INTERNATIONAL STANDARD

ISO 230-2

Second edition
1997-12-15

Test code for machine tools —

Part 2:
Determination of accuracy and repeatability of positioning numerically controlled axes

Code d'essai des machines-outils —

Partie 2: Détermination de la précision et de la répétabilité de positionnement des axes en commande numérique

Reference number
ISO 230-2:1997(E)

Contents

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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 IS0 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 commitee. 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.

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.

International Standard ISO 230-2 was prepared by Technical Committee ISO/TC 39, *Machine tools,* Subcommittee SC2, *Test conditions for metal cutting machine tools*.

ISO 230 consists of the following parts, under the general title *Test code for machine tools*:

— *Part 1: Geometric accuracy of machines operating under no-load or finishing conditions*

— *Part 2: Determination of accuracy and repeatability of positioning of numerically controlled axes*

— *Part 3: Evaluation of thermal effects*

— *Part 4: Circular tests for numerically controlled machine tools*

— *Part 5: Noise emissions*

Annexes A and B to this part of ISO 230 are for information only.

This second edition cancels and replaces the first edition (ISO 230-2:1988), which has been technically revised.

Introduction

Since this part of ISO 230 uses statistical treatment of measured values to define various parameters related to machine tool behaviour, Subcommittee SC 2 has decided to follow the recommendations provided by the *Guide to the expression of uncertainty of measurements* [1].

The first modification is related to the assumption of the type of distribution of the positional deviations. The modified definitions in this document use no assumptions for the shape of the distribution by referring to "standard uncertainties" rather than "standard deviations". The new definition of expanded uncertainty with a coverage factor of 2 instead of 3 is also used following the recommendations of the Guide.

Secondly, in order to highlight the systematic behaviour of machine tools, Subcommittee SC 2 has added new definitions to this document, namely *E* (corresponding to term “Accuracy” in ANSI B5.54) and *M* (corresponding to the term “Positional Deviation, P_a” in VDI 3441).

Subcommittee SC 2 believes that with these additions this part of ISO 230 will become more uniformly accepted across all member countries.

Test code for machine tools —

Part 2:
Determination of accuracy and repeatability of positioning of numerically controlled axes

1 Scope

This part of ISO 230 specifies methods of testing and evaluating the accuracy and repeatability of positioning of numerically controlled machine tool axes by direct measurement of individual axes on the machine. The methods described apply equally to linear and rotary axes.

NOTE - When several axes are simultaneously under test, this method does not apply.

This part of ISO 230 may be used for type testing, acceptance tests, comparison testing, periodic verification, machine compensation, etc.

The methods used involve repeat measurements at each position. The related parameters are defined and calculated as described in the *Guide to the expression of uncertainty in measurement* [1] (see annex B).

Annex A describes the application of an optional test cycle — the step cycle. The results from this cycle should neither be used in the technical literature with reference to this standard, nor for acceptance purposes, except under special written agreements between supplier/manufacturer and user. Pure reference to this part of ISO 230 for machine acceptance always refers to the standard test cycle.

2 Definitions and symbols

For the purposes of this part of ISO 230, the following definitions and symbols apply.

2.1 axis travel: Maximum travel, linear or rotary, over which the moving component can move under numerical control.

2.2 measurement travel: Part of the axis travel which is used for data capture, selected so that the first and the last target positions may be approached bidirectionally (see figure 1).

2.3 target position, P_i (i = 1 to m)**:** Position to which the moving part is programmed to move. The subscript i identifies the particular position among other selected target positions along or around the axis.

2.4 actual position, P_{ij} (i = 1 to m; j = 1 to n)**:** Measured position reached by the moving part on the jth approach to the ith target position.

2.5 deviation of position; positional deviation, x_{ij}: Actual position reached by the moving part minus the target position.

$$x_{ij} = P_{ij} - P_i$$

2.6 unidirectional: Refers to a series of measurements in which the approach to a target position is always made in the same direction along or around the axis. The symbol $\uparrow$ signifies a parameter derived from a measurement made after an approach in the positive direction, and $\downarrow$ one in the negative direction, e.g. $x_{ij}\uparrow$ or $x_{ij}\downarrow$.

2.7 bidirectional: Refers to a parameter derived from a series of measurements in which the approach to a target position is made in either direction along or around the axis.

2.8 expanded uncertainty: Quantity defining an interval about the result of a measurement that may be expected to encompass a large fraction of the distribution of values.

2.9 coverage factor: Numerical factor used as a multiplier of the combined standard uncertainty in order to obtain an expanded uncertainty.

2.10 mean unidirectional positional deviation at a position, $\bar{x}_i\uparrow$ or $\bar{x}_i\downarrow$: Arithmetic mean of the positional deviations obtained by a series of n unidirectional approaches to a position P_i.

$$\bar{x}_i\uparrow = \frac{1}{n}\sum_{j=1}^{n} x_{ij}\uparrow$$

and

$$\bar{x}_i\downarrow = \frac{1}{n}\sum_{j=1}^{n} x_{ij}\downarrow$$

2.11 mean bidirectional positional deviation at a position, $\bar{x}_i$: Arithmetic mean of the mean unidirectional positional deviations, $\bar{x}_i\uparrow$ and $\bar{x}_i\downarrow$, obtained from the two directions of approach at a position P_i.

$$\bar{x}_i = \frac{\bar{x}_i\uparrow + \bar{x}_i\downarrow}{2}$$

2.12 reversal value at a position, B_i: Value of the difference between the mean unidirectional positional deviations obtained from the two directions of approach at a position P_i.

$$B_I = \bar{x}_i\uparrow - \bar{x}_i\downarrow$$

2.13 reversal value of an axis, B: Maximum of the absolute reversal values $|B_i|$ at all target positions along or around the axis.

$$B = \max.\left[|B_\mathrm{i}|\right]$$

2.14 mean reversal value of an axis, $\overline{B}$: Arithmetic mean of the reversal values B_i at all target positions along or around the axis.

$$\overline{B} = \frac{1}{m}\sum_{i=1}^{m} B_i$$

2.15 estimator of the unidirectional standard uncertainty of positioning at a position, $s_i\uparrow$ or $s_i\downarrow$: Estimator of the standard uncertainty of the positional deviations obtained by a series of n unidirectional approaches at a position P_i.

$$s_i\uparrow = \sqrt{\frac{1}{n-1}\sum_{j=1}^{n}\left(x_{ij}\uparrow - \bar{x}_i\uparrow\right)^2}$$

and

$$s_i\downarrow = \sqrt{\frac{1}{n-1}\sum_{j=1}^{n}\left(x_{ij}\downarrow - \bar{x}_i\downarrow\right)^2}$$

2.16 unidirectional repeatability of positioning at a position, $R_i\uparrow$ or $R_i\downarrow$: Range derived from the expanded uncertainty of unidirectional positional deviations at a position P_i, using a coverage factor of 2.

$$R_i\uparrow = 4s_i\uparrow$$

and

$$R_i\downarrow = 4s_i\downarrow$$

2.17 bidirectional repeatability of positioning at a position, R_i:

$$R_i = \text{max.}\left[2s_i\uparrow + 2s_i\downarrow + \left|B_i\right|; R_i\uparrow; R_i\downarrow\right]$$

2.18 unidirectional repeatability of positioning $R\uparrow$ or $R\downarrow$ and bidirectional repeatability of positioning R of an axis: Maximum value of the repeatability of positioning at any position P_i along or around the axis.

$$R\uparrow = \text{max.}\left[R_i\uparrow\right]$$

$$R\downarrow = \text{max.}\left[R_i\downarrow\right]$$

$$R = \text{max.}\left[R_i\right]$$

2.19 unidirectional systematic positional deviation of an axis, $E\uparrow$ or $E\downarrow$: The difference between the algebraic maximum and minimum of the mean unidirectional positional deviations for one approach direction $\bar{x}_i\uparrow$ or $\bar{x}_i\downarrow$ at any position P_i along or around the axis.

$$E\uparrow = \text{max.}\left[\bar{x}_i\uparrow\right] - \text{min.}\left[\bar{x}_i\uparrow\right]$$

and

$$E\downarrow = \text{max.}\left[\bar{x}_i\downarrow\right] - \text{min.}\left[\bar{x}_i\downarrow\right]$$

2.20 bidirectional systematic positional deviation of an axis, *E***:** The difference between the algebraic maximum and minimum of the mean unidirectional positional deviations for both approach directions $\bar{x}_i\uparrow$ and $\bar{x}_i\downarrow$ at any position P_i along or around the axis.

$$E = \text{max.}\left[\bar{x}_i\uparrow;\bar{x}_i\downarrow\right] - \text{min.}\left[\bar{x}_i\uparrow;\bar{x}_i\downarrow\right]$$

2.21 mean bidirectional positional deviation of an axis, *M***:** The difference between the algebraic maximum and minimum of the mean bidirectional positional deviations $\bar{x}_i$ at any position P_i along or around the axis.

$$M = \text{max.}\left[\bar{x}_i\right] - \text{min.}\left[\bar{x}_i\right]$$

2.22 unidirectional accuracy of positioning of an axis, $A\uparrow$ **or** $A\downarrow$**:** Range derived from the combination of the unidirectional systematic deviations and the estimator of the standard uncertainty of unidirectional positioning using a coverage factor of 2.

$$A\uparrow = \text{max.}\left[\bar{x}_i\uparrow + 2s_i\uparrow\right] - \text{min.}\left[\bar{x}_i\uparrow + 2s_i\uparrow\right]$$

and

$$A\downarrow = \text{max.}\left[\bar{x}_i\uparrow + 2s_i\downarrow\right] - \text{min.}\left[\bar{x}_i\downarrow - 2s_i\downarrow\right]$$

2.23 bidirectional accuracy of positioning of an axis, *A***:** Range derived from the combination of the bidirectional systematic deviations and the estimator of the standard uncertainty of bidirectional positioning using a coverage factor of 2.

$$A = \text{max.}\left[\bar{x}_i\uparrow + 2s_i\uparrow;\bar{x}_i\downarrow + 2s_i\downarrow\right] - \text{min.}\left[\bar{x}_i\uparrow - 2s_i\uparrow;\bar{x}_i\downarrow - 2s_i\downarrow\right]$$

3 Test conditions

3.1 Environment

It is recommended that the supplier/manufacturer offer guidelines regarding what kind of thermal environment should be acceptable for the machine to perform with the specified accuracy.

Such general guidelines could contain, for example, a specification on the mean room temperature, maximum amplitude and frequency range of deviations from this mean temperature, and environmental thermal gradients. It shall be the responsibility of the user to provide an acceptable thermal environment for the operation and the performance testing of the machine tool at the installation site. However, if the user follows the guidelines provided by the machine supplier/manufacturer, the responsibility for machine performance according to the specifications reverts to the machine supplier/manufacturer.

Ideally, all dimensional measurements are made when both the measuring instrument and the measured object are soaked in an environment at a temperature of 20 °C. If the measurements are taken at temperatures other than 20 °C, then correction for nominal differential expansion (NDE) between the axis positioning system and the test equipment must be applied to yield results corrected to 20 °C. This condition requires temperature measurement of the representative part of the machine positioning system as well as the test equipment.

It should be noted, however, that any temperature departure from 20 °C can cause an additional uncertainty related to the uncertainty in the effective expansion coefficient(s) used for compensation. A typical value for the resulting uncertainty is ± 2 µm/(m °C) (see annex B). Therefore the actual temperatures shall be recorded in the test report. The machine tool supplier/manufacturer should supply the effective expansion coefficient(s) of the axis positioning systems.

The machine and, if relevant, the measuring instruments shall have been in the test environment long enough (preferably overnight) to have reached a thermally stable condition before testing. They shall be protected from draughts and external radiation such as sunlight, overhead heaters, etc.

For 12 h before and during the measurements, the environmental temperature gradient in degrees per hour shall be within limits agreed between the supplier/manufacturer and the user.

3.2 Machine to be tested

The machine shall be completely assembled and fully operational. All necessary levelling operations and geometric alignment tests shall be completed satisfactorily before starting the accuracy and repeatability tests.

If built-in compensation routines are used during the test cycle, this should be stated in the test report.

All tests shall be carried out with the machine in the unloaded condition, i.e. without a workpiece.

The positions of the axis slides or moving components on the axes which are not under test shall be stated in the test sheet.

3.3 Warm-up

To test the machine under normal operating conditions, the tests shall be preceded by an appropriate warm-up operation specified by the supplier/manufacturer of the machine, or agreed between the supplier/manufacturer and the user.

If no conditions are specified, the preliminary movements shall be restricted to those necessary for setting up the measuring instruments.

Non-stable thermal conditions are recognized as an ordered progression of deviations between successive approaches to any particular target position. These trends should be minimized through the warm-up operation.

4 Test programme

4.1 Mode of operation

The machine shall be programmed to move the moving part along or around the axis under tests, and to position it at a series of target positions where it will remain at rest long enough for the actual position reached to be measured and recorded.
The machine shall be programmed to move between the target positions at an agreed feed rate.

4.2 Selection of target position

Where the value of each target position can be freely chosen, it shall take the general form

$$P_i = (i - 1)p + r$$

where

i is the number of the current target position;

p is an interval based on a uniform spacing of target points over the measurement travel;

r takes a different value at each target position, yielding a non uniform spacing of the target positions over the measurement travel to ensure that periodic errors (such as the errors caused by the pitch of the ball screw, and pitch of linear or rotary scales) are adequately sampled.

4.3 Measurements

4.3.1 Setup and instrumentation

The measurement setup is designed to measure the relative displacements between the component that holds the tool and the component that holds the workpiece in the direction of motion of the axis under test.

The position of the measuring instrument shall be recorded on the test sheet.

The position of the temperature sensor(s) on the machine components and the type of compensation routine shall be stated on the test sheet.

4.3.2 Tests for linear axes up to 2 000 mm

On machine axes of travel up to 2 000 mm, a minimum of five target positions per metre and with an overall minimum of five target positions shall be selected in accordance with 4.2.

Measurements shall be made at all the target positions according to the standard test cycle (see figure 1). Each target position shall be attained five times in each direction.

NOTE — The position of changing direction should be chosen to allow for normal behaviour of the machine (to achieve the agreed feed rate).

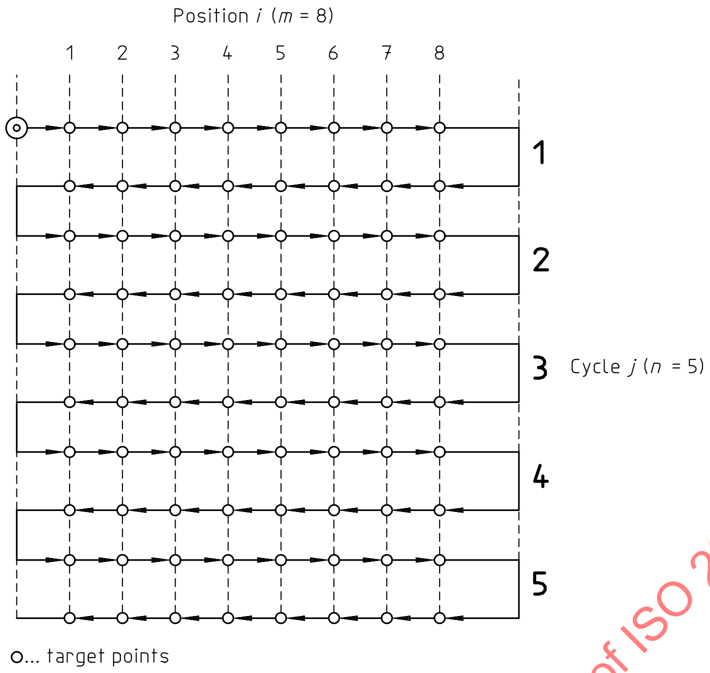

Figure 1 — Standard test cycle

4.3.3 Tests for linear axes exceeding 2 000 mm

For axes longer than 2 000 mm, the whole measurement travel of the axis shall be tested by making one unidirectional approach in each direction to target positions selected according to 4.2 with an average interval length p of 250 mm. Where the measuring transducer consists of several segments, additional target points may have to be selected to ensure that each segment has at least one target position.

The test specified in 4.3.2 shall be made over a length of 2 000 mm in the normal working area as agreed between the supplier/manufacturer and the user.

4.3.4 Tests for rotary axes up to 360°

Tests shall be made at the target positions given in table 1. The principal positions 0°, 90°, 180° and 270° should be included when available along with other target positions in accordance with 4.2.

Table 1 — Target Positions for Rotary Axes

Measurement travel	Minimum number of target positions
≤ 90°	3
> 90° and ≤ 180°	5
> 180°	8

4.3.5 Tests for rotary axes exceeding 360°

For axes exceeding 360°, the total measurement travel of the axis up to 1 800° (five revolutions) shall be tested by making one unidirectional approach in each direction at intervals not exceeding 45°.

The test specified in 4.3.4 shall be made over an angle of 360° in the normal working area as agreed between the supplier/manufacturer and the user.

5 Evaluation of the results

5.1 Linear axes up to 2 000 mm and rotary axes up to 360°

For each target position P_i and for five approaches (n = 5) in each direction the parameters defined in clause 2 are evaluated. Furthermore the deviation boundaries

$\bar{x}_i \uparrow + 2s_i \uparrow$ and $\bar{x}_i \uparrow - 2s_i \uparrow$

and

$\bar{x}_i \downarrow + 2s_i \downarrow$ and $\bar{x}_i \downarrow - 2s_i \downarrow$

are calculated.

5.2 Linear axes exceeding 2 000 mm and rotary axes exceeding 360°

For each target position and for one approach (n = 1) in each direction the applicable parameters defined in clause 2 are evaluated. Estimators of the standard uncertainty (2.15), repeatabilities (2.16, 2.17 and 2.18) and accuracies (2.22 and 2.23) are not applicable.

6 Points to be agreed between supplier/manufacturer and user

The points to be agreed between the supplier/manufacturer and the user are as follows:

a) the maximum rate of environmental temperature gradient in degrees per hour for 12 h before and during the measurements (see 3.1);

b) the location of the measuring instrument and the positions of the temperature sensors (see 4.3.1);

c) the warm-up operation to precede testing the machine (see 3.3);

d) the feed rate between target positions;

e) the position of the 2 000 mm or 360° measurement travel to be regarded as the normal working area (see 4.3.3 or 4.3.5) if relevant;

f) position of the slides or moving components which are not under test;

g) dwell time at each target position;

h) location of first and last target positions.

7 Presentation of the results

7.1 Method of presentation

The preferred method of presentation of the results is a graphical one with the following list of items recorded on the test report in order to identify the measurement setup.

— position of the measuring instrument;

— position of the temperature sensor(s) on the machine components and the type of compensation routine;

— date of test;

— machine name, type (horizontal spindle or vertical spindle) and its coordinate axes travels;

— list of the test equipment used, including supplier/manufacturer's name, type and serial number of the components (e.g. laser head, optics, temperature sensors, etc.);

— type of machine scale used for positioning of axis and its coefficient of thermal expansion used for nominal differential expansion (NDE) correction (e.g. ball screw and rotary resolver, glass scale or inductosyn scale, etc.),

— axis name under test and the location of its measurement line relative to the axes not under test (this location is determined by the offset to tool reference, offset to workpiece reference and the locations of axes not under test. Both of these offsets are determined by specific machine configuration);

— feed rate and dwell time at each target position, list of nominal target positions;

— warm-up operation to precede testing the machine (number of cycles or idling time and feed rate);

— temperatures of sensors attached to the relevant components of the machine representing machine scale and workpiece, at the start and end of the test;

— environmental temperature at the start and end of the test;

— if relevant, air pressure and humidity at the start and end of the test;

— whether or not built-in compensation routines were used during the test cycle;

— use of air- or oil-shower, when applied;

— number of runs ($n = 5$ or $n = 1$).

7.2 Parameters

The following parameters shall be specified numerically. A summary of results using the parameters denoted with an asterisk followed by a parenthesis may provide a basis for machine acceptance. A presentation is shown in figures 2a and 2b of the results are given in table 2.

7.2.1 Tests for linear axes up to 2 000 mm and rotary axes up to 360°

— Bidirectional accuracy of positioning of an axis*)	A
— Unidirectional accuracy of positioning of an axis*)	$A\uparrow$ and $A\downarrow$
— Bidirectional systematic positional deviation of an axis*)	E
— Unidirectional systematic positional deviation of an axis	$E\uparrow$ and $E\downarrow$
— Range of the mean bidirectional positional deviation of an axis*)	M
— Bidirectional repeatability of positioning of an axis	R
— Unidirectional repeatability of positioning of an axis*)	$R\uparrow$ and $R\downarrow$
— Reversal value of an axis*)	B
— Mean reversal value of an axis	$\overline{B}$

7.2.2 Tests for linear axes exceeding 2 000 mm and rotary axes exceeding 360°

— Bidirectional systematic positional deviation of an axis*)	E
— Unidirectional systematic positional deviation of an axis	$E\uparrow$ and $E\downarrow$
— Range of the mean bidirectional positional deviation of an axis*)	M
— Reversal value of an axis*)	B
— Mean reversal value of an axis	$\overline{B}$

Table 2 — Typical test results (test for linear axis up to 2 000 mm)

i	1		2		3		4		5		6		7		8		9		10		11	
Target position P_i (mm)	6,711		175,077		353,834		525,668		704,175		881,868		1 055,890		1 234,304		1 408,462		1 580,269		1 750,920	
Approach direction	↓	↑	↓	↑	↓	↑	↓	↑	↓	↑	↓	↑	↓	↑	↓	↑	↓	↑	↓	↑	↓	↑
Positional deviations (µm) j=1	2,3	-1,2	3,6	-0,5	3,5	0,2	3,0	-0,6	1,7	-1,9	0,4	-3,0	-0,4	-3,7	-0,2	-3,7	0,2	-3,5	0,3	-3,2	-0,1	-3,6
2	2,1	-1,7	3,5	-0,9	3,3	-0,6	2,7	-1,2	1,5	-2,3	0,2	-3,5	-0,7	-4,3	-0,6	-4,4	-0,2	-4,3	-0,1	-3,8	-0,6	-4,0
3	1,9	-1,9	3,1	-1,1	3,0	-0,7	2,4	-1,3	1,0	-2,9	-0,2	-3,7	-1,0	-4,6	-1,0	-5,1	-1,0	-5,0	-0,9	-4,7	-1,2	-4,5
4	2,8	-1,3	3,7	-0,2	3,8	0,1	3,2	-0,3	1,9	-1,4	0,9	-2,8	0,0	-3,6	-0,2	-3,6	0,5	-3,2	0,5	-2,8	0,4	-3,2
5	2,2	-1,9	3,2	-0,8	3,5	-0,7	2,6	-1,3	1,1	-2,3	-0,1	-3,7	-0,9	-4,5	-1,1	-4,6	-0,5	-4,5	-0,4	-4,1	-0,9	-4,5
Mean unidirectional Positional deviation $\overline{x_i}$ (µm)	2,3	-1,6	3,4	-0,7	3,4	-0,4	2,8	-0,9	1,4	-2,2	0,2	-3,3	-0,6	-4,1	-0,6	-4,3	-0,2	-4,1	-0,1	-3,7	-0,5	-4,0
Estimator of standard uncertainty s_i (µm)	0,3	0,4	0,3	0,4	0,3	0,5	0,3	0,5	0,4	0,5	0,4	0,4	0,4	0,5	0,4	0,6	0,6	0,7	0,6	0,7	0,6	0,6
$2s_i$ (µm)	0,7	0,7	0,6	0,7	0,6	0,9	0,6	0,9	0,8	1,1	0,9	0,8	0,9	1,0	0,9	1,3	1,2	1,4	1,1	1,5	1,2	1,2
$\overline{x_i} - 2s_i$ (µm)	1,6	-2,3	2,8	-1,4	2,8	-1,3	2,2	-1,9	0,6	-3,2	-0,6	-4,2	-1,4	-5,1	-1,5	-5,5	-1,4	-5,5	-1,3	-5,2	-1,7	-5,1
$\overline{x_i} + 2s_i$ (µm)	2,9	-0,9	4,0	0,0	4,0	0,5	3,4	0,0	2,2	-1,1	1,1	-2,5	0,3	-3,2	0,3	-3,0	1,0	-2,7	1,0	-2,3	0,8	-2,8
Unidirectional repeatability $R_i = 4s_i$ (µm)	1,3	1,4	1,2	1,5	1,2	1,8	1,2	1,9	1,6	2,2	1,7	1,7	1,7	1,9	1,8	2,5	2,3	2,9	2,3	2,9	2,5	2,3
Reversal value B_i (µm)	-3,9		-4,1		-3,8		-3,7		-3,6		-3,6		-3,6		-3,7		-3,9		-3,6		-3,5	
Bidirectional repeatability R_i (µm)	5,2		5,4		5,3		5,2		5,5		5,3		5,4		5,8		6,5		6,2		5,9	
Mean bidirectional positional deviation $\overline{x_i}$ (µm)	0,3		1,4		1,5		0,9		-0,4		-1,5		-2,4		-2,5		-2,2		-1,9		-2,2	

Axis deviation (mm)	Unidirectional ↓		Unidirectional ↑		Bidirectional	
Reversal value B	Not Applicable		Not Applicable		0,004 1	(at i = 2)
Mean reversal value $\overline{B}$	Not Applicable		Not Applicable		-0,003 7	
Range mean bidirectional positional deviation M	Not Applicable		Not Applicable		0,004 0	(0,001 5- -0,002 5)
Systematic positional deviation E	0,004 0	(0,003 4- -0,000 6)	0,003 9	(-0,000 4- -0,004 3)	0,007 7	(0,003 4- -0,004 3)
Repeatability of positioning R	0,002 5	(at i = 11)	0,002 9	(at i = 10)	0,006 5	(at i = 9)
Accuracy A	0,005 7	(0,004 0- -0,001 7)	0,006 1	(0,000 5- -0,005 5)	0,009 6	(0,004 0- -0,005 5)

- date of test:	YY/MM/DD		
- name of inspector:	Joe Smith		
- machine name, type and serial No.:	AAA, vertical spindle machining centre, Serial No.: 1111111		
- measuring instrument and serial No.:	BBB, Serial No.: 1234567		
Test parameters			
- tested axis:	X		
- type of scale:	ball screw and rotary encoder		
- NDE correction (yes or no):	yes		
- coefficient of thermal expansion of scale (used for NDE correction):	11 µm/(m °C)		
- feed rate:	1 000 mm/min.		
- dwell time at each target position:	5 sec.		
- compensation used:	reversal and leadscrew		
Test location			
- position of axes not under test:	Y = 300 mm; Z = 350 mm; C = 0°		
- offset to tool reference (X/Y/Z):	0/0/120 mm		
- offset to workpiece reference (X/Y/Z):	0/0/30 mm		
Test conditions			
- temperature sensor	location	*T* start (°C)	*T* end (°C)
material sensor #1	table, X = 50 mm	21,8	22,9
material sensor #2	table, X = 1 700 mm	22,4	23,1
air sensor	centre of work zone	20,6	20,9
- air pressure:	102,4 KPa		
- air humidity:	60 %		

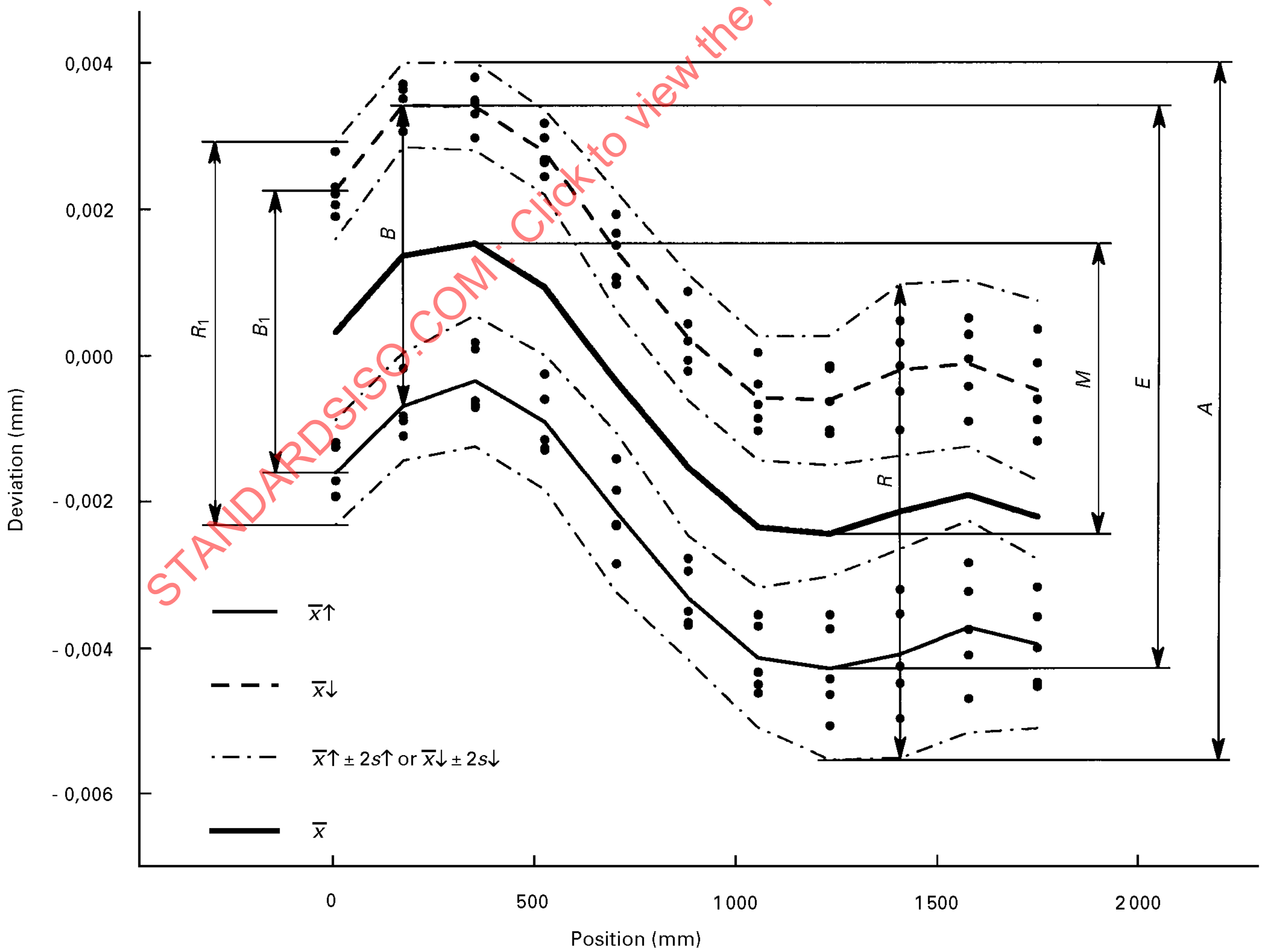

Figure 2a — Bidirectional accuracy and repeatability of positioning