) 45° (same feed speed); b) 1) 3° to Z-axis motion (very low X-axis feed speed); 2) 3° to X-axis motion (very low Z-axis feed speed).				

Diagram



Tolerance	**Measured deviations**			
0,020 for any length of 100		a)	b) 1)	b) 2)
	Measured error			
	Measuring length			

Measuring instruments

Straightness reference artefact or sine bar or special cone mandrels and linear displacement sensor, or two-dimensional digital scale

Observations and references to ISO 230-1:2012, 11.2.3 and ISO/TR 230-11:—, 6.3

a) and b) 1)

For tests using special cone mandrels, clamp the cone mandrel [of the apex angle approximately a) 90° or b) 6°] in the workholding spindle chuck or collet. The spindle shall be locked. Attach a linear displacement sensor to the tool slide with the stylus contacting the conical surface square to the surface.

b) 2)

For tests using the straightness reference artefact, attach the straightness reference artefact 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 straightness reference artefact.

For all straightness of the motion 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 of the motion 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.

Circular interpolations

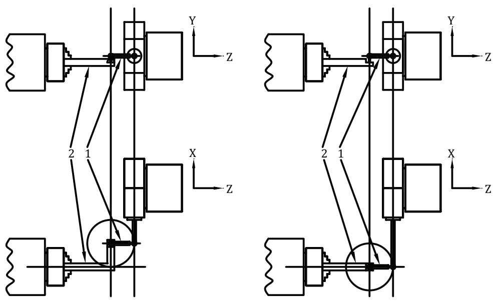
Object — **AK4**

Checking of circular deviation, G, and the bi-directional circular deviation, G(b), of the path generated by circular interpolation of two linear axes over 360°,where applicable, according to ISO 230-4, at one of the following diameters and at two feed speeds:

1) 50 mm diameter	2) 100 mm diameter	3) 200 mm diameter	4) 300 mm diameter
a) 250 mm/min	a) 350 mm/min	a) 500 mm/min	a) 610 mm/min
b)1 000 mm/min	b) 1 400 mm/min	b) 2 000 mm/min	b) 2 440mm/min

The circular deviation, G, shall be checked for clockwise and counter-clockwise (anticlockwise) contouring motion. This test shall be performed in the XY, YZ, and ZX planes, or in the plane composed by other pairs of linear axes (X2, Z2, etc.).

Diagram



Alternative

Key

1 telescopic ball bar

2 special fixture

Tolerance

Tolerance of G_{ab} and G_{ba} is the same as $G(b)_{ab}$, where ab = XY, YZ, or ZX.

a) $G(b)_{XZ}$ = 0,03 mm
$G(b)_{XY,YZ}$ = 0,05 mm

b) $G(b)_{XZ}$ = 0,05 mm
$G(b)_{XY,YZ}$ = 0,07 mm

Measuring deviation

a) feed speed = ...
G_{XZ} = ...
$G_{XY,YZ}$ = ...
$G(b)_{XZ}$ = ...
$G(b)_{XY,YZ}$ = ...

b) feed speed = ...
G_{XZ} = ...
$G_{XY,YZ}$ = ...
$G(b)_{XZ}$ = ...
$G(b)_{XY,YZ}$ = ...

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

Telescopic ball bar or two-dimensional digital scale (grid scale)

Observations and references to ISO 230-1:2012, 11.3 and 11.4, and ISO 230-4:2005.

If 360° rotation is not possible, see AK5.

Diameters can differ from the above values in agreement between the manufacturer/supplier and user. In such cases, the feed speed has to be adjusted according to ISO 230-4:2005, Annex C.

Start the interpolation in one of the four quadrants. Ideally, measurements should be recorded at a start point other than one of the four reversal points and should have adequate feed in/out motion around the area being inspected; this will help ensure accurate capture of machine performance measurements, including that at the reversal points.

Radial interpolations

Object — **AK5**

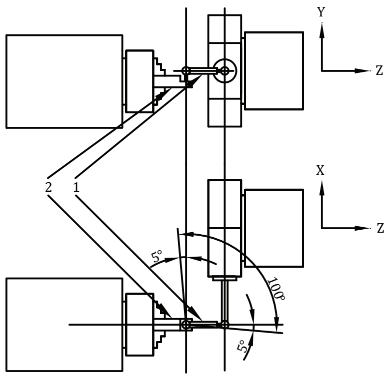
Checking of radial deviation, *F*, of the path generated by circular interpolation of two linear axes over 100°, according to ISO 230-4, at one of the following diameters and at two feed speeds:

1) 50 mm diameter	2) 100 mm diameter	3) 200 mm diameter	4) 300 mm diameter
a) 250 mm/min	a) 350 mm/min	a) 500 mm/min	a) 610 mm/min
b) 1 000 mm/min	b) 1 400 mm/min	b) 2 000 mm/min	b) 2 440mm/min

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

This test shall be performed in the XY, YZ, and ZX planes, or in the plane composed by other pairs of linear axes (X2, Z2, etc.).

Diagram



Key

1 telescopic ball bar

2 special fixture

Tolerance

Tolerance of G_{ab} and G_{ba} is the same as $G(b)_{ab}$, where ab = XY, YZ, or ZX.

a)		b)	
	$F_{XZ,max.}$ = 0,05 mm		$F_{XZ,max.}$ = 0,07 mm
	$F_{XZ,min.}$ = −0,05 mm		$F_{XZ,min.}$ = −0,07 mm
	$F_{XY,YZ,max.}$ = 0,07 mm		$F_{XY,YZ,max.}$ = 0,09 mm
	$F_{XY,YZ,min.}$ = −0,07 mm		$F_{XY,YZ,min.}$ = −0,09 mm

References to ISO 230-4:2005, 3.5

NOTE The radial deviation contains the influence of the position (setup) error of the work spindle side sphere of the ball bar and thus is generally larger than the circular deviation.

Measuring deviation

a) feed speed = ...	Diameter of nominal path ....
$F_{XZ,max.}$ = ...	Location of measuring instrument
$F_{XZ,min.}$ = ...	— centre of circle (X/Y/Z) ....
$F_{XY,YZ,max.}$ = ...	— offset to tool reference (X/Y/Z) ....
$F_{XY,YZ,min.}$ = ...	— offset to workpiece reference (X/Y/Z) ....
	Data acquisition method
b) feed speed = ...	— starting point ....
$F_{XZ,max.}$ = ...	— number of measuring points ....
$F_{XZ,min.}$ = ...	— data smoothing process ....
$F_{XY,YZ,max.}$ = ...	Compensation used ....
$F_{XY,YZ,min.}$ = ...	Positions of axes not under test ....

Measuring instruments

Telescopic ball bar or two-dimensional digital scale (grid scale)

Observations and references to ISO 230-1:2012, 11.3

This test is an alternative to Test AK4, in cases where the test machine cannot perform a 360° measurement sweep or the test is not relevant.

Diameters can differ from the above values in agreement between the manufacturer/supplier and user. In such cases, the feed speed has to be adjusted according to ISO 230-4:2005, Annex C.

Circular interpolation motion by simultaneous three-axis control (X-, Y- and, C-axes)

Object | **AK6**

Checking of the deviations of the tool centre point trajectory (ideally a fixed point in the workpiece coordinate system) with the simultaneous three axes interpolation of two linear axes (X- and Y- axes) and a rotary axis (C-axis) over 180° or 360° at a diameter 2/3 of X-axis stroke or Y-axis stroke, whichever is smaller. The sensitive direction of the measurement shall be set as follows:

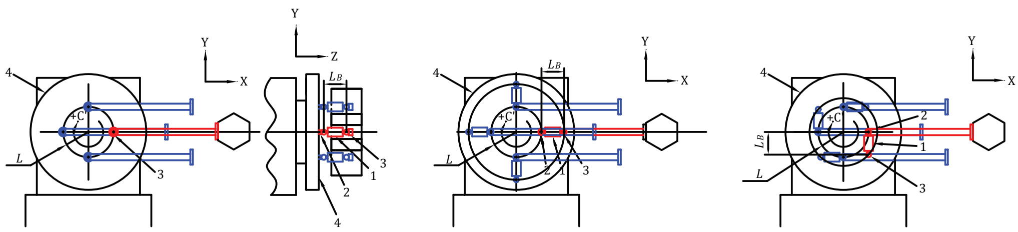
a) Parallel to the rotary axis (C-axis), $E_{\text{int,axialC,XYC (CW, CCW)}}$;

b) Radial to the rotary axis (C-axis), $E_{\text{int,radialC,XYC (CW, CCW)}}$;

c) Tangential to the rotation of the rotary axis (C-axis), $E_{\text{int,tangentialC,XYC (CW, CCW)}}$.

The reference length of the ball bar*L* is 100 mm, and the feed speed is 500 mm/min or agreed between the manufacturer/supplier and user. Measurements shall be conducted for clockwise and counter-clockwise (anticlockwise) of C-axis motion.

Diagram



a) b) c)

Key

1 telescopic ball bar

2 sphere socket (spindle side)

3 sphere socket (tool side)

4 spindle

L nominal distance between the centre of toolholding spindle-side sphere and axis of rotation

Tolerance (to be agreed between manufacturer/supplier and user)	**Measured deviations**
a) $E_{\text{int,axialC,XYC (CW, CCW)}}$ = ...	a) $E_{\text{int,axialC,XYC (CW, CCW)}}$ = ...
b) $E_{\text{int,radialC,XYC (CW, CCW)}}$ = ...	b) $E_{\text{int,radialC,XYC (CW, CCW)}}$ = ...
c) $E_{\text{int,tangentialC,XYC (CW, CCW)}}$ = ...	c) $E_{\text{int,tangentialC,XYC (CW, CCW)}}$ = ...

Measuring instruments

Telescopic ball bar, or sphere-ended test mandrel and flat-ended linear displacement sensor(s) or sensors nest (e.g. R-test).

Observations and references to ISO 230-1:2012, 11.3.5

The circular path of the NC programme has to be centred in the C-axis average line. For each test, continuously record the readings of the ball bar (changes of its length) or linear displacement sensor(s) during the interpolated motion. Report the difference between the maximum and minimum recorded values for a), b), and c).

The offset of the workholding spindle-side sphere to C-axis average line, *L*, shall be reported. In b) and c), the centre of the toolholding spindle-side sphere shall be aligned on the toolholding spindle axis average line. Any misalignment will influence the test result. Sphere-ended test mandrel and a sensors nest (e.g. R-test) can be also used. See Annex D for test procedure and for additional precautions.

NOTE It is recommended to present test results in a graphical form (see D.3.3).

Annex B
(normative)

Kinematic tests for machines with a vertical workholding spindle

B.1 Machine configuration and designation

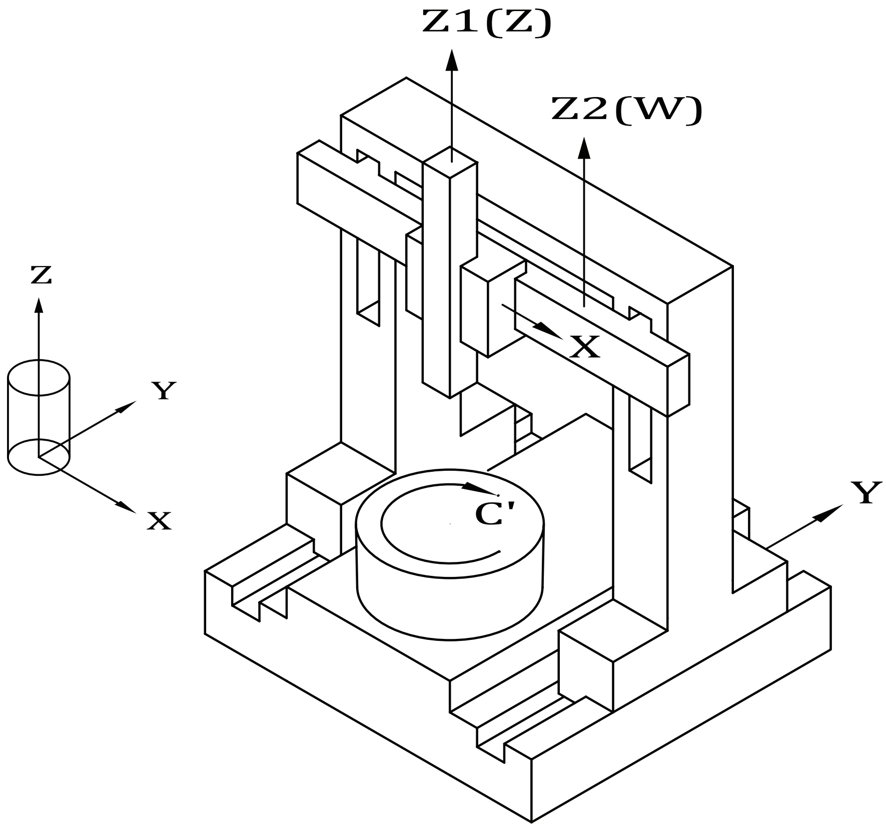


Figure B.1 — Typical example of a turning machine with a vertical workholding spindle [w (C') b Y Z2 X Z1 t]

Figure B.1 shows a typical example of a turning machine with a vertical workholding spindle.

The structural configuration is described by using the structural codes to serially connect the motion axis from the workpiece side to the tool side, and vice versa. The name of axes of motion follows ISO 841. As an example, the structural code of the machine shown in Figure B.1 can be described as [w (C') b Y X Z B t] by connecting the motion axes from the workpiece side to the tool side. In this description, the workpiece side and the tool side are distinguished by naming the workpiece by "w", the tool by "t", and the bed by "b"; (C') stands for the spindle axis without numerical control for angular positioning.

B.2 Kinematic tests

B.2.1 General

Tests specified in this Annex refer, for simplicity, to the example of machine configuration depicted in Figure B.1 but they are applicable to all configurations of turning machines and turning centres with a vertical workholding spindle.

NOTE These tests might not be used directly to predict the actual workpiece errors resulting from cutting.

B.2.2 Spindle speeds (BK1) and feed speeds (BK2)

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 and the physical movement of the component.

B.2.3 Linear interpolations (BK3)

The purpose of these tests is to check the coordinated motion of two linear axes in the following two conditions:

— while these are moving either at the same speed (45°) or

— while one of these is moving at a significantly lower speed than the other (small angles).

B.2.4 Circular interpolations (BK4)

The purpose of circular interpolation motion tests is to check the coordinated motion of two linear axes along a circular path, including points in which the motion of one axis slows down to zero and the direction of movement is reversed. During these tests, axes move with variable speeds.

B.2.5 Radial interpolations (BK5)

These tests are an alternative to BK4, in cases where the machine under test does not have a measurement sweep of 360° or if BK4 is otherwise not relevant. The purpose of these tests is to check the mutual behaviour of two linear axes (generally X and Z) at variable feed speeds, including points in which the feed of one axis slows down to zero and the direction of movement is reversed.

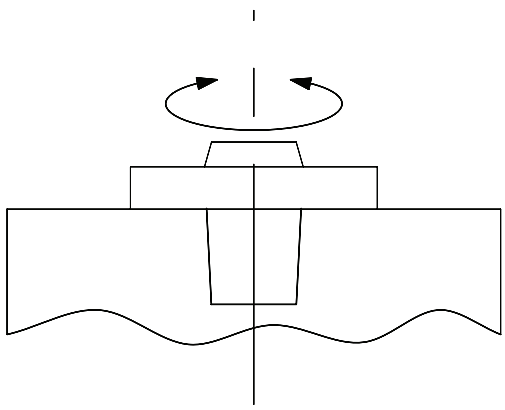
B.2.6 Circular interpolation motion by simultaneous three-axis control (X-, Y-, and C-axes) (BK6)

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

Spindle speeds

Object	**BK1**
Checking of deviations in the spindle speed at the mid-speed and the maximum speed of each range, in the clockwise and counter-clockwise (anticlockwise) directions of rotation.	

Diagram



Tolerance

±5 %

Measuring deviation

Speed range		Direction of rotation	Programmed speed	Measured speed	Deviation %
	Mid.	counter-clockwise (anticlockwise)			
		clockwise			
	Max.	counter-clockwise (anticlockwise)			
		clockwise			
	Mid.	counter-clockwise (anticlockwise)			
		clockwise			
	Max.	counter-clockwise (anticlockwise)			
		clockwise			

Measuring instruments

Revolution counter or stroboscope[a)]

a) Measuring instruments that are independent of numerical control shall be used.

Observations

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

When reading the speed instantaneously, at least five readings shall be taken and the average calculated. This test shall be done for both workholding and toolholding spindles.

The override control shall be set at 100 %.

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

$$D = \frac{A_S - P_S}{P_S} \times 100$$

where

D is the deviation in percentage;

A_S is the actual speed;

P_S is the programmed speed.

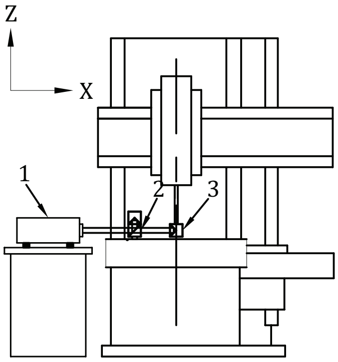
Linear axes feed speeds

Object — **BK2**

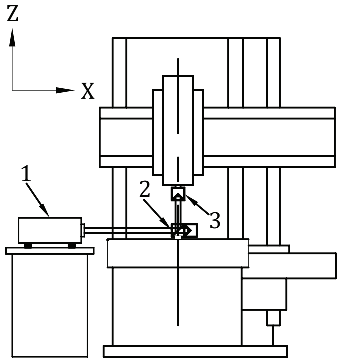
Checking of accuracy of the feed speed of the linear axes at the following feed speeds: 1 000 mm/min and maximum speed.

This test shall be performed for all linear axes. Caution should be taken when using this test over a short measurement range, due to the effects of acceleration and deceleration (typically for y-axis).

Diagram



For X-axis



For Z-axis

Key

1 laser head

2 interferometer

3 reflector

Tolerance

To be agreed between manufacturer/supplier and user.

Measuring deviation

Programmed feed speed	Axis	X		Y		Z	
	Direction	Measured average feed speed	% dev.	Measured average feed speed	% dev.	Measured average feed speed	% dev.
1 000 mm/min	positive						
	negative						
Maximum feed speed .... mm/min	positive						
	negative						

Measuring instruments

Laser interferometer

Observations

Align the laser interferometer (setup for positioning deviation) with the motion of the axis under test. Axis shall be commanded to execute a simple motion with two end points specified. Travel a distance of about half the axis travel range (or 500 mm whichever is shorter) to allow the axis to accelerate, then move at constant speed, and then decelerate to stop shall be selected. Same travel distance shall be used for all feed speeds. The tests shall be carried out for both directions of travel (positive and negative). Speed data should be sampled with a minimum frequency of 100 Hz, no smoothing or averaging shall be allowed. The override control shall be set at 100 %. Reading shall be taken at constant speed, avoiding the acceleration/deceleration at start and stop. For each direction, calculate the average feed speed as the average of all measured constant feed speed values (minimum 1 000 sampled points) for a given test.

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

$$D_f = \frac{A_f - P_f}{P_f} \times 100$$

where

D_f is the deviation in percentage;

A_f is the measured average feed speed;

P_f is the programmed feed speed.

The measurement's sampling frequency shall be reported.

NOTE This test can be carried out in conjunction with the linear positioning test.

Linear interpolations

Object	**BK3**

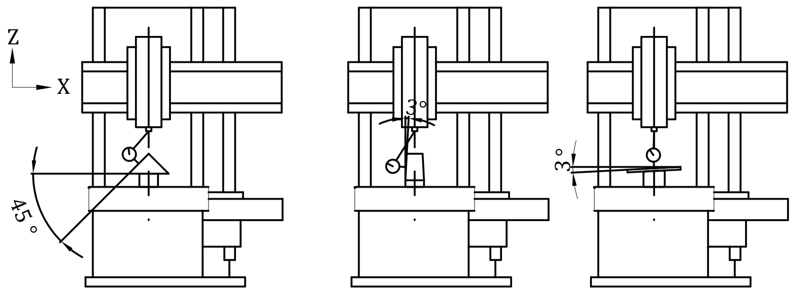
Checking of straightness of the motion described by linear interpolation of two linear axes over a maximum measuring length of 300 mm with a measurement angle of approximately:

a) 45° (same feed speed);

b) 1) 3° to Z-axis motion (very low X-axis feed speed);

2) 3° to X-axis motion (very low Z-axis feed speed).

Diagram



Tolerance	**Measured deviations**			
		a)	b) 1)	b) 2)
0,020 for any length of 100	Measured error			
	Measuring length			

Measuring instruments

Straightness reference artefact or sine bar or special cone mandrels and linear displacement sensor or two-dimensional digital scale

Observations and references to ISO 230-1:2012, 11.2.3 and ISO/TR 230-11:2005, 6.3

a) and b) 1)

For tests using special cone mandrels, clamp the cone mandrel [of the apex angle approximately a) 90° or b) 6°] in the workholding spindle chuck or collet. The spindle shall be locked. Attach a linear displacement sensor to the tool slide with the stylus contacting the conical surface square to the surface.

b) 2)

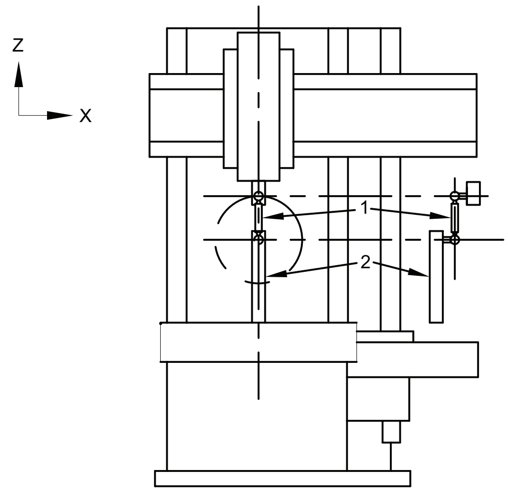
For tests using the straightness reference artefact, attach the straightness reference artefact to the workholding spindle faceplate or four-jaw chuck with gauging surface at approximately 3° to the X-axis travel. Lock the workholding spindle rotation. Attach a linear displacement sensor to the tool slide with the stylus contacting the gauging surface of the straightness reference artefact.

For all straightness of the motion 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 of the motion 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.

Circular interpolations

Object	**BK4**
Checking the circular deviation, G, and the bi-directional circular deviation, G(b), of the path generated by circular interpolation of two linear axes over 360°,where applicable, according to ISO 230-4, at one of the following diameters and at two feed speeds, as follows: 1) 50 mm diameter / 2) 100 mm diameter / 3) 200 mm diameter / 4) 300 mm diameter a) 250 mm/min / a) 350 mm/min / a) 500 mm/min / a) 610 mm/min b)1 000 mm/min / b) 1 400 mm/min / b) 2 000 mm/min / b) 2 440mm/min The circular deviation, G, shall be checked for clockwise and counter-clockwise (anticlockwise) contouring motion. This test shall be performed in the XY, YZ, and ZX planes, or in the plane composed by other pairs of linear axes (X2, Z2, W, etc.).	

Diagram



Key

1 telescopic ball bar

2 special fixture

Alternative

Tolerance

Tolerance of G_{ab} and G_{ba} is the same as $G(b)_{ab}$, where ab = XY, YZ, or ZX.

a)	$G(b)_{XZ}$ = 0,03 mm	b)	$G(b)_{XZ}$ = 0,05 mm
	$G(b)_{XY,YZ}$ = 0,05 mm		$G(b)_{XY,YZ}$ = 0,07 mm

Measuring deviation

a)	feed speed = ...	Diameter of nominal path ....
	G_{XZ} = ...	Location of measuring instrument
	$G_{XY,YZ}$ = ...	— centre of circle (X/Y/Z) ....
	$G(b)_{XZ}$ = ...	— offset to tool reference (X/Y/Z) ....
	$G(b)_{XY,YZ}$ = ...	— offset to workpiece reference (X/Y/Z) ....
b)	feed speed = ...	Data acquisition method
	G_{XZ} = ...	— starting point ....
	$G_{XY,YZ}$ = ...	— number of measuring points ....
	$G(b)_{XZ}$ = ...	— data smoothing process ....
	$G(b)_{XY,YZ}$ = ...	Compensation used ....
		Positions of axes not under test ....

Measuring instruments

Telescopic ball bar or two-dimensional digital scale (grid scale)

Observations and references to ISO 230-1:2012, 11.3 and 11.4, and ISO 230-4

If 360° rotation is not possible, see BK5.

Diameters can differ from the above values in agreement between the manufacturer/supplier and user. In such cases, the feed speed has to be adjusted according to ISO 230-4:2005, Annex C.

Start the interpolation in one of the four quadrants. Ideally, measurements should be recorded at a start point other than one of the four reversal points and should have adequate feed in/out motion around the area being inspected; this will help ensure accurate capture of machine performance measurements, including that at the reversal points.

Radial interpolations

Object | **BK5**

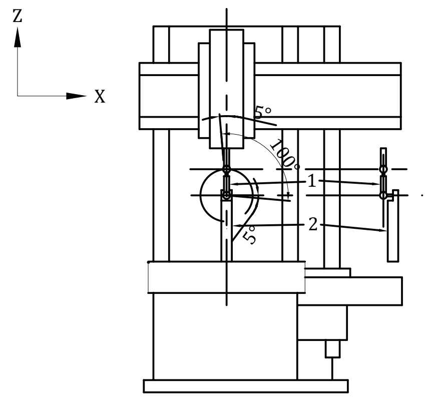
Checking the radial deviation, *F*, of the path generated by circular interpolation of two linear axes over 100°, according to ISO 230-4, at one of the following diameters and at two feed speeds:

1) 50 mm diameter	2) 100 mm diameter	3) 200 mm diameter	4) 300 mm diameter
a) 250 mm/min	a) 350 mm/min	a) 500 mm/min	a) 610 mm/min
b) 1 000 mm/min	b) 1 400 mm/min	b) 2 000 mm/min	b) 2 440mm/min

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

This test shall be performed in the XY, YZ, and ZX planes, or in the plane composed by other pairs of linear axes (X2, Z2, W, etc.).

Diagram



Key

1 telescopic ball bar

2 special fixture

Tolerance

a)

$F_{XZ,max.}$ = 0,05 mm

$F_{XZ,min.}$ = −0,05 mm

$F_{XY,YZ,max.}$ = 0,07 mm

$F_{XY,YZ,min.}$ = −0,07 mm

b)

$F_{XZ,max.}$ = 0,07 mm

$F_{XZ,min.}$ = −0,07 mm

$F_{XY,YZ,max.}$ = 0,09 mm

$F_{XY,YZ,min.}$ = −0,09 mm

References to ISO 230-4:2005, 3.5

NOTE The radial deviation contains the influence of the position (setup) error of the work spindle side sphere of the ball bar and thus is generally larger than the circular deviation.

Measuring deviation

a) feed speed = ...	Diameter of nominal path	
$F_{XZ,max.}$ = ...	Location of measuring instrument	
$F_{XZ,min.}$ = ...	—	centre of circle (X/Y/Z) ....
$F_{XY,YZ,max.}$ = ...	—	offset to tool reference (X/Y/Z) ....
$F_{XY,YZ,min.}$ = ...	—	offset to workpiece reference (X/Y/Z) ....
	Data acquisition method	
b) feed speed = ...	—	starting point ....
$F_{XZ,max.}$ = ...	—	number of measuring points ....
$F_{XZ,min.}$ = ...	—	data smoothing process ....
$F_{XY,YZ,max.}$ = ...	Compensation used	
$F_{XY,YZ,min.}$ = ...	Positions of axes not under test	

Measuring instruments

Telescopic ball bar or two-dimensional digital scale (grid scale)

Observations and references to ISO 230-1:2012, 11.3

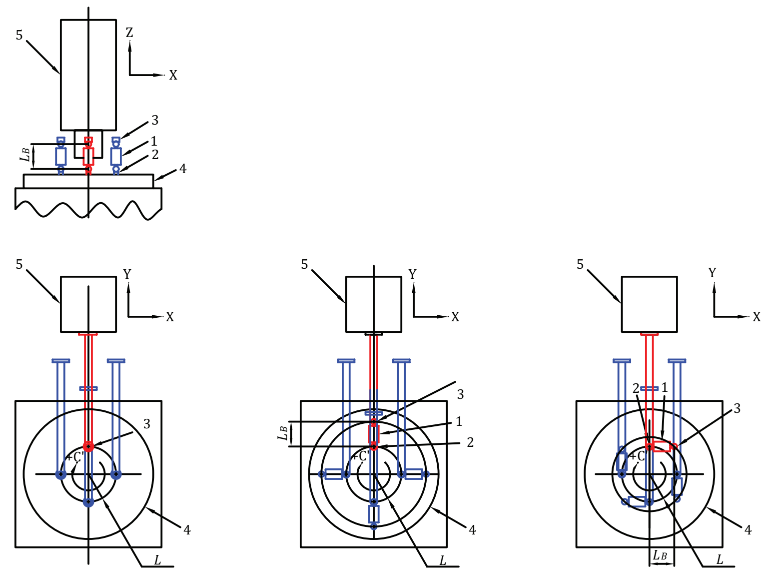
This test is an alternative to Test BK4, in cases where the test machine cannot perform a 360° measurement sweep or the test is not relevant.

Diameters can differ from the above values in agreement between the manufacturer/supplier and user. In such cases, the feed speed has to be adjusted according to ISO 230-4:2005, Annex C.

Circular interpolation motion by simultaneous three-axis control (X-, Y-, and C-axes)

Object	**BK6**
Checking of the deviations of the tool centre point trajectory (ideally a fixed point in the workpiece coordinate system) with the simultaneous three axes interpolation of two linear axes (X- and Y-axes) and a rotary axis (C-axis) over 180° or 360° at a diameter 2/3 of x-axis stroke or Y-axis stroke, whichever is smaller. The sensitive direction of the measurement shall be set as follows: a) Parallel to the rotary axis (C-axis), $E_{\text{int,axialC,XYC (CW, CCW)}}$; b) Radial to the rotary axis (C-axis), $E_{\text{int,radialC,XYC (CW, CCW)}}$; c) Tangential to the rotation of the rotary axis (C-axis), $E_{\text{int,tangentialC,XYC (CW, CCW)}}$. The reference length of the ball bar, L_B, is 100 mm, and the feed speed is 500 mm/min or agreed between the manufacturer/supplier and user. Measurements shall be conducted for clockwise and counter-clockwise (anticlockwise) of C-axis motion.	

Diagram



a) b) c)

Key

1 telescopic ball bar
2 sphere socket (spindle side)
3 sphere socket (tool side)
4 workholding spindle
5 ram(toolhead)
L nominal distance between the centre of toolholding spindle-side sphere and axis of rotation

Tolerance (to be agreed between manufacturer/ supplier and user)	**Measured deviations**
a) $E_{\text{int,axialC,XYC (CW, CCW)}}$ = ...	a) $E_{\text{int,axialC,XYC (CW, CCW)}}$ = ...
b) $E_{\text{int,radialC,XYC (CW, CCW)}}$ = ...	b) $E_{\text{int,radialC,XYC (CW, CCW)}}$ = ...
c) $E_{\text{int,tangentialC,XYC (CW, CCW)}}$ = ...	c) $E_{\text{int,tangentialC,XYC (CW, CCW)}}$ = ...

Measuring instruments

Telescopic ball bar, or sphere-ended test mandrel and flat-ended linear displacement sensor(s) or sensors nest (e.g. R-test)

Observations and references to ISO 230-1:2012, 11.3.5

The circular path of the NC programme has to be centred in the C-axis average line. For each test, continuously record the readings of the ball bar (changes of its length) or linear displacement sensor(s) during the interpolated motion. Report the difference between the maximum and minimum recorded values for a), b), and c).

The offset of the workholding spindle-side sphere to C-axis average line, *L*, shall be reported. In b) and c), the centre of the toolholding spindle-side sphere shall be aligned on the toolholding spindle axis average line. Any misalignment will influence the test result. Sphere-ended test mandrel and a sensors nest (e.g. R-test) can be also used. See Annex D for test procedure and for additional precautions.

NOTE It is recommended to present test results in a graphical form (see D.3.3).

Annex C
(normative)

Kinematic tests for machines with inverted vertical workholding spindles

C.1 Machine configuration and designation

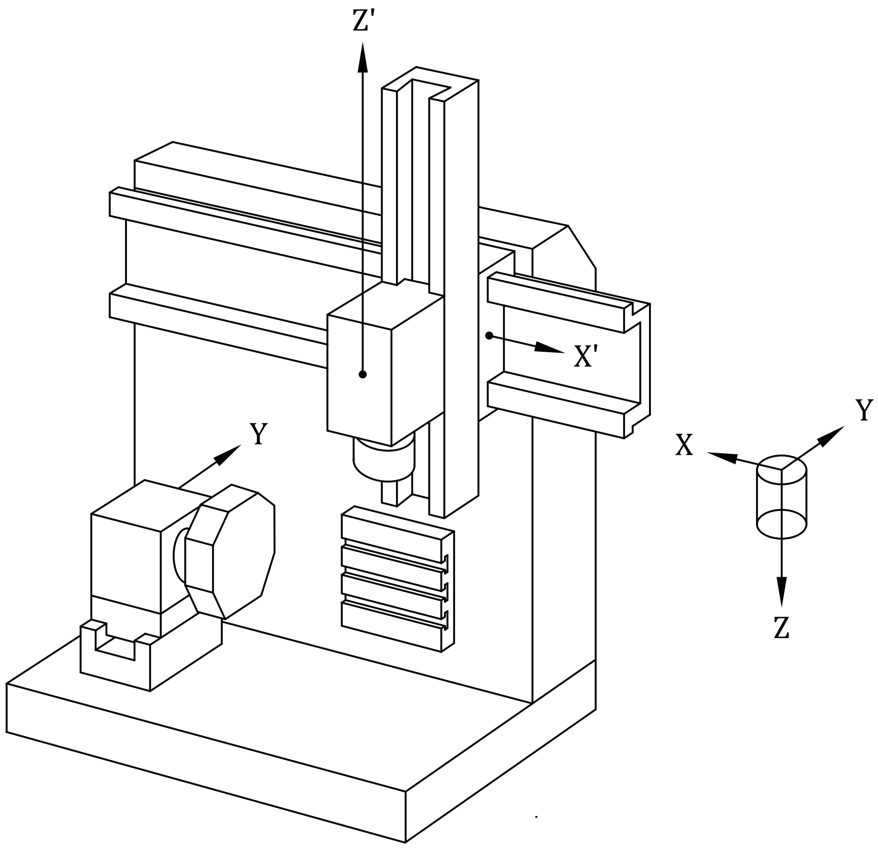


Figure C.1 — Typical example of a turning machine with an inverted vertical workholding spindle [w (C’) Z’ X’ b Y A t]

Figure C.1 shows a typical example of a turning machine with an inverted vertical workholding spindle.

The structural configuration is described by using the structural codes to serially connect the motion axis from the workpiece side to the tool side, and vice versa. The name of axes of motion follows ISO 841. As an example, the structural code of the machine shown in Figure A.1 can be described as [w (C’) Z’ X’ b Y A t] by connecting the motion axes from the workpiece side to the tool side. In this description, the workpiece side and the tool side are distinguished by naming the workpiece by “w”, the tool by “t”, and the bed by “b”; (C’) stands for the spindle axis without numerical control for angular positioning.

C.2 Kinematic tests

C.2.1 General

Tests specified in this Annex refer, for simplicity, to the example of machine configuration depicted in Figure C.1 but they are applicable to all configurations of turning machines and turning centres with an inverted vertical workholding spindle.

NOTE These tests might not be used directly to predict the actual workpiece errors resulting from cutting.

C.2.2 Spindle speeds (CK1) and feed speeds (CK2)

The purposes of these tests are to check the overall accuracy of all the electric, electronic, and kinematic chain in the control system between the command and the physical movement of the component.

C.2.3 Linear interpolations (CK3)

The purpose of these tests is to check the coordinated motion of two linear axes in the following two conditions:

— while these are moving either at the same speed (45°);

— while one of these is moving at a significantly lower speed than the other (small angles).

C.2.4 Circular interpolations (CK4)

The purpose of circular interpolation motion tests is to check the coordinated motion of two linear axes along a circular path, including points in which the motion of one axis slows down to zero and the direction of movement is reversed. During these tests, axes move with variable speeds.

C.2.5 Radial interpolations (CK5)

These tests are an alternative to CK4, in cases where the machine under test does not have a measurement sweep of 360° or if CK4 is otherwise not relevant. The purpose of these tests is to check the mutual behaviour of two linear axes (generally X and Z) at variable feed speeds, including points in which the feed of one axis slows down to zero and the direction of movement is reversed.

C.2.6 Circular interpolation motion by simultaneous three-axis control (X-, Y- and C-axes) (CK6)

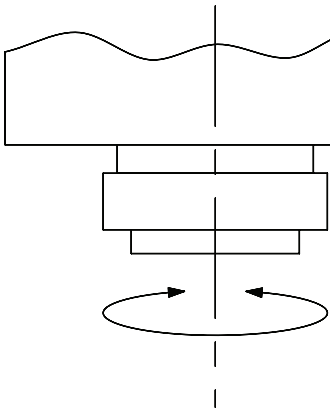
The purpose of these tests is to check the interpolation between the X-, Y-, and C-axes of a turning centre for clockwise and counter-clockwise(anticlockwise) contouring motions.

Spindle speeds

Object | **CK1**

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

Diagram



Tolerance

±5 %

Measuring deviation

Speed range		Direction of rotation	Programmed speed	Measured speed	Deviation %
	Mid.	counter-clockwise (anticlockwise)			
		clockwise			
	Max.	counter-clockwise (anticlockwise)			
		clockwise			
	Mid.	counter-clockwise (anticlockwise)			
		clockwise			
	Max.	counter-clockwise (anticlockwise)			
		clockwise			

Measuring instruments

Revolution counter or stroboscope [a)]

a) Measuring instruments that are independent of numerical control shall be used.

Observations

Readings shall be taken at constant speed, avoiding the acceleration/deceleration at start and stop. When reading the speed instantaneously, at least five readings shall be taken and the average calculated. This test shall be done for both workholding and toolholding spindles.

The override control shall be set at 100 %.

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

$$D = \frac{A_S - P_S}{P_S} \times 100$$

where

D is the deviation in percentage;

A_S is the actual speed;

P_S is the programmed speed.

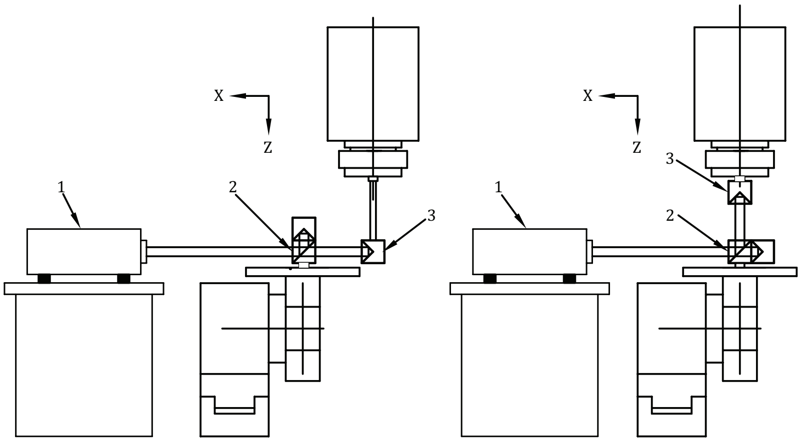
Linear axes feed speeds

Object — **CK2**

Checking of accuracy of the feed speed of the linear axes at the following feed speeds: 1 000 mm/min and maximum speed.

This test shall be performed for all linear axes. Caution should be taken when using this test over a short measurement range, due to the effects of acceleration and deceleration (typically for *y*-axis).

Diagram



For X-axis   For Z-axis

Key

laser head

interferometer

reflector

Tolerance

To be agreed between manufacturer/supplier and user.

Measuring deviation

	Axis	X		Y		Z	
	Direction	Measured average feed speed	% dev.	Measured average feed speed	% dev.	Measured average feed speed	% dev.
Programmed feed speed 1 000 mm/min	positive						
	negative						
Maximum feed speed .... mm/min	positive						
	negative						

Measuring instruments

Laser interferometer

Observations

Align the laser interferometer (setup for positioning deviation) with the motion of the axis under test. Axis shall be commanded to execute a simple motion with two end points specified. Travel a distance of about half the axis travel range (or 500 mm whichever is shorter) to allow the axis to accelerate, then move at constant speed, and then decelerate to stop shall be selected. Same travel distance shall be used for all feed speeds. The tests shall be carried out for both directions of travel (positive and negative). Speed data should be sampled with a minimum frequency of 100 Hz, no smoothing or averaging shall be allowed. The override control shall be set at 100 %. Reading shall be taken at constant speed, avoiding the acceleration/deceleration at start and stop. For each direction, calculate the average feed speed as the average of all measured constant feed speed values (minimum 1 000 sampled points) for a given test.

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

$$D_f = \frac{A_f - P_f}{P_f} \times 100$$

where

D_f is the deviation in percentage;

A_f is the measured average feed speed;

P_f is the programmed feed speed.

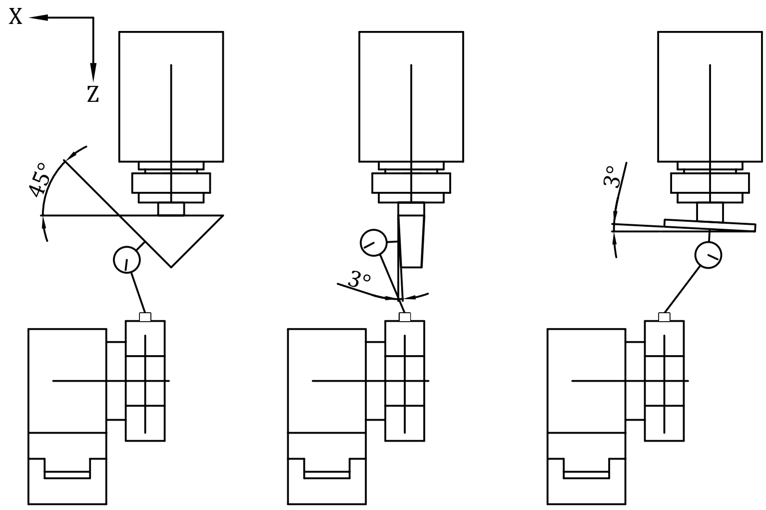
The measurement's sampling frequency shall be reported.

NOTE This test can be carried out in conjunction with the linear positioning test.

Linear interpolations

Object	**CK3**
Checking of straightness of the motion described by linear interpolation of two linear axes over a maximum measuring length of 300 mm with a measurement angle of approximately: a) 45° (same feed speed); b) 1) 3° to Z-axis motion (very low X-axis feed speed); 2) 3° to X-axis motion (very low Z-axis feed speed).	

Diagram



Tolerance	**Measured deviations**			
		a)	b) 1)	b) 2)
0,020 for any length of 100	Measured error			
	Measuring length			

Measuring instruments

Straightness reference artefact or sine bar or special cone mandrels and linear displacement sensor or two-dimensional digital scale

Observations and references to ISO 230-1:2012, 3.9.2 and ISO/TR 230-11:—, 6.3

a) and b) 1)

For tests using special cone mandrels, clamp the cone mandrel [of the apex angle approximately a) 90° or b) 6°] in the workholding spindle chuck or collet. The spindle shall be locked. Attach a linear displacement sensor to the tool slide with the stylus contacting the conical surface square to the surface.

b) 2)

For tests using the straightness reference artefact, attach the straightness reference artefact 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 sraightness reference artefact.

For all straightness of the motion 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 of the motion 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.

Circular interpolations

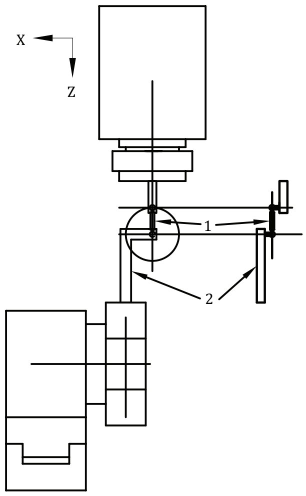
Object — **CK4**

Checking the circular deviation, G, and the bi-directional circular deviation, G(b), of the path generated by circular interpolation of two linear axes over 360°,where applicable, according to ISO 230-4, at one of the following diameters and at two feed speeds, as follows:

1) 50 mm diameter	2) 100 mm diameter	3) 200 mm diameter	4) 300 mm diameter
a) 250 mm/min	a) 350 mm/min	a) 500 mm/min	a) 610 mm/min
b)1 000 mm/min	b) 1 400 mm/min	b) 2 000 mm/min	b) 2 440mm/min

The circular deviation, G, shall be checked for clockwise and counter-clockwise (anticlockwise) contouring motion. This test shall be performed in the XY, YZ, and ZX planes, or in the plane composed by other pairs of linear axes (U, V, W, etc.).

Diagram



Key

1 telescopic ball bar

2 special fixture

Tolerance

Tolerance of G_{ab} and G_{ba} is the same as $G(b)_{ab}$, where ab = XY, YZ, or ZX.

a) $G(b)_{XZ}$ = 0,03 mm
$G(b)_{XY,YZ}$ = 0,05 mm

b) $G(b)_{XZ}$ = 0,05 mm
$G(b)_{XY,YZ}$ = 0,07 mm

Measuring deviation

a) feed speed = ...
G_{XZ} = ...
$G_{XY,YZ}$ = ...
$G(b)_{XZ}$ = ...
$G(b)_{XY,YZ}$ = ...

b) feed speed = ...
G_{XZ} = ...
$G_{XY,YZ}$ = ...
$G(b)_{XZ}$ = ...
$G(b)_{XY,YZ}$ = ...

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

Telescopic ball bar or two-dimensional digital scale (grid scale)

Observations and references to ISO 230-1:2012, 11.3 and 11.4, and ISO 230-4

If 360° rotation is not possible, see CK5.

Diameters can differ from the above values in agreement between the manufacturer/supplier and user. In such cases, the feed speed has to be adjusted according to ISO 230-4:2005, Annex C.

Start the interpolation in one of the four quadrants. Ideally, measurements should be recorded at a start point other than one of the four reversal points and should have adequate feed in/out motion around the area being inspected; this will help ensure accurate capture of machine performance measurements, including that at the reversal points.

Radial interpolations

Object | **CK5**

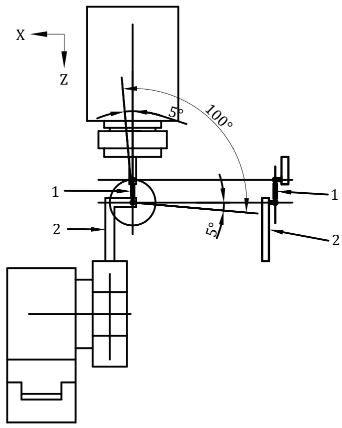
Checking the radial deviation, F, of the path generated by circular interpolation of two linear axes over 100°, according to ISO 230-4, at one of the following diameters and at two feed speeds:

1) 50 mm diameter	2) 100 mm diameter	3) 200 mm diameter	4) 300 mm diameter
a) 250 mm/min	a) 350 mm/min	a) 500 mm/min	a) 610 mm/min
b) 1 000 mm/min	b) 1 400 mm/min	b) 2 000 mm/min	b) 2 440mm/min

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

This test shall be performed in the XY, YZ, and ZX planes, or in the plane composed by other pairs of linear axes (X2, Z2, etc.).

Diagram



Key

1 telescopic ball bar

2 special fixture

Tolerance

a) $F_{XZ,max.}$ = 0,05 mm
$F_{XZ,min.}$ = −0,05 mm
$F_{XY,YZ,max.}$ = 0,07 mm
$F_{XY,YZ,min.}$ = −0,07 mm

b) $F_{XZ,max.}$ = 0,07 mm
$F_{XZ,min.}$ = −0,07 mm
$F_{XY,YZ,max.}$ = 0,09 mm
$F_{XY,YZ,min.}$ = −0,09 mm

References to ISO 230-4:2005, 3.5

NOTE The radial deviation contains the influence of the position (setup) error of the work spindle side sphere of the ball bar and thus is generally larger than the circular deviation.

Measuring deviation

a) feed speed = ...
$F_{XZ,max.}$ = ...
$F_{XZ,min.}$ = ...
$F_{XY,YZ,max.}$ = ...
$F_{XY,YZ,min.}$ = ...

b) feed speed = ...
$F_{XZ,max.}$ = ...
$F_{XZ,min.}$ = ...
$F_{XY,YZ,max.}$ = ...
$F_{XY,YZ,min.}$ = ...

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

Telescopic ball bar or two-dimensional digital scale (grid scale)

Observations and references to ISO 230-1:2012, 11.3

This test is an alternative to Test CK4, in cases where the test machine cannot perform a 360° measurement sweep or the test is not relevant.

Diameters can differ from the above values in agreement between the manufacturer/supplier and user. In such cases, the feed speed has to be adjusted according to ISO 230-4:2005, Annex C.

Circular interpolation motion by simultaneous three-axis control (X-, Y-, and C-axes)

Object	**CK6**

Checking of the deviations of the tool centre point trajectory (ideally a fixed point in the workpiece coordinate system) with the simultaneous three axes interpolation of two linear axes (X- and Y-axes) and a rotary axis (C-axis) over 180° or 360° at a diameter 2/3 of X-axis stroke or Y-axis stroke, whichever is smaller. The sensitive direction of the measurement shall be set as follows:

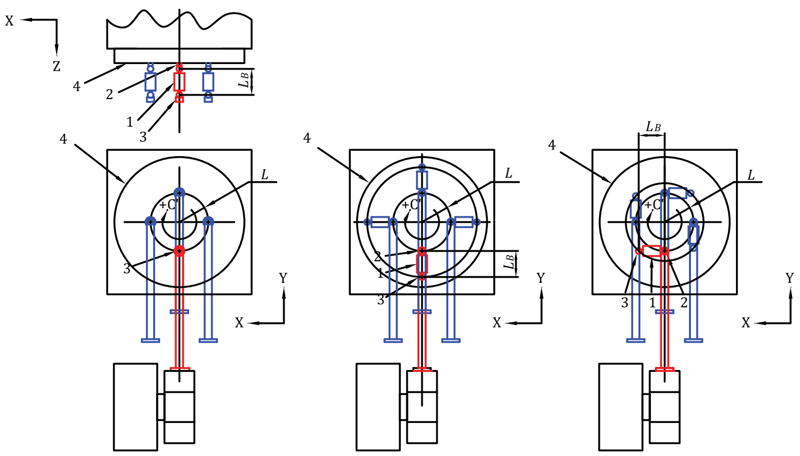
a) Parallel to the rotary axis (C-axis), $E_{\text{int,axialC,XYC (CW, CCW)}}$;

b) Radial to the rotary axis (C-axis), $E_{\text{int,radialC,XYC (CW, CCW)}}$;

c) Tangential to the rotation of the rotary axis (C-axis), $E_{\text{int,tangentialC,XYC (CW, CCW)}}$.

The reference length of the ball bar, L_B, is 100 mm, and the feed speed is 500 mm/min or agreed between the manufacturer/supplier and user. Measurements shall be conducted for clockwise and counter-clockwise (anticlockwise) of C-axis motion.

Diagram



a) b) c)

Key

1 telescopic ball bar

2 sphere socket (spindle side)

3 sphere socket (tool side)

4 spindle

L nominal distance between the centre of toolholding spindle-side sphere and axis of rotation

Tolerance (to be agreed between manufacturer/ supplier and user)	**Measured deviations**
a) $E_{\text{int,axialC,XYC (CW, CCW)}}$ = ...	a) $E_{\text{int,axialC,XYC (CW, CCW)}}$ = ...
b) $E_{\text{int,radialC,XYC (CW, CCW)}}$ = ...	b) $E_{\text{int,radialC,XYC (CW, CCW)}}$ = ...
c) $E_{\text{int,tangentialC,XYC (CW, CCW)}}$ = ...	c) $E_{\text{int,tangentialC,XYC (CW, CCW)}}$ = ...

Measuring instruments

Telescopic ball bar, or sphere-ended test mandrel and flat-ended linear displacement sensor(s) or sensors nest (e.g. R-test)

Observations and references to ISO 230-1:2012, 11.3.5

The circular path of the NC programme has to be centred in the C-axis average line. For each test, continuously record the readings of the ball bar (changes of its length) during the interpolated motion. Report the difference between the maximum and minimum recorded values for a), b), and c).

The offset of the workholding spindle-side sphere to C-axis average line, *L*, shall be reported. In b) and c), the centre of the toolholding spindle-side sphere shall be aligned on the toolholding spindle axis average line. Any misalignment will influence the test result. Sphere-ended test mandrel and a sensors nest (e.g. R-test) can be also used. See Annex D for test procedure and for additional precautions.

NOTE It is recommended to present test results in a graphical form, e.g. similar to Figure D.2.

Annex D
(informative)

Precautions for test setup for AK6, BK6, and CK6

D.1 General

Test result in AK6, BK6, and CK6 using either of a) the telescoping ball bar or, b) a sphere-ended test mandrel and flat-ended linear displacement sensor(s) or, c) a sphere-ended test mandrel and a sensors nest (e.g. R-test) can be affected by the setup of measuring instruments. This Annex gives precautions for test procedure to minimize the influence of setup errors.

D.2 Tests with ball bar

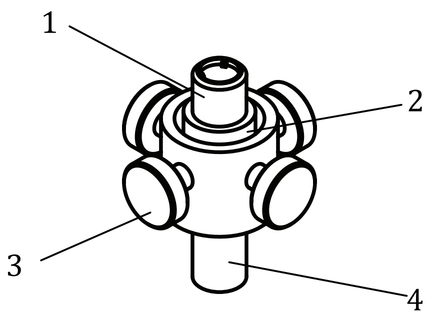
D.2.1 Alignment of precision spheres

The precision sphere of the ball bar in the turret side is aligned to the axis average line of the toolholding spindle or the turret toolholding bore axis. Any misalignment will influence the test result.

This alignment can be done by using a fixture attached to the spindle to minutely adjust the sphere position. See Figure D.1 for an example of such a fixture.

Alternatively, the position of the sphere centre relative to the axis average line of the spindle is measured, and then the machine coordinate system can be shifted to cancel it. The position of the sphere centre can be measured by measuring the run-out in the radial direction of spindle rotation by using a linear displacement sensor.

The sphere of the ball bar on the workholding spindle (C-axis) is located at the position such that the ball bar is directed to the measurement's sensitive direction specified in each test. The workholding spindle side sphere of ball bar does not have to be precisely located. It does not affect the test result (effect of 2nd order).



Key

1 magnetic socket

2 magnet holder

3 screw

4 stem to chuck

Figure D.1 — An example of fixture to align the sphere in the spindle-side

D.2.2 Programming

The workholding spindle (C-axis) is driven as specified in each test. The motion of linear axes is programmed such that the ball bar is directed in a) axial, b) radial, or c) tangential direction of the rotary axis throughout the test cycle.

When AK6, BK6, and CK6 are performed by using a ball bar, the turret side sphere is located away from the C-axis average line by the distance, L. The sphere in the workholding spindle side is located such that the ball bar is aligned in b) radial or c) tangential direction of the rotary axis [see Figure D.2 a)]. In other words, the sphere in the workholding spindle side is located away from the C-axis average line by the distance (L-L_B) for the b) radial test and (L^2-L_B^2)$^{1/2}$ for the c) tangential test, where, L_B, is the nominal length of the ball bar. In this setup, the tests by the ball bar can be thus seen kinematically equivalent to the tests by the sphere-ended mandrel and linear displacement sensor(s) (i.e. the trajectory of linear axes becomes the same) [see Figure D.2 b)].

For the convenience of programming, set the TCP (Tool Centre Position) control function ON, when it is available. TCP function enables automatic coordination of linear axes with respect to the programmed motion of rotary axis (axes).

In all tests, feed speeds and travels of linear axes in the machine coordinate system are changed according to the distance of the sphere centre to the rotary axis. Sensitivity to angular error motions and to orientation errors of the axis of rotation increases, as well as the sensitivity to linear axes error motions and orientation errors, if this distance becomes larger.

D.2.3 Test procedure

In all tests in AK6, BK6, and CK6, the reference length, L_B, of the ball bar should be known, and the offset of the precision sphere on the toolholding spindle to the spindle nose (spindle gauge line) or the gauge line of the turret toolholding bore should be known for the programming. The offset of the precision sphere to the toolholding spindle nose (spindle gauge line) can be typically calibrated by using a tool length setting system.

In all tests, two actual paths have to be measured consecutively in clockwise and counter-clockwise (anticlockwise) directions of the rotary axis under the test.

D.2.4 Presentation of results

All measured data corresponding to the actual path, including reversal points and eventually any peaks at start and end points, are used in the evaluation.

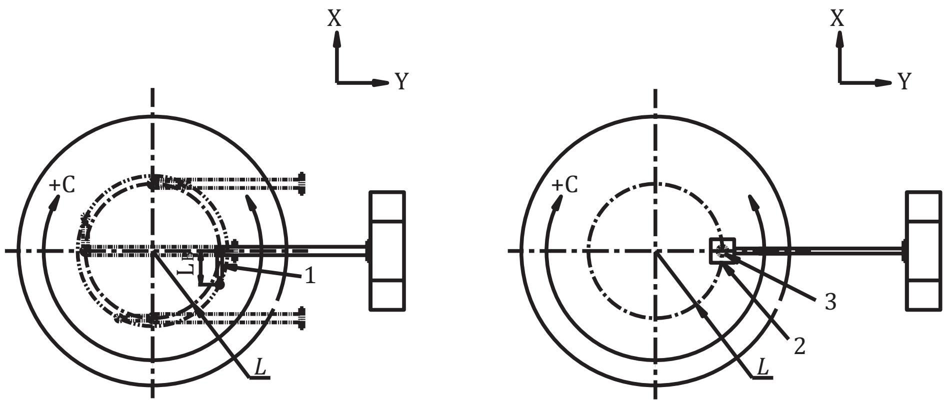
It is preferred to display the measured displacement in the same format as circular tests in ISO 230-4. The deviation has to be plotted with the nominal angular position of the rotary axis of interest (see Figure D.3 for an example).

Some commercial software for circular tests by default perform automatic centring to evaluate the circular deviation. It should be turned off to evaluate “raw” readings of the ball bar (changes of its length). When possible, the ball bar displacement has to be reset to zero at the start of measurement.

The tests only require reporting the difference between the maximum and minimum recorded values.

D.3 Tests with sphere-ended mandrel and linear displacement sensor(s) or sensors nest

When AK6, BK6, and CK6 are performed by using a sphere-ended mandrel and linear displacement sensor(s), the workholding spindle side sphere is located away from the C-axis average line by the distance *L* [see Figure D.2 b)].



a) Setup by ball bar (tangential direction) **b) Setup by sphere-ended mandrel and sensors nest**

Key

1 telescopic ball bar

2 sensors nest

3 reference ball

Figure D.2 — Test setups for AK6

D.3.1 Alignment of precision sphere

A sphere-ended mandrel is mounted in a toolholding spindle or a turret toolholding bore. The sphere centre is aligned to the axis average line of the toolholding spindle or the turret toolholding bore axis. Any misalignment will influence the test result. The offset of the precision sphere to the toolholding spindle nose (spindle gauge line) should be known for the programming.

Test procedure with sphere-ended mandrel and linear displacement sensor(s), or a sensors nest (e.g. R-test), can be the same with the one with the ball bar when the same offset, the same diameter, and the same velocity are used (See D.2.2).

D.3.2 Test procedure

General test procedure is as follows: position the sphere as is specified in each test. Bring the linear displacement sensor to sense the test mandrel sphere and rotate the toolholding spindle to find the mean run-out position. Zero the linear displacement sensor. Then, start the test motion and record the readings of the linear displacement sensor.

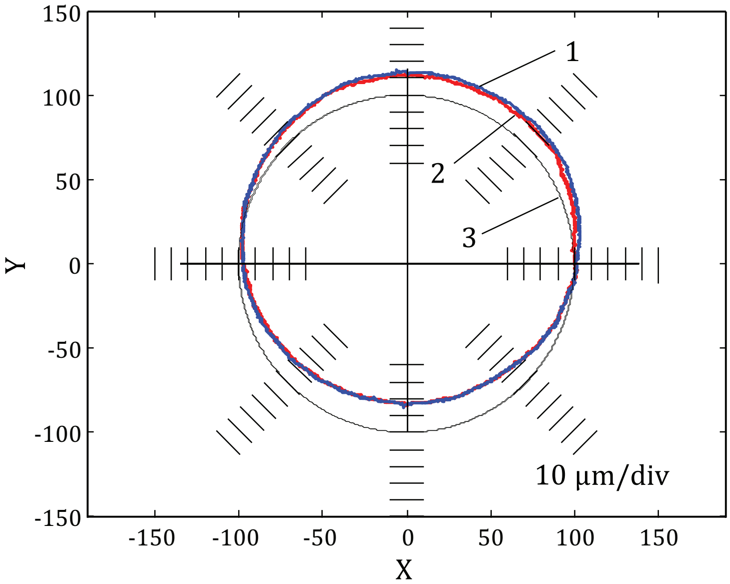
In all tests in AK6, BK6, and CK6, two actual paths have to be measured consecutively in clockwise and counter-clockwise (anticlockwise) directions of the rotary axis under the test.

D.3.3 Presentation of results

All measured data corresponding to the actual path, including any peaks at starting and end points, and reversal points, are used in the evaluation.

It is preferred to display the measured displacement in a polar format as circular tests in ISO 230-4 (see Figure D.3 for an example). When it is not available, an X-Y plot with the nominal angular position of the rotary axis of interest is acceptable (see Figure D.4 for an example).

The tests only require reporting the difference between the maximum and minimum recorded values.



Key

1 clockwise

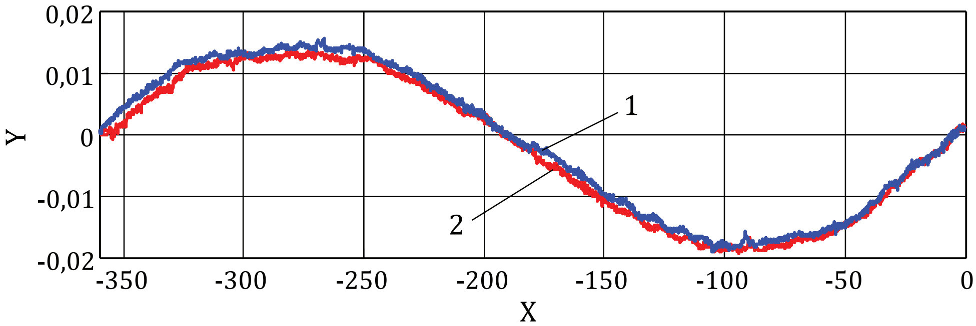
2 counter-clockwise (anticlockwise)

3 reference circle representing nominal ball bar length

X X-axis in millimetre

Y Y-axis in millimetre

Figure D.3 — An example of data presentation for AK6 in a polar plot format



Key

1 clockwise

2 counter-clockwise (anticlockwise)

X C-axis angular position in degree

Y deviation in millimetre

Figure D.4 — An example of data presentation for AK6 in an X-Y plot format

Bibliography

[1] ISO/TR 230-11:—[2], *Test code for machine tools — Part 11: Measuring instruments suitable for machine tool geometry tests*

2) Under preparation.

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