
**Test conditions for numerically controlled
turning machines and turning centres —**

Part 2:

**Geometric tests for machines
with a vertical workholding spindle**

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

Partie 2: Essais géométriques pour les machines à broche verticale

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Foreword

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

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 13041-2 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 horizontal workholding spindle*
- *Part 2: Geometric tests for machines with 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 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

The object of ISO 13041 (all parts) 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 (all parts) specifies, with reference to ISO 230-1 and ISO 230-7, tests for turning centres and numerically controlled turning machines with/without tailstocks standing alone or integrated in flexible manufacturing systems. ISO 13041 (all parts) 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.

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Test conditions for numerically controlled turning machines and turning centres —

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

1 Scope

This part of ISO 13041 specifies, with reference to ISO 230-1 and ISO 230-7, the geometric tests on general purpose numerically controlled (NC) turning machines and turning centres with vertical workholding spindles, as well as the corresponding applicable tolerances.

This part of ISO 13041 explains different concepts or configurations and common features of NC turning machines and turning centres with vertical workholding spindles. It also provides a terminology and designation of controlled axes (see Figures 1, 2, 3, and 4).

This part of ISO 13041 deals only with the verification of the accuracy of the machine. It does not apply to the operational testing of the machine (e.g. vibration, abnormal noise, stick slip motion of components) nor to machine characteristics (e.g. speeds, feeds) as such checks are generally carried out before testing the accuracy.

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 230-7:2006, *Test code for machine tools — Part 7: Geometric accuracy of axes of rotation*

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

3 Terms and definitions

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

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

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

3.3 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

[ISO 2806:1994]

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

3.5 numerically controlled turning machine
NC turning machine
turning machine that operates under **numerical control (NC, 3.3)** or **computerized numerical control (CNC, 3.3)**

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

NOTE 1 This machine is controlled by a numerical control (NC) providing automatic function.

NOTE 2 For vertical spindle-turning machines with inverted workholding spindle, i.e. with workholding device at the lower end of the spindle, see ISO 13041-3.

3.7 vertical spindle-turning centre
numerically controlled vertical spindle-turning machine equipped with toolholding spindles and the capacity to orientate the workholding spindle around its axis

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

NOTE 2 For vertical spindle-turning machines with inverted workholding spindle, i.e. with workholding device at the lower end of the spindle, see ISO 13041-3.

4 Preliminary remarks

4.1 Units of measurement

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

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

4.2 Reference to ISO 230-1 and ISO 230-7

To apply this part of ISO 13041, reference shall be made to ISO 230-1, especially for installation of the machine before testing, warming up of the spindle and over-moving components, description of measuring methods and recommended measurement uncertainty of testing equipment.

In the "Observation" block of the tests described in Clause 5, the instructions are preceded by a reference to the corresponding clause in ISO 230-1 or in ISO 230-7 in cases where the test concerned is in compliance with their specifications. Tolerances are given for each test (see G1 to G21).

4.3 Machine levelling

Prior to conducting tests on a machine, the machine should be levelled according to the recommendations of the supplier/manufacture (see ISO 230-1:1996, 3.11).

4.4 Test sequence

The sequence in which tests are presented in this part of ISO 13041 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.

4.5 Test to be performed

When testing a machine, it is not always necessary or possible to carry out all the tests described in this part of ISO 13041. When the tests are required for acceptance purposes, it is up to the user to choose, in agreement with the supplier/manufacture, those tests relating to the components and/or the properties of the machine which are of interest. These tests are to be clearly stated when ordering a machine. 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.

4.6 Measuring instruments

The measuring instruments indicated in the tests described in the following are examples only. Other instruments measuring the same quantities and having at least the same measurement uncertainty may be used. Linear displacement sensors shall have a resolution of 0,001 mm or better.

4.7 Diagrams

In this part of ISO 13041, for reasons of simplicity, the diagrams associated with geometric tests generally illustrate only one type of machine.

4.8 Software compensation

When built-in software facilities are available for compensating geometric, positioning, contouring, and thermal deviations, their use during these tests should be based on an agreement between the user and the supplier/manufacture. When software compensation is used, this shall be stated in the test report.

4.9 Minimum tolerance

When the tolerance for a geometric test is established for a measuring length different from that given in this part of ISO 13041 (see ISO 230-1:1996, 2.311), it shall be taken into consideration that the minimum value of tolerance is 0,005 mm.

4.10 Machine classifications

The machines considered in this part of ISO 13041 are divided into the following basic configurations:

- type A: single column machines (Figure 1);
- type B: dual column machines (Figure 2).

Type B machine configurations are further classified into the following types:

- fixed columns — portal type;
- moving columns — gantry type.

4.11 Linear motions

For simplicity, all the machine examples shown in Figures 1 and 2 use the axis designation of a letter and a number (e.g. X, X1, X2...) as defined in ISO 841:2001, 6.1. In all examples the use of the letters U, V, or W could be substituted.

4.12 Turrets — toolholding components (element)

Depending on the machine configuration, cutting tools (stationary or power driven) can be located on the railhead ram and/or the side head ram and/or the turret. An automatic tool change device can also be used. However, ISO 13041 (all parts) does not provide any test methods for automatic tool change operations.

4.13 Machine size category

The machines are classified into four size categories, on the basis of the criteria specified in Table 1.

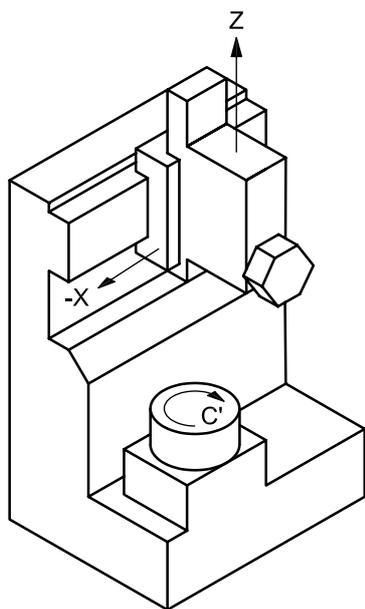
Table 1 — Machine size range

Criteria	Category 1	Category 2	Category 3	Category 4
Nominal diameter of chuck <i>d</i>	$d \leq 500$	$500 < d \leq 1\ 000$	$1\ 000 < d \leq 5\ 000$	$d > 5\ 000$
Diameter of workholding spindle/table <i>D</i>	$D \leq 500$	$500 < D \leq 1\ 000$	$1\ 000 < D \leq 5\ 000$	$D > 5\ 000$

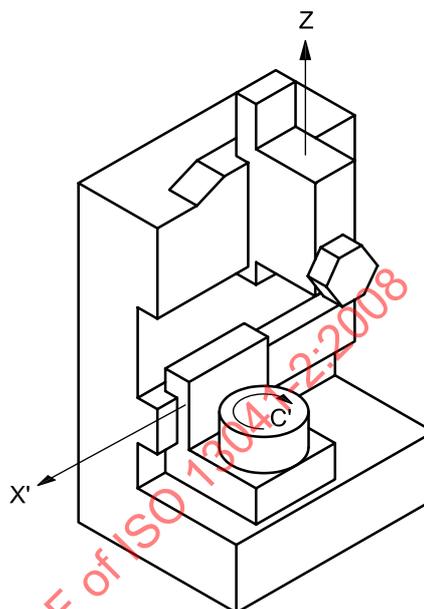
NOTE 1 The choice of criteria is at the manufacturer's discretion.

NOTE 2 Nominal diameter of chuck (up to 800 mm) is defined in ISO 3442-1, ISO 3442-2, and ISO 3442-3.

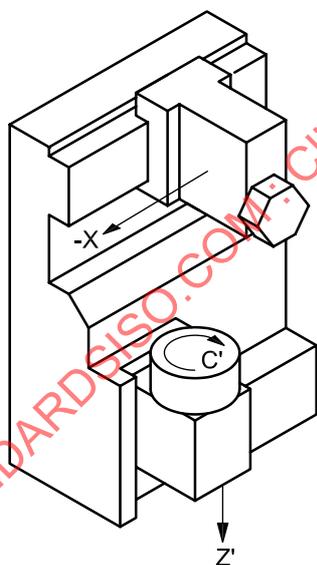
4.14 Machine configurations



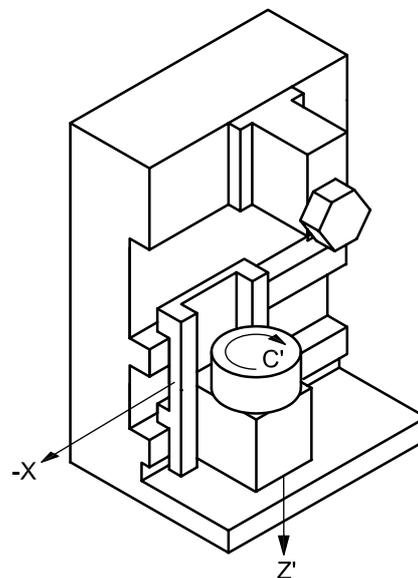
a) Compound head type



b) Shared motion (moving workholding spindle) type

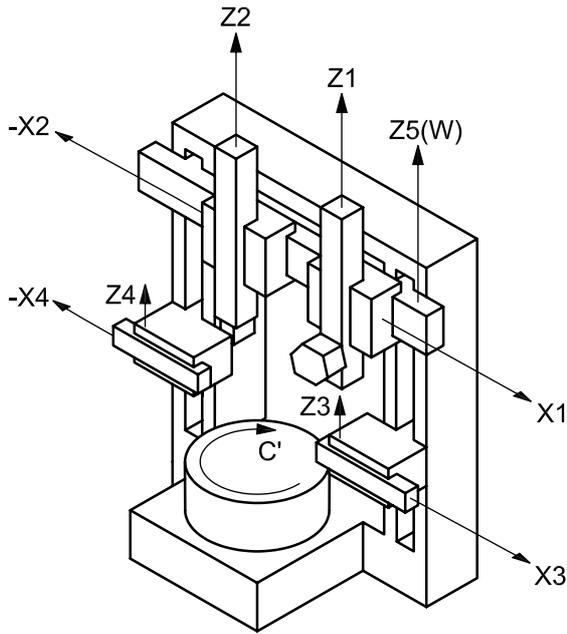


c) Shared motion (moving head/saddle) type

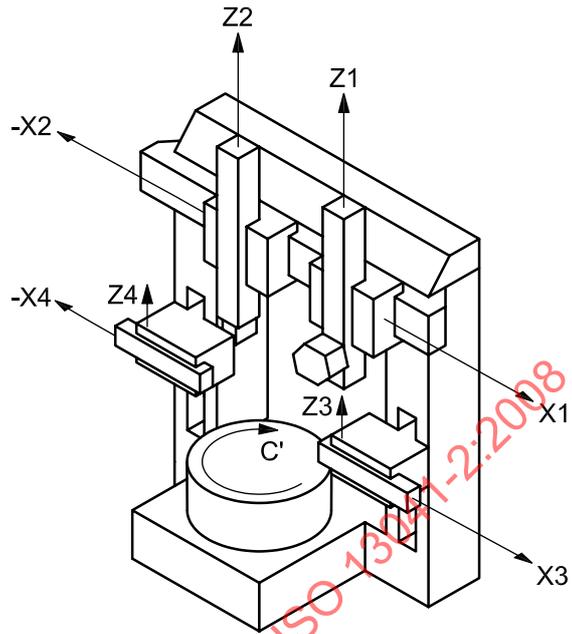


d) Compound workholding spindle type

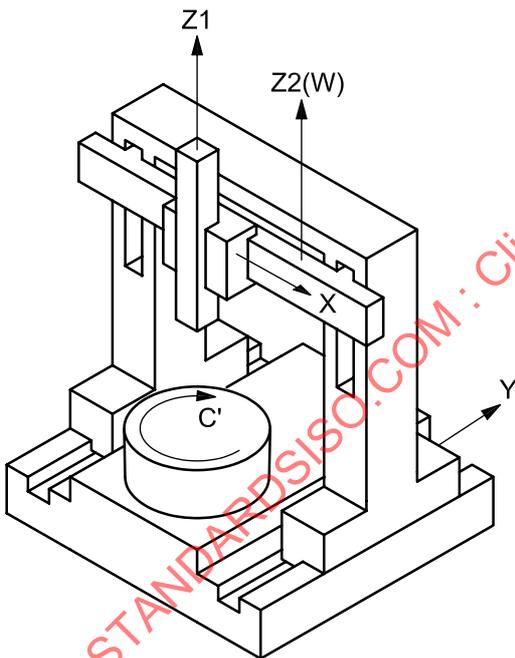
Figure 1 — Examples of machine configurations: single column machines (type A)



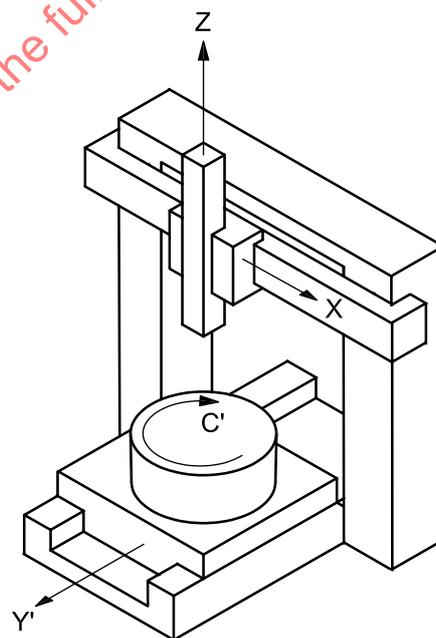
a) Fixed column, moving cross-rail



b) Fixed column, fixed cross-rail



c) Moving column (gantry type), moving cross-rail



d) Fixed column (portal type), moving workholding spindle (Y axis)

Figure 2 — Examples of machine configurations: dual column machines (type B)

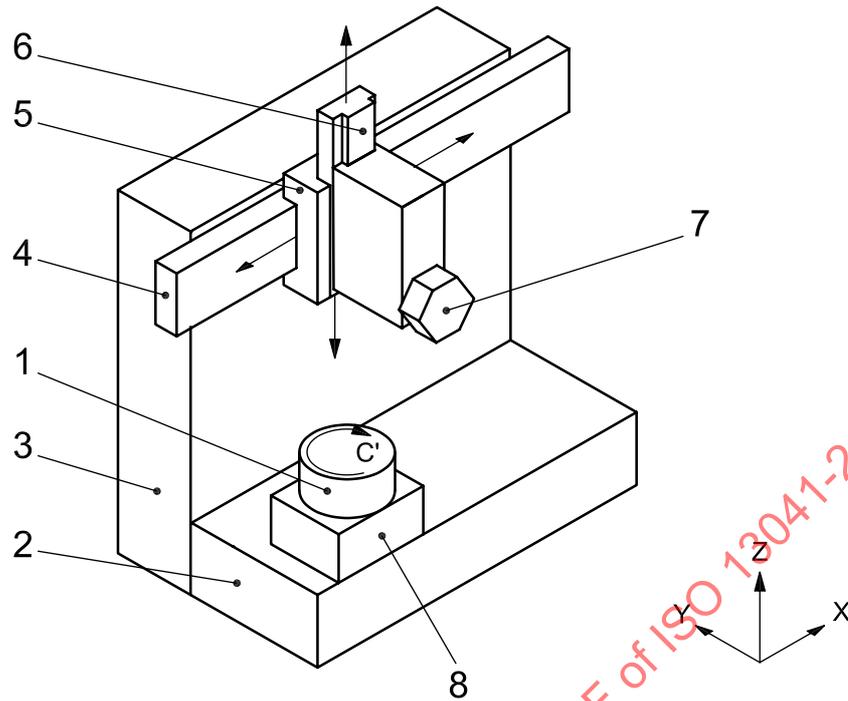


Figure 3 — Machine with single column

Table 2 — Terminology corresponding to Figure 3

Item number	Designation		
	English	German	French
1	workholding spindle (turntable)	Spannfutter	broche porte-outils
2	base	Maschinenbett	base
3	column	Maschinenständer	montant
4	cross-rail	Querführung	traverse porte-chariot
5	railhead (saddle)	Querschlitten	chariot de traverse (trainard)
6	turret slide	Revolverschlitten	chariot de tourelle
7	turret	Revolver	tourelle
8	workholding spindle head	Spindelkasten	tête de broche porte-outils

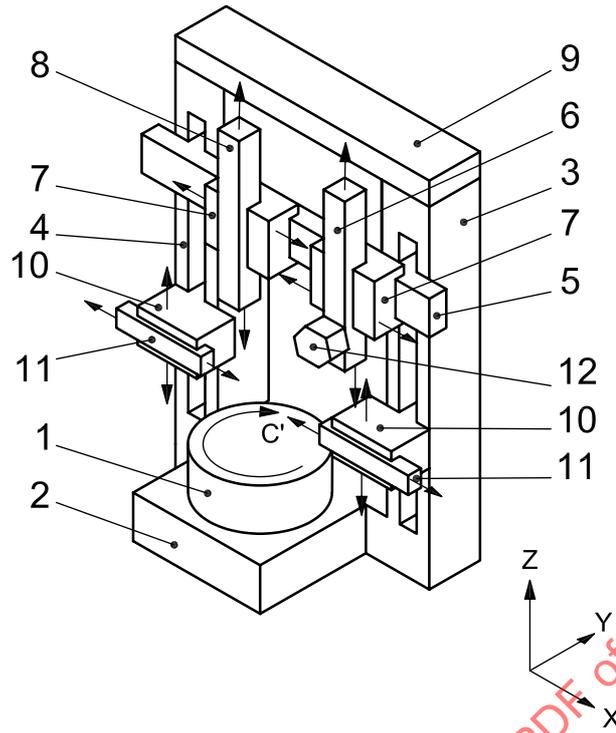


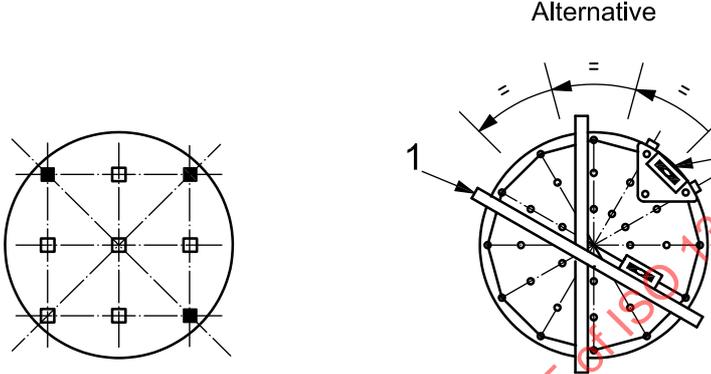
Figure 4 — Machine with dual columns

Table 3 — Terminology corresponding to Figure 4

Item number	Designation		
	English	German	French
1	workholding spindle (turntable)	Spannfutter	broche porte-outils
2	base	Maschinenbett	base
3	right-hand column	rechter Maschinenständer	montant droit
4	left-hand column	linker Maschinenständer	montant gauche
5	cross-rail	Querführung	traverse porte-chariot
6	turret slide	Revolverschlitten	chariot de tourelle
7	railhead (saddle)	Querschlitten	chariot de traverse (traînard)
8	railhead ram	Traghülse	coulisseau du chariot de traverse
9	bridge	Brücke/Traverse	traverse
10	side head	seitlicher Werkzeugträger	chariot porte-outils latéral
11	side head ram	seitliche Traghülse	broche porte-outils
12	turret	Revolver	tourelle

5 Geometric tests

5.1 Workholding spindle

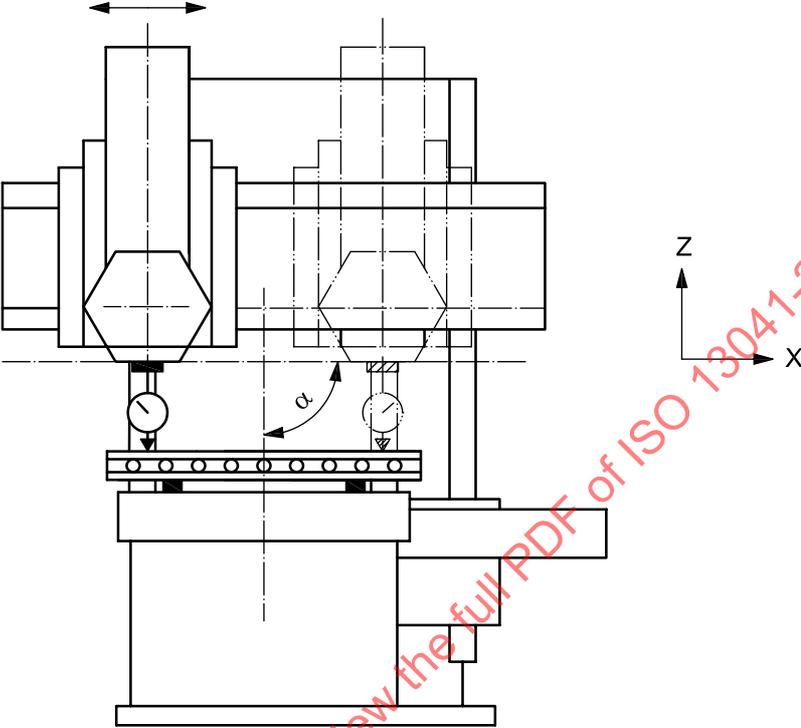
<p>Object</p> <p>To check the flatness of the workholding spindle face (workholding table).</p> <p>NOTE Table type only.</p>		<p>G1</p>								
<p>Diagram</p> <div style="display: flex; justify-content: space-around; align-items: center;">  </div>										
<p>Key</p> <p>1 guide bar 2 isostatic 3-bearing support</p>										
<p>Tolerance</p> <p>Local tolerance 0,01 over any measuring length of 300.</p> <table border="1" style="width: 100%; text-align: center;"> <thead> <tr> <th>Category 1</th> <th>Category 2</th> <th>Category 3</th> <th>Category 4</th> </tr> </thead> <tbody> <tr> <td>0,02</td> <td>0,03</td> <td>0,07</td> <td>0,07</td> </tr> </tbody> </table> <p>NOTE Category 4 machines only — for each further 1 000 increase in diameter, increase the tolerance by 0,01.</p> <p>Spindle face shall not be convex.</p>		Category 1	Category 2	Category 3	Category 4	0,02	0,03	0,07	0,07	<p>Measured deviation</p>
Category 1	Category 2	Category 3	Category 4							
0,02	0,03	0,07	0,07							
<p>Measuring instruments</p> <p>Straightedge, gauge blocks and linear displacement sensor or optical instruments</p> <p>For alternative method: Guide bar and support blocks, precision level and an isostatic 3-bearing support.</p>										
<p>Observations and references to ISO 230-1:1996, 5.322, 5.324</p> <p>Alternative method (checking with the aid of a precision level): 5.323</p> <ol style="list-style-type: none"> 1) Circular checking The precision level shall be placed on a support having three bearing points on the workholding table. The isostatic 3-bearing support shall be moved to positions equally spaced along the workholding table. 2) Diametrical checking The precision level shall be placed on the workholding table and along a diametrical direction with the aid of a guide bar. The precision level shall be moved at positions equally spaced along the guide bar. The procedure shall be repeated, moving the guide bar according to the successive positions occupied by the isostatic 3-bearing support or at maximum of 12 intervals (minimum of 30°). <p>Subject to agreement between manufacturer and user, it is permissible to carry out diametrical checking only.</p>										

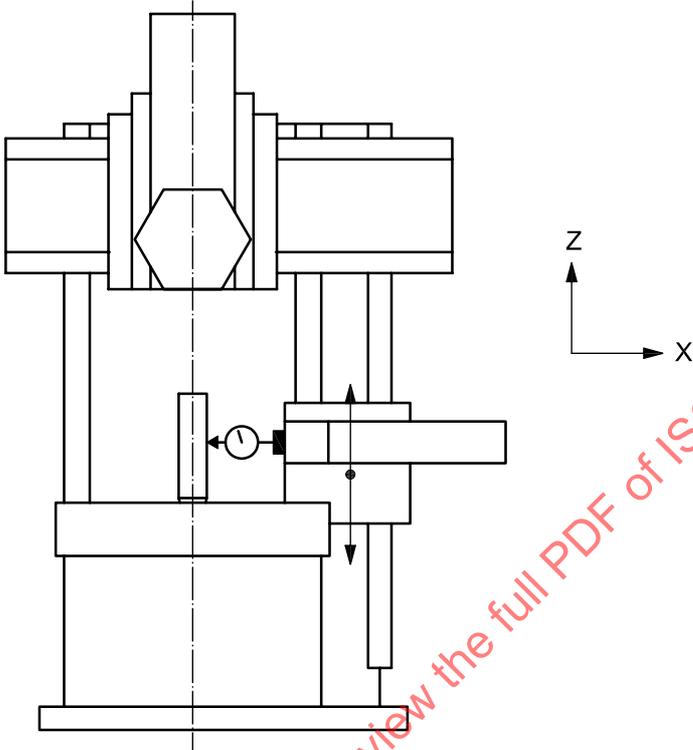
Object					G2
<p>To check the face run-out of workholding spindle:</p> <p>a) face run-out of the workholding table surface;</p> <p>b) face run-out of the spindle face.</p>					
Diagram					
Tolerance					Measured deviation
	Category 1	Category 2	Category 3	Category 4	
a)	0,01	0,02	0,035	0,05	a)
<p>NOTE Category 4 machines only — for each further 1 000 increase in diameter, increase the tolerance by 0,01.</p>					
b)	0,01	0,015	0,02	0,02	b)
Measuring instruments					
Linear displacement sensor					
Observations and references to ISO 230-1:1996, 5.632					
<p>a) The linear displacement sensor shall be placed on a fixed part of the machine and shall be placed as near as possible to the workholding table periphery and approximately 180° from the position occupied by the tool when the workholding spindle was machined.</p> <p>Cross-rail and railhead locked in position, where possible.</p>					
<p>b) Measurements shall be taken on the maximum diameter.</p>					
<p>NOTE If detaching the workholding table is difficult, this test need not be done.</p>					

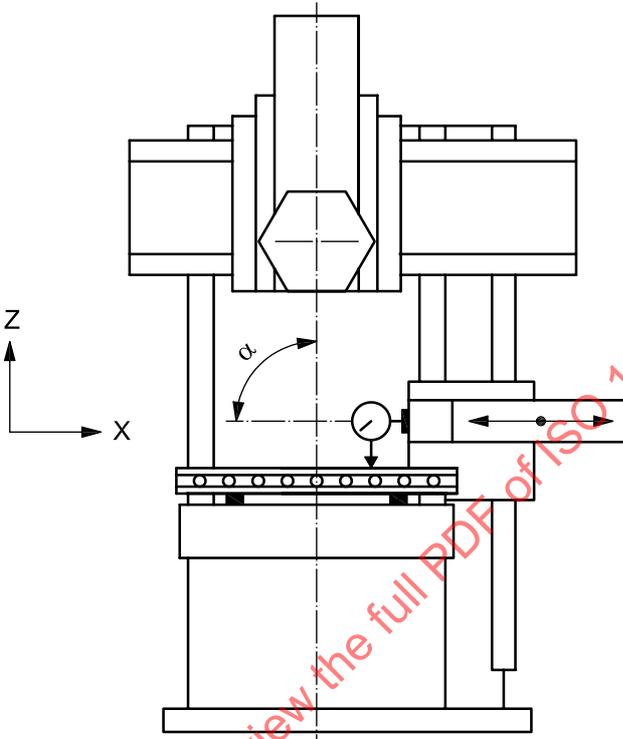
Object					G3
To check run-out of					
<ul style="list-style-type: none"> a) the workholding spindle bore; b) the external cylindrical surface of the workholding spindle (in the case of a workholding spindle not having a central bore); c) centring diameter. 					
Diagram					
Tolerance					Measured deviation
	Category 1	Category 2	Category 3	Category 4	
a) and b)	0,01	0,02	0,035	0,05	a)
NOTE Category 4 machines only — for each further 1 000 increase in diameter, increase the tolerance by 0,01.					
c)	0,01	0,015	0,02	0,02	c)
Measuring instruments					
Linear displacement sensor					
Observations and references to ISO 230-1:1996, 5.611.4 and 5.612.2					
<ul style="list-style-type: none"> a) The linear displacement sensor shall be placed approximately 180° from the position occupied by the tool when the workholding spindle was machined. Cross-rail, railhead and slide locked in position, where possible. The linear displacement sensor shall also be placed on a fixed part of the machine. b) Subclauses 5.611.4 and 5.612.2. c) Subclause 5.612.2. When the surface is conical, the stylus of the linear displacement sensor shall be normal to the contacting surface. 					

5.2 Relationship between workholding spindle and linear axes of motion

<p>Object</p> <p>To check the parallelism between the Z-axis motion (railhead ram or turret slide) and the workholding spindle axis of rotation:</p> <p>a) in the YZ plane;</p> <p>b) in the XZ plane.</p> <p>NOTE Also applicable for a second railhead ram and turret slides on the column.</p>		<p>G4</p>
<p>Diagram</p> <div style="display: flex; justify-content: space-around; align-items: flex-start;"> <div style="text-align: center;"> </div> <div style="text-align: center;"> <p>Alternative method</p> </div> </div>		
<p>Tolerance</p> <p>a) 0,015 for the measuring length of 300</p> <p>b) 0,01 for the measuring length of 300</p>	<p>Measured deviation</p> <p>a)</p> <p>b)</p>	
<p>Measuring instruments</p> <p>Test mandrel or cylindrical square and linear displacement sensors and adjustable blocks</p> <p>Alternative method: Precision test ball and linear displacement sensors</p>		
<p>Observations and references to ISO 230-1:1996, 5.412.1 and 5.422.3</p> <p>Turn the workholding spindle to find the mean position of run-out and then move railhead ram successively in the Z direction to the upper position (3), mid-travel (2), and in the lower position (1) and take the maximum difference of the readings. The largest change of the difference gives the parallelism deviation in the XZ plane. The test is then repeated for the YZ plane.</p> <p>Alternative method</p> <p>In this case, the test ball is positioned just using the Z-axis travel and the measurement repeated for each position (1, 2 and 3). The readings at 0° and 180° are taken and the difference between these two readings is noted for positions 1, 2 and 3. The largest change of the difference gives the parallelism deviation in the YZ plane. The test is then repeated for the XZ plane.</p> <p>If the machine under test has an adjustable cross-rail, the test should be repeated with the cross-rail in its lower, mid, and upper positions. This test applies to all railheads.</p>		

Object To check the squareness between the railhead motion (X axis) and the workholding spindle axis of rotation (C axis).	G5
Diagram 	
Tolerance For a measuring length of 300 or full stroke up to 300: categories 1 and 2: 0,020 categories 3 and 4: 0,030 Direction of deviation: $\alpha \geq 90^\circ$	Measured deviation
Measuring instruments Straightedge, adjustable blocks and linear displacement sensor	
Observations and references to ISO 230-1:1996, 5.422.22, 5.522.2 A linear displacement sensor is fixed to the turret close to the tool position. Block gauges are used to set the straightedge square to the workholding spindle rotation axis. Checking shall be carried out by placing the stylus of the linear displacement sensor placed on the railhead onto a straightedge laid square to the axis of rotation of the workholding spindle. Or Set straightedge approximately parallel to the work table surface. Measurements should be taken at several positions of the X-axis motion, then rotate the spindle through 180° and take a second set of measurements at the same X locations. The squareness deviation is the range of the mean of these two sets of measurements. The surface generated shall be concave unless by special arrangement between the user and supplier/manufacturer.	

<p>Object</p> <p>To check the parallelism between the side head (Z axis) motion and the workholding spindle axis of rotation (C axis).</p>	<p>G6</p>
<p>Diagram</p> 	
<p>Tolerance</p> <p>0,02 over a measuring length of 300</p>	<p>Measured deviation</p>
<p>Measuring instruments</p> <p>Test mandrel or cylindrical square and linear displacement sensor</p>	
<p>Observations and references to ISO 230-1:1996, 5.422.3</p> <p>Turn the workholding spindle to find the mean position of run-out and then move the side head in the Z direction and take maximum difference of the readings.</p> <p>Or</p> <p>Take readings at several positions of the Z axis and then rotate the workholding spindle by 180° and take the second set of readings at the same Z positions. The parallelism deviation is the range of the mean of these two sets of measurements.</p> <p>This test applies to all side heads.</p>	

Object To check the squareness between the side head ram (X axis) motion and the workholding spindle axis of rotation.	G7
Diagram 	
Tolerance 0,02 over a measuring length of 300 Direction of deviation: $\alpha \geq 90^\circ$	Measured deviation
Measuring instruments Straightedge, gauge blocks, and linear displacement sensor	
Observations and references to ISO 230-1:1996, 5.522.2 The side head shall be locked in position. Gauge blocks are used to set the straightedge perpendicular to the workholding spindle rotation axis. Checking shall be carried out by placing the stylus of the linear displacement sensor placed on the side head ram on to a straightedge laid square to the axis of rotation of the workholding spindle. Or Set straightedge approximately parallel to the work table surface. Take readings at several positions of the X axis and then rotate the C axis by 180° and take the second set of readings at the same X positions. The squareness deviation is the range of the mean of these two sets of measurements. This test applies to all side heads.	

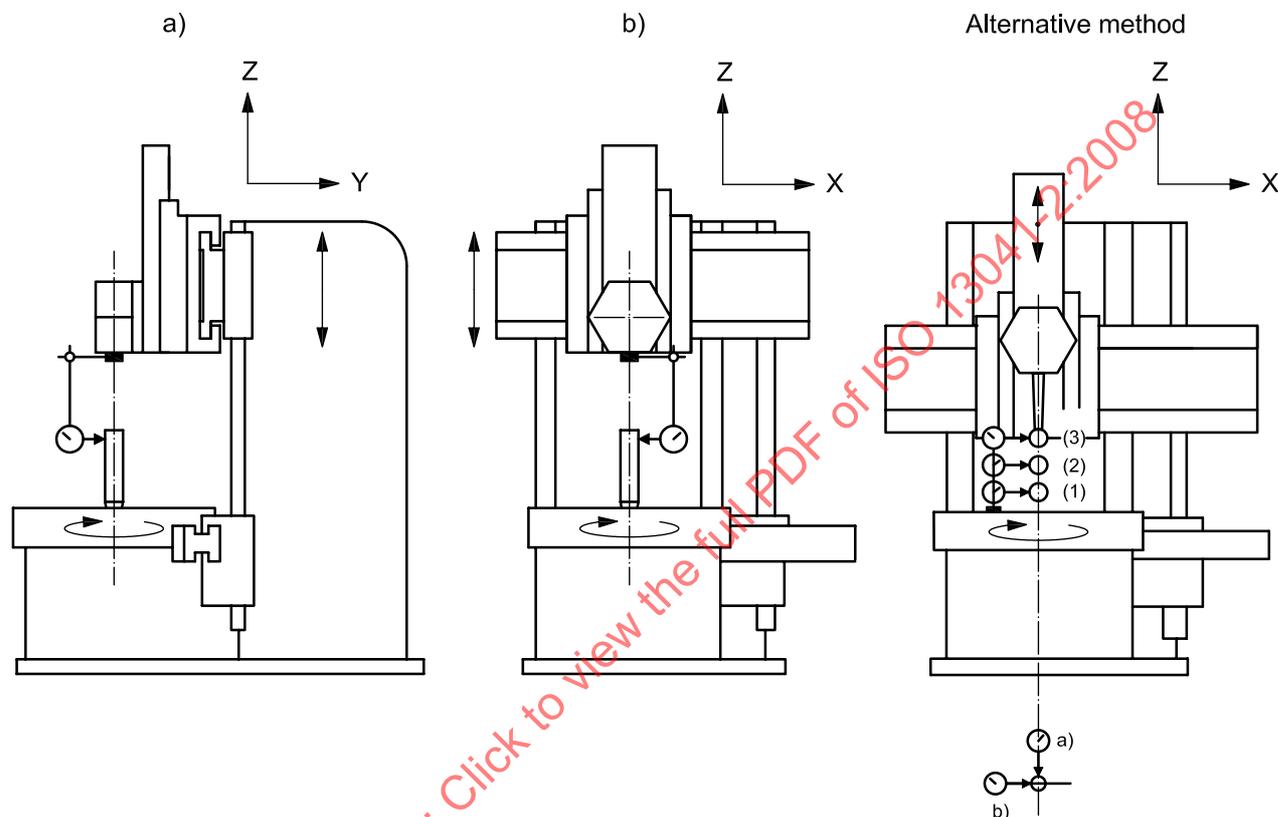
<p>Object</p> <p>To check the parallelism between the toolholding spindle axis of rotation and the railhead ram motion:</p> <p>a) in the YZ plane;</p> <p>b) in the ZX plane.</p>		<p>G8</p>
<p>Diagram</p>		
<p>Tolerance</p> <p>For a) and b)</p> <p>0,02 for any measuring length of 300</p>	<p>Measured deviation</p> <p>a)</p> <p>b)</p>	
<p>Measuring instruments</p> <p>Linear displacement sensor and test mandrel</p>		
<p>Observations and references to ISO 230-1:1996, 5.412.1, 5.422.3</p> <p>A test mandrel is mounted on the live tooling spindle.</p> <p>NOTE If necessary, workholding spindle should be clamped.</p> <p>a) Linear displacement sensor is attached to the workholding spindle indicating against the mandrel in the Y direction. Mean orientation of the mandrel is determined by rotating the live tooling spindle between the two extreme readings of the displacement sensor. Displacement sensor is set to zero at this mean orientation. Then the railhead ram is moved to the other end of the measuring stroke and the displacement sensor reading is recorded.</p> <p>b) Linear displacement sensor is attached to the workholding spindle indicating against the mandrel in the X direction. Mean orientation of the mandrel is determined by rotating the live tooling spindle between the two extreme readings of the displacement sensor. Displacement sensor is set to zero at this mean orientation. Then the railhead ram is moved to the other end of the measuring stroke and the displacement sensor reading is recorded.</p> <p>Or</p> <p>Take readings at several positions of the Z axis and then rotate the toolholding spindle by 180° and take the second set of readings at the same Z positions. The parallelism deviation is the range of the mean of these two sets of measurements.</p>		

Object

G9

To check the parallelism between the cross-rail Z-axis motion and the workholding spindle axis of rotation:

- a) in the YZ plane;
b) in the ZX plane.

Diagram**Tolerance**

For a) and b)
0,02 for a measuring length of 300

Measured deviation

a)
b)

Measuring instruments

Linear displacement sensor and test mandrel or cylindrical square

Observations and references to ISO 230-1:1996, 5.422.3

Turn the workholding spindle to find the mean position of run-out and then move the cross-rail in the Z direction and take the maximum difference of the readings.

Or

Take readings at several positions of the cross-rail Z axis and then rotate the workholding spindle by 180° and take the second set of readings at the same Z positions. The parallelism deviation is the range of the mean of these two sets of measurements.

Alternative method

In this case, the test ball is positioned just using the Z-axis travel and the measurement repeated for each position (1, 2 and 3). The readings at 0° and 180° are taken and the difference between these two readings is noted for positions 1, 2 and 3. The largest change of the difference gives the parallelism deviation in the YZ plane. The test is then repeated for the XZ plane.

If the machine under test has an adjustable cross-rail, the test should be repeated with the cross-rail in its lower, mid, and upper positions. This test applies to all railheads.

5.3 Angular deviations of linear axes of motion

<p>Object</p> <p>To check the angular deviation of the cross-rail in its Z-axis motion in the vertical ZX plane (EBZ).</p>	<p>G10</p>
<p>Diagram</p> <p>Key</p> <p>1 measuring level 2 reference level</p>	
<p>Tolerance</p> <p>For any measuring length up to 1 000:</p> <p>categories 1 and 2: 0,02/1 000 (20 μrad or 4")</p> <p>categories 3 and 4: 0,04/1 000 (40 μrad or 8")</p>	<p>Measured deviation</p>
<p>Measuring instruments</p> <p>Precision level</p>	
<p>Observations and references to ISO 230-1:1996, 5.232.21</p> <p>Place the measuring level at possibly mid-position of the cross-rail on an appropriate surface and read the indication in the quoted positions.</p> <p>The railhead shall be placed in a central position of the cross-rail.</p> <p>When Z-axis motion causes angular deviation of both the cross-rail and the workholding spindle, differential measurements of the two angular movements shall be taken.</p> <p>When differential measurement is applied, the reference level shall be placed on the workholding spindle.</p> <p>Lock the cross-rail at each position, where possible.</p>	

<p>Object</p> <p>To check the angular deviations of the moving column (gantry type) or moving workholding spindle (portal type) in the Y direction:</p> <p>a) in the YZ plane EAY (pitch);</p> <p>b) in the ZX plane EBY (roll);</p> <p>c) in the XY plane ECY (yaw).</p>	G11
<p>Diagram</p> <p>Key</p> <p>1 measuring level 2 reference level 3 autocollimator 4 mirror</p>	
<p>Tolerance</p> <p>For a), b), and c).</p> <p>For any measuring length up to 1 000:</p> <p>categories 1 and 2: 0,02/1 000 (20 μrad or 4")</p> <p>categories 3 and 4: 0,04/1 000 (40 μrad or 8")</p>	<p>Measured deviation</p> <p>a)</p> <p>b)</p> <p>c)</p>
<p>Measuring instruments</p> <p>a) Precision level, or optical angular deviation measuring instrument</p> <p>b) Precision level</p> <p>c) Optical angular deviation measuring instrument</p>	
<p>Observations and references to ISO 230-1:1996, 5.231.3, 5.232.2</p> <p>The measuring level or instrument shall be placed on the railhead which is fixed in position:</p> <p>a) (EAY: pitch) in the Y-axis direction;</p> <p>b) (EBY: roll) in the X-axis direction;</p> <p>c) (ECY: yaw) in the Z-axis direction.</p> <p>When workholding spindle slide motion causes angular deviations of both workholding spindle and column, differential measurements of the two angular deviations shall be made and this shall be stated.</p> <p>The reference level shall be placed on the workholding spindle (turntable), which is fixed in position.</p> <p>Measurements shall be carried out at a minimum of five positions equally spaced along the path of travel in both directions of the movement.</p>	

<p>Object</p> <p>To check the angular deviations of the railhead motion on the cross-rail (X axis);</p> <p>a) in the ZX plane EBX (pitch);</p> <p>b) in the YZ plane EAX (roll);</p> <p>c) in the XY plane ECX (yaw).</p>	<p>G12</p>
<p>Diagram</p> <p>Key</p> <p>1 measuring level</p> <p>2 reference level</p> <p>3 autocollimator</p> <p>4 mirror</p>	
<p>Tolerance</p> <p>For a), b), and c).</p> <p>For any measuring length up to 1 000:</p> <p>categories 1 and 2: 0,02/1 000 (20 μrad or 4")</p> <p>categories 3 and 4: 0,04/1 000 (40 μrad or 8")</p>	<p>Measured deviation</p> <p>a)</p> <p>b)</p> <p>c)</p>
<p>Measuring instruments</p> <p>a) Precision level, or optical angular deviation measuring instrument</p> <p>b) Precision level</p> <p>c) Optical angular deviation measuring instrument</p>	
<p>Observations and references to ISO 230-1:1996, 5.231.3, 5.232.2</p> <p>The measuring level or instrument shall be placed on the turret or railhead.</p> <p>a) (EBX: pitch) in the X-axis direction (set vertically);</p> <p>b) (EAX: roll) in the Y-axis direction (set vertically);</p> <p>c) (ECX: yaw) in the Z-axis direction (set horizontally).</p> <p>When railhead motion causes an angular deviation of both railhead and workholding spindle, differential measurements of the two angular deviations shall be made and this shall be stated.</p> <p>The reference level shall be placed on the workholding spindle.</p> <p>Measurements shall be carried out at a minimum of five positions equally spaced along the path of travel in both directions of the movement.</p>	

<p>Object</p> <p>To check the angular deviations of the turret slide (ram) motion (Z axis);</p> <p>a) in the YZ plane EAZ (tilt around X);</p> <p>b) in the XZ plane EBZ (tilt around Y).</p>		<p>G13</p>
<p>Diagram</p>		
<p>Key</p> <p>1 measuring level</p> <p>2 reference level</p>		
<p>Tolerance</p> <p>For any measuring length up to 1 000:</p> <p>0,02/1 000 (20 μrad or 4")</p>		<p>Measured deviation</p> <p>a)</p> <p>b)</p>
<p>Measuring instruments</p> <p>Precision level or optical angular deviation measuring instrument.</p>		
<p>Observations and references to ISO 230-1:1996, 5.231.3, 5.232.2</p> <p>The measuring level shall be placed on the workholding spindle and the measuring level placed on a special fixture located at the tool location.</p> <p>Measurements shall be carried out at a minimum of five positions equally spaced along the travel in both directions of the movement.</p>		

5.4 Straightness deviation of linear axes of motion

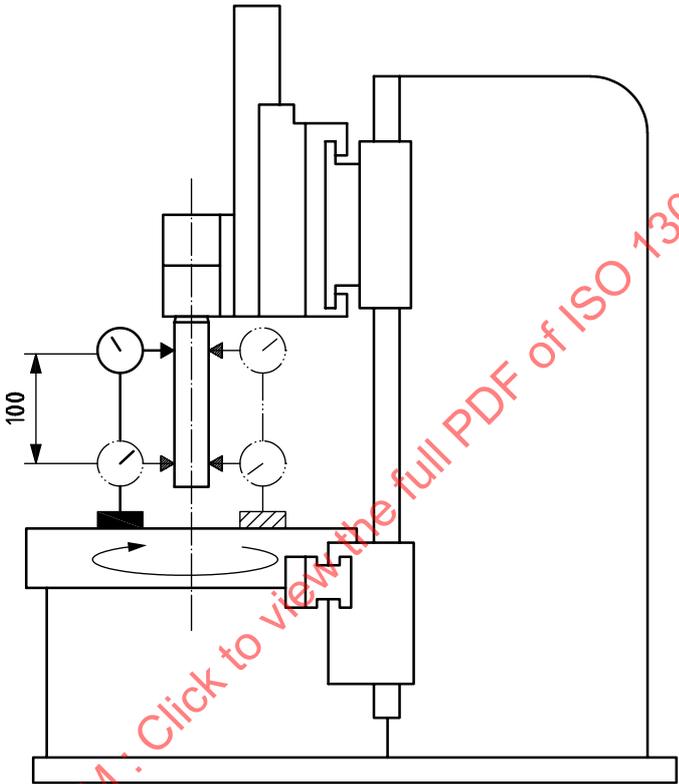
<p>Object</p> <p>To check the straightness of the railhead (X axis) motion on the cross-rail:</p> <p>a) in the vertical ZX plane (EZX);</p> <p>b) in the horizontal XY plane (EYX).</p> <p>NOTE Applicable for turning centres only.</p>		<p>G14</p>
<p>Diagram</p>		
<p>Tolerance</p> <p>For a) and b)</p> <p>0,015 for a measuring length of 1 000</p> <p>Add 0,01 for each additional length of 500</p> <p>Local tolerance: 0,01 for any measuring length of 500</p>		<p>Measured deviation</p> <p>a)</p> <p>b)</p>
<p>Measuring instruments</p> <p>a) Straightedge, adjustable block and linear displacement sensor or optical equipment</p> <p>b) Straightedge, adjustable block and linear displacement sensor or optical equipment or taut wire and microscope</p>		
<p>Observations and references to ISO 230-1:1996, 5.232.1</p> <p>If the column or workholding spindle (table) is movable in the Y-axis direction, it shall be positioned such that the railhead ram or turret tool pockets are in line with the workholding spindle axis average line.</p> <p>Position and lock the cross-rail in the middle position of its travel, with the column locked in position near to the workholding spindle (if movable in the Y-axis direction and if locking is possible). The straightness reference (straightedge, the straightness reflector, the alignment telescope, the taut wire) shall be placed on the workholding spindle parallel (parallel means that the readings at both ends of the movement are the same value and, in this case, the maximum difference of the readings gives the straightness deviation) to the railhead slide movement.</p> <p>The linear displacement sensor, the interferometer, the target or the microscope shall be mounted on the railhead near to the position of a tool. The cross-rail is in the middle of its path of travel.</p>		

Object		G15
<p>To check the straightness of motion of moving column(s) (gantry type) or moving workholding spindle (portal type) in the Y-axis direction:</p> <p>a) in the vertical YZ plane (EZY);</p> <p>b) in the horizontal XY plane (EXY).</p>		
Diagram		
Tolerance		Measured deviation
a) 0,02 for a measuring length of 500		a)
b) 0,04 for a measuring length of 500		b)
Measuring instruments		
<p>a) Straightedge, adjustable block and linear displacement sensor or optical equipment</p> <p>b) Straightedge, adjustable block and linear displacement sensor optical equipment or microscope and taut wire</p>		
Observations and references to ISO 230-1:1996, 5.212.11		
<p>Cross-rail locked in the middle position, railhead locked in the measuring position, where possible.</p> <p>The straightness reference (straightedge, the straightness reflector, the alignment telescope, the taut wire) shall be placed on the workholding spindle parallel (parallel means that the readings at both ends of the movement are the same value and, in this case, the maximum difference of the readings gives the straightness deviation) to the column movement.</p> <p>The linear displacement sensor, the interferometer, the target or the microscope shall be mounted on the railhead near to the position of a tool. The measuring line should be close to the workholding spindle axis of rotation.</p>		

<p>Object</p> <p>To check the straightness of motion of the cross-rail in the Z-axis direction:</p> <p>a) in the YZ plane;</p> <p>b) in the ZX plane.</p>		<p>G16</p>
<p>Diagram</p> <div style="display: flex; justify-content: space-around; align-items: center;"> <div style="text-align: center;"> <p>a)</p> </div> <div style="text-align: center;"> <p>b)</p> </div> </div>		
<p>Tolerance</p> <p>For a) and b)</p> <p>0,02 for a measuring length of 300</p>		<p>Measured deviation</p> <p>a)</p> <p>b)</p>
<p>Measuring instruments</p> <p>Straightedge, square, adjustable blocks or test mandrel and linear displacement sensor</p>		
<p>Observations and references to ISO 230-1:1996, 5.212.11</p> <p>The square is set on the workholding spindle surface to obtain the same readings at both ends of the measuring length.</p>		

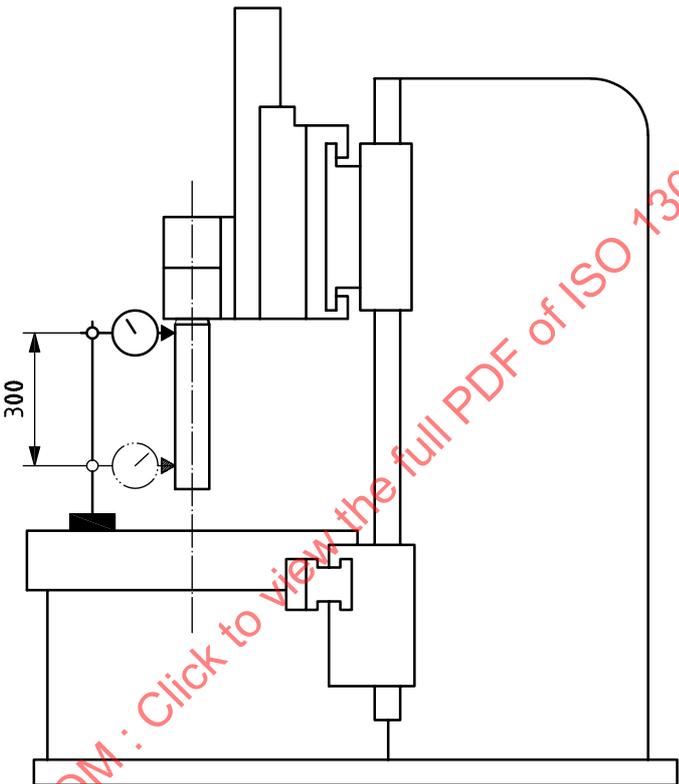
5.5 Turret and workholding and toolholding spindle(s)

5.5.1 Turret and workholding spindle

Object To check the co-axiality deviation between the axes of the turret bore(s) and the workholding spindle axis of rotation.	G17
Diagram 	
Tolerance 0,025	Measured deviation
Measuring instruments Test mandrel and linear displacement sensor	
Observations and references to ISO 230-1:1996, 5.442 A mandrel of sufficient length shall be inserted in one of the turret bores. A linear displacement sensor shall be fixed on the workholding spindle and shall touch the test mandrel near the turret bore and a distance of 100 mm without moving the railhead ram or cross-rail in the vertical direction. Repeat the same operations for each of the turret bores. NOTE The value of permissible deviation is equal to half of the readings of the linear displacement sensor.	

<p>Object</p> <p>To check the squareness between the tool-fixing faces of the turret and the workholding spindle axis of rotation.</p> <p>NOTE The test applies to tool-fixing faces of turrets that are square to the workholding spindle axis.</p>		<p>G18</p>
<p>Diagram</p>		
<p>Tolerance</p> <p>0,02/100</p> <p><i>L</i> is the diameter of measurement</p>		<p>Measured deviation</p>
<p>Measuring instruments</p> <p>Linear displacement sensor and reference block</p>		
<p>Observations and references to ISO 230-1:1996, 5.512.11</p> <p>A linear displacement sensor shall be fixed on the workholding spindle and shall touch the reference block located on the face of turret located opposite.</p> <p>The workholding spindle shall be rotated and the linear displacement sensor shall be moved to touch the face of the turret on the largest possible diameter.</p> <p>The test shall be repeated for each of the tool-fixing faces of the turret.</p>		

5.5.2 Turret and toolholding spindle(s)

<p>Object</p> <p>To check the run-out of the internal taper of the toolholding spindle(s):</p> <p>a) at the spindle nose;</p> <p>b) at a distance of 300 mm from the spindle nose.</p> <p>NOTE Carry out these tests for each toolholding spindle of the machine.</p>	G19
<p>Diagram</p> 	
<p>Tolerance</p> <p>$D_f \leq 200$ a) 0,010 b) 0,020</p> <p>$D_f > 200$ a) 0,015 b) 0,030</p> <p>where D_f is the external diameter of the spindle-nose face.</p>	<p>Measured deviation</p> <p>a)</p> <p>b)</p>
<p>Measuring instruments</p> <p>Linear displacement sensor and test mandrel</p>	
<p>Observations and references to ISO 230-1:1996, 5.612.3</p> <p>Attach a linear displacement sensor to the table (workholding spindle) and insert the test mandrel in the live tooling spindle.</p> <p>Place the displacement sensor as close as possible to position a), rotate the toolholding spindle and record the reading.</p> <p>Repeat the same operation at position b).</p>	

5.5.3 Accuracy of turret indexing

Object				G20
To check the repeatability of the turret indexing: a) in the X direction; b) in the Z direction.				
Diagram				
<p>The diagram illustrates the measurement setup for turret indexing accuracy. It shows a vertical test mandrel with a horizontal turret assembly. A linear displacement sensor, labeled 'a)', is positioned to measure the turret's axis position in the X direction. Another linear displacement sensor, labeled 'b)', is positioned to measure the turret's axis position in the Z direction. The distance from the turret face or tool-fixing face to the measurement point is denoted as 'l'.</p>				
Tolerance			Measured deviation	
	Category 1	Category 2	Categories 3 and 4	a)
	$l = 50$	$l = 100$	$l = 100$	b)
a) and b)	0,005	0,010	0,015	
Measuring instruments				
Test mandrel and linear displacement sensor				
Observations and references to ISO 230-1:1996, 6.42				
Measure at distance l from the turret face or tool-fixing face. With the turret in mid-stroke, position the linear displacement sensors so they contact the test mandrel at the 0° and 90° measurement positions. Record the turret's axis position and the linear displacement sensor readings.				
Move the turret to a position clear of the linear displacement sensors, then index the turret 360° . Move the turret axis to the recorded position under an automatic cycle. Record the linear displacement sensor readings.				
Repeat the cycle three times; the linear displacement sensor should be reset to zero at the start of the test. Deviation is the maximum difference between the three sets of readings.				
Also, the linear displacement sensor can be mounted on the spindle housing to avoid locking the spindle (preferred method).				
The test should be repeated at a minimum of three different turret orientations and, for each orientation, the linear displacement sensor should be set to zero.				
The repeatability of positioning of the linear axes (used for clearing the linear displacement sensors) may influence the measuring result.				

Object		G21
To check the accuracy of the turret indexing.		
Diagram		
Tolerance		Measured deviation
Category 1	Categories 2, 3, and 4	
0,030	0,040	
Measuring instruments		
Linear displacement sensor		
Observations and references to ISO 230-1		
<p>Position the linear displacement sensor styli a), b) and c) so that they contact the turret reference holes or grooves. Record the turret axis position. Record the linear displacement sensor readings. Withdraw the turret position to clear off the linear displacement sensor, index the turret to the next orientation, and reposition the turret axis. Record the linear displacement sensor readings.</p> <p>If the turret reference face is used, the linear displacement sensor should be used at position f).</p> <p>Repeat the test three times for each turret orientation; the readings at each orientation are then averaged to minimize the effect of turret repeatability. The maximum difference of all averaged linear displacement sensor readings is the accuracy of turret indexing.</p> <p>The repeatability of the turret indexing might influence the readings.</p>		