39

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Acceptance code for machine tools —

Part 2: Determination of accuracy and repeatability of positioning of numerically controlled machine tools

Code de réception des machines-outils —

Partie 2: Détermination de la précision et de la répétabilité de positionnement des machines-outils à commande numérique

Reference number
ISO 230-2 : 1988 (E)

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.

Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council. They are approved in accordance with ISO procedures requiring at least 75 % approval by the member bodies voting.

International Standard ISO 230-2 was prepared by Technical Committee ISO/TC 39, *Machine tools.*

Users should note that all International Standards undergo revision from time to time and that any reference made herein to any other International Standard implies its latest edition, unless otherwise stated.

Acceptance code for machine tools —

Part 2: Determination of accuracy and repeatability of positioning of numerically controlled machine tools

0 Introduction

The purpose of ISO 230 is to standardize methods of testing the accuracy of machine tools, excluding portable power tools: it consists of the following parts:

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 machine tools.

Part 3: Accuracy of machines operating under load.[1)]

Part 4: Vibration.[1)]

Part 5: Noise.[2)]

Part 6: Safety.[1)]

1 Scope and field of application

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

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

This part of ISO 230 is concerned with measurement of the repeatability and accuracy of positioning of the moving parts of a numerically controlled machine along or around each axis of the machine.

The methods used involve repeat measurements at each position but the number of measurements and the nature of the errors do not allow the confidence level of the results to be estimated accurately. Nevertheless the methods chosen, which assume Gaussian distribution, have been shown in practice to have an adequate confidence level and, provided that the specified procedure is followed, will give acceptable results.

2 Definitions and symbols

2.1 target position, P_j: Position to which the moving part is programmed to move. The subscript j identifies the particular position from other selected target positions along or around the axis.

2.2 actual position, P_{ij}: Measured position reached by the moving part on the ith approach to the jth target position.

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

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

2.4 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 $x_{ij}\downarrow$.

2.5 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.

2.6 mean unidirectional positional deviation at a position, $\bar{x}_j\uparrow$ **or** $\bar{x}_j\downarrow$: Arithmetic mean of the positional deviations obtained at a position P_j in a series of n unidirectional approaches to the target position.

$$\bar{x}_j\uparrow = \frac{1}{n} \sum_{i=1}^{n} x_{ij}\uparrow$$

and

$$\bar{x}_j\downarrow = \frac{1}{n} \sum_{i=1}^{n} x_{ij}\downarrow$$

1) In preparation.

2) At present at the stage of draft.

2.7 reversal value [error] at a position, B_j: Value of the difference between the mean positional deviations at a position obtained for the two directions of approach.

$$B_j = \bar{x}_j\uparrow - \bar{x}_j\downarrow$$

2.8 range of positional deviation, W_j: Difference between the algebraically greatest and least of the positional deviations in a series of unidirectional approaches to a target position P_j.

$$W_j\uparrow = x_{ij}\uparrow \text{ max.} - x_{ij}\uparrow \text{ min.}$$

and

$$W_j\downarrow = x_{ij}\downarrow \text{ max.} - x_{ij}\downarrow \text{ min.}$$

2.9 estimator, s, of the standard deviation: The estimator s of the standard deviation of the positional deviations of a series of n unidirectional measurements at a target position P_j may be found using the formula method or the range method.

a) Formula method

$$s_j\uparrow = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_{ij}\uparrow - \bar{x}_j\uparrow)^2}$$

and

$$s_j\downarrow = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_{ij}\downarrow - \bar{x}_j\downarrow)^2}$$

b) Range method

$$s_j\uparrow = W_j\uparrow / k$$

and

$$s_j\downarrow = W_j\downarrow / k$$

where k depends on the number n of repeated measurements at the target position P_j.

Values of k are given in table 1.

Table 1 — Values of k as a function of n

n	2	3	4	5	6	7	8	9	10
k	1,128	1,693	2,059	2,326	2,534	2,704	2,847	2,97	3,078

2.10 unidirectional repeatability of positioning, $R_j\uparrow$ or $R_j\downarrow$, at a target position P_j: Greatest range of $6s_j\uparrow$ or $6s_j\downarrow$, i.e. the range between $\bar{x}_j\uparrow + 3s_j\uparrow$ and $\bar{x}_j\uparrow - 3s_j\uparrow$ or $\bar{x}_j\downarrow + 3s_j\downarrow$ and $\bar{x}_j\downarrow - 3s_j\downarrow$.

NOTE — This will give worst case rather than mean results.

2.11 bidirectional repeatability of positioning R_j at a target position P_j: Range equal to the maximum value of

$$3s_j\uparrow + 3s_j\downarrow + |B_j|$$

$$6s_j\uparrow$$

or

$$6s_j\downarrow$$

2.12 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 along or around the axis determined using the procedure and under the conditions specified in this part of ISO 230.

2.13 accuracy A of an axis: Maximum difference between the extreme values of $\bar{x} + 3s$ and $\bar{x} - 3s$ regardless of the position and the direction of motion. This definition applies to both unidirectional and bidirectional accuracy.

3 Test conditions

3.1 Environment

Where the temperature of the environment can be controlled it shall be set to 20 ± 0,5 °C. 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.

If the measuring instrument incorporates compensation for environmental factors such as air pressure and temperature, or machine temperature, these shall be used to yield results corrected to 20 °C.

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

3.2 Machine to be tested

The machine shall be completely assembled (with the possible exception of safety machine guards) and fully operational. All necessary levelling operations, geometric alignment tests and functional checks shall be completed satisfactorily before starting the accuracy and repeatability tests.

NOTE — Built-in compensation routines may be used during the test.

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 elements 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 manufacturer of the machine or agreed between the manufacturer and the customer.

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

4 Test programme

4.1 Mode of operation

The machine shall be programmed to move the moving part along or around the axis under test 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 (or stored in the memory of a computer).

The machine shall be programmed to move between the target positions at the rapid traverse rate or at an agreed feed rate.

4.2 Selection of target positions

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

$$P = (N + r)p$$

where

N is an integer,

r is a random decimal fraction,

p is the largest cyclic pitch of the axis under test,

and where r takes a different value at each target position and N is chosen to give uniform spacing of the target positions along or around the axis. This should ensure adequate sampling of any position errors.

4.3 Measurements

4.3.1 Location of the measurement reference

The position of the measuring instrument shall be recorded on the test sheet or specified in relevant standards.

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

4.3.2 Full check

On machine axes of length up to 2 m, a minimum of five target positions per metre, with an overall minimum of five target positions, shall be selected uniformly spaced along the axis.

Measurements shall be made at all the target positions according to either the test cycle shown in figure 1 (linear cycle) or that shown in figure 2 (quasi-pilgrim step cycle). Each target position shall be attained five times in each direction. The test cycle chosen (figure 1 or figure 2) shall be specified on the test sheet.

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

4.3.3 Individual check

For axes longer than 2 m, the whole length of the axis shall be tested by making at least one unidirectional approach in each direction to a target position on each element of the measuring transducer or at intervals of 250 mm where the measuring system is continuous (e.g. linear transducer or ball screw and rotary transducer).

The full test specified in 4.3.2 shall be made over a length of 2 m in the normal working region as agreed between the supplier and customer.

4.3.4 Rotary axes

Tests shall be made at the principal positions 0°, 90°, 180°, 270° and, if a measuring instrument with a continuous scale of adequate accuracy is available, tests shall be made at three positions selected according to 4.2.

If an optical polygon is used, the number of target positions will be determined by the number of sides of the polygon.

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

5 Evaluation of the results

For each target position P_j and for five approaches in each direction calculate

a) the deviation of position

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

b) the mean deviation of position

$$\bar{x}_j\uparrow = \frac{1}{5}\sum_{i=1}^{5} x_{ij}\uparrow$$

and

$$\bar{x}_j\downarrow = \frac{1}{5}\sum_{i=1}^{5} x_{ij}\downarrow$$

c) the reversal value

$$B_j = \bar{x}_j\uparrow - \bar{x}_j\downarrow$$

d) the estimator of the standard deviation

$$s_j\uparrow = \sqrt{\frac{1}{4}\sum_{i=1}^{5} (x_{ij}\uparrow - \bar{x}_j\uparrow)^2}$$

and

$$s_j\downarrow = \sqrt{\frac{1}{4}\sum_{i=1}^{5} (x_{ij}\downarrow - \bar{x}_j\downarrow)^2}$$

or

$$s_j\uparrow = |x_{ij}\uparrow \text{ max.} - x_{ij}\uparrow \text{ min.}| \times \frac{1}{2{,}326}$$

and

$$s_j\downarrow = |x_{ij}\downarrow \text{ max.} - x_{ij}\downarrow \text{ min.}| \times \frac{1}{2{,}326}$$

e) the limits

$$\bar{x}_j\uparrow + 3s_j\uparrow \quad \text{and} \quad \bar{x}_j\uparrow - 3s_j\uparrow$$

and

$$\bar{x}_j\downarrow + 3s_j\downarrow \quad \text{and} \quad \bar{x}_j\downarrow - 3s_j\downarrow$$

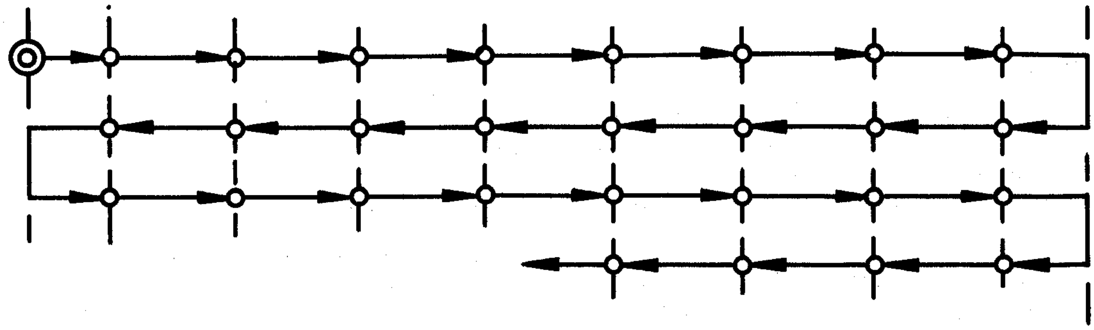
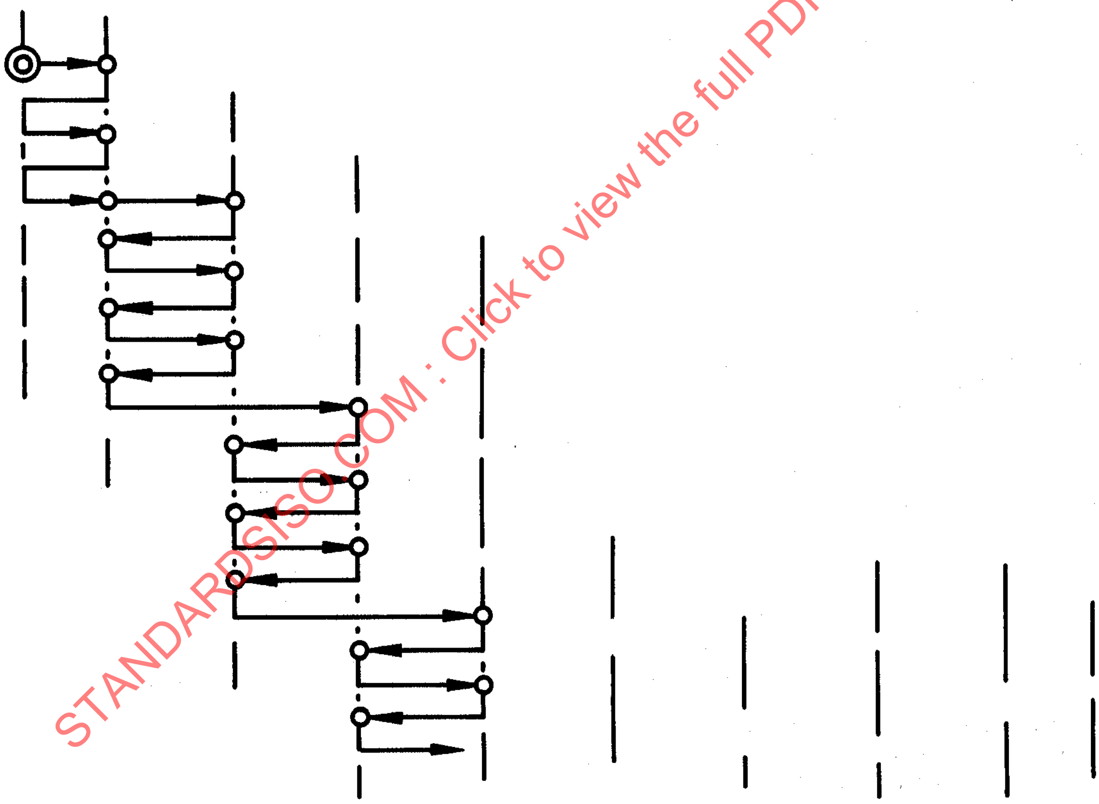


Figure 1 — Linear cycle



NOTE — Only three of the five target positions (see 4.3.2) have been shown for simplicity.

Figure 2 — Quasi-pilgrim step cycle

6 Expression of results

6.1 Record the repeatability of the axis positioning (2.12), bidirectional, and, if unidirectional, give the direction in which it is measured.

6.2 Record the accuracy of the axis (2.13).

6.3 Record the mean reversal error (2.7).

$$\bar{B} = \frac{1}{n} \sum_{j=1}^{n} B_j$$

7 Presentation of the results

The preferred method of presentation of the results is a graphical one with the principal parameters — accuracy, unidirectional and bidirectional repeatability and mean reversal value — specified numerically.

A typical presentation is shown in figure 3 of the results given in table 2.

NOTE — In addition, results may be supplemented with the mean values of repeatability along or around the axis.

$$\bar{r}\uparrow = \frac{1}{n} \sum_{j=1}^{n} R_j\uparrow$$

$$\bar{r}\downarrow = \frac{1}{n} \sum_{j=1}^{n} R_j\downarrow$$

$$\bar{r} = \frac{1}{n} \sum_{j=1}^{n} R_j$$

8 Points to be agreed between supplier and customer

The points to be agreed between the supplier and the customer are as follows:

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

b) the location of the measurement reference (see 4.3.1);

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

d) the feed rate between target positions if the rapid traverse rate is not used (see 4.1);

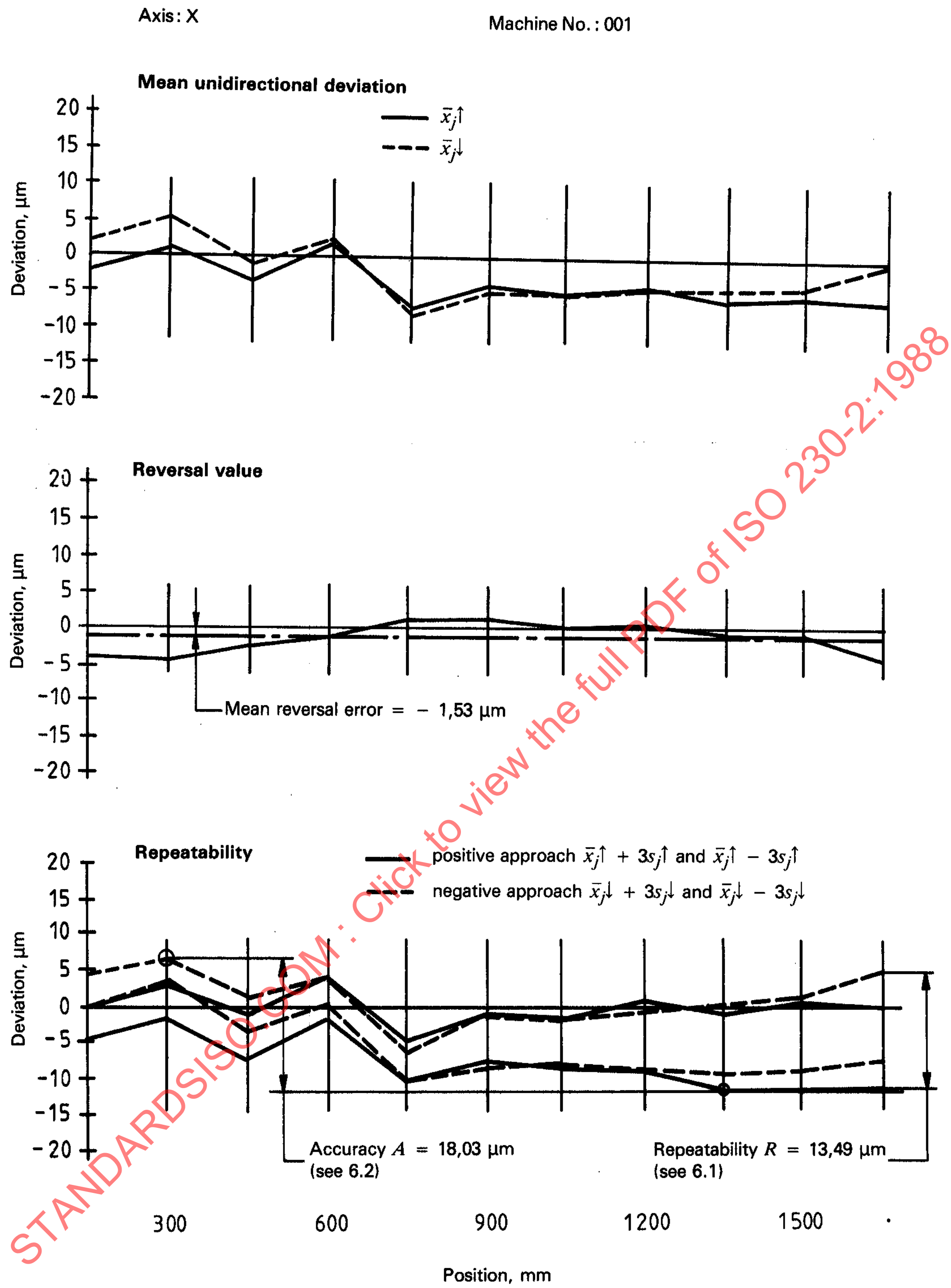
e) the test cycle according to figure 1 or figure 2 (see 4.3.2);

f) the position of the 2 m length to be regarded as the normal working region (see 4.3.3).

Table 2 — Typical test results

j	1		2		3		4		5		6		7		8		9		10		11	
Target position mm P_j	0		150,71		300,85		450,33		601,11		750,31		901,55		1 050,02		1 201,9		1 351,56		1 500,41	
Approach direction	↑	↓	↑	↓	↑	↓	↑	↓	↑	↓	↑	↓	↑	↓	↑	↓	↑	↓	↑	↓	↑	↓
Positional deviations x_{ij} µm, i = 1	−2,6	2,3	0,2	5,4	−5	−1,5	0,6	2,4	−8,4	−9	−4,9	−5,9	−6,3	−5,8	−5,5	−5,6	−8,2	−6,1	−7,4	−5,6	−7,8	−3
2	−1,6	1,1	0,7	4,6	−5,6	−1	1,6	2,1	−7,4	−9,4	−3,7	−5,9	−5,1	−5,6	−3,6	−4,8	−5,9	−5	−5,5	−4,6	−5,8	−1,8
3	−2,7	3,2	0,4	5,7	−4,8	−0,8	0,5	3,6	−7,8	−8,1	−4,7	−4	−5,6	−4,7	−5	−4,4	−6,3	−4,8	−5,4	−2,9	−5,6	−0,2
4	−1,8	2,5	1,8	5,4	−2,7	−2,6	2,3	2,2	−6,1	−8,3	−3,4	−4,3	−4,1	−4,2	−2,3	−4,4	−4,5	−3,1	−3,7	−2,8	−4,7	0
5	−0,9	1,5	1,5	5,9	−2,8	−0,8	2,3	2,9	−6,9	−7,8	−2,3	−2,9	−3,2	−3,3	−2,3	−2	−3,4	−2	−2,2	−1,4	−2,7	−2,7
Mean positional deviation $\bar{x}_j$	−1,92	2,12	0,92	5,4	−4,18	−1,34	1,46	2,64	−7,32	−8,52	−3,8	−4,6	−4,86	−4,72	−3,74	−4,24	−5,66	−4,2	−4,84	−3,46	−5,32	−1,54
Standard deviation s_j	0,746	0,832	0,698	0,495	1,339	0,76	0,879	0,619	0,876	0,661	1,054	1,296	1,226	1,028	1,488	1,345	1,828	1,632	1,973	1,649	1,851	1,388
$3s_j$	2,24	2,49	2,09	1,49	4,01	2,28	2,64	1,86	2,63	1,98	3,16	3,89	3,68	3,08	4,46	4,03	5,48	4,9	5,92	4,95	5,55	4,16
$\bar{x}_j + 3s_j$	0,32	4,61	3,01	6,89	−0,16	0,94	4,1	4,5	−4,69	−6,54	−0,64	−0,71	−1,18	−1,64	0,72	−0,2	−0,18	0,7	1,08	1,49	0,23	2,62
$\bar{x}_j - 3s_j$	−4,16	−0,36	−1,17	3,92	−8,18	−3,62	−1,18	0,78	−9,95	−10,5	−6,96	−8,49	−8,54	−7,8	−8,2	−8,27	−11,14	−9,1	−10,76	−8,41	−10,87	−5,69
Reversal value $B_j = \bar{x}_j\uparrow - \bar{x}_j\downarrow$	−4,04		−4,48		−2,84		−1,18		1,2		0,8		−0,14		0,5		−1,46		−1,38		−3,78	
Greater value of $6s_j\uparrow$ or $6s_j\downarrow$ or $3s_j\uparrow + 3s_j\downarrow + \|B_j\|$	8,77		8,06		9,13		5,68		5,81		7,85		7,36		8,99		11,84		12,25		13,49	

Mean reversal value $\bar{B} = -1{,}53$ µm	
Repeatability of positioning unidirectional	$R\uparrow$ = 11,84 µm (at j = 10) $R\downarrow$ = 9,9 µm (at j = 10)
bidirectional	R = 13,49 µm (at j = 11)
Accuracy	$A = (\bar{x}_j + 3s_j)$ max. $- (\bar{x}_j - 3s_j)$ min. $= 6{,}89 - (-11{,}14) = 18{,}03$ µm



Mean reversal error: −1,53 µm
Repeatability: $R\uparrow$ = 11,84 µm (at j = 10); $R\downarrow$ = 9,9 µm (at j = 10); R = 13,49 µm (at j = 11)
Accuracy: 18,03 µm

Figure 3 — Graphical presentation of results