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ISO 230-2

Third edition
2006-03-15

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 l'exactitude et de la répétabilité de positionnement des axes en commande numérique

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

This third edition cancels and replaces the second edition (ISO 230-2:1997), which has been technically revised. In particular, the following modifications have been made:

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- a measurement uncertainty statement requirement has been added to the presentation of results (Clause 7);
- determination of measurement uncertainty is included as a new Annex A;
- some editorial changes have been made in the body of the document, mainly to the Introduction;
- ISO 230-2:1997/Cor 1:1999 has been incorporated as 2.23.

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 numerically controlled axes*
- *Part 3: Determination of thermal effects*
- *Part 4: Circular tests for numerically controlled machine tools*
- *Part 5: Determination of the noise emission*
- *Part 6: Determination of positioning accuracy on body and face diagonals (Diagonal displacement tests)*
- *Part 7: Geometric Accuracy of axes of rotation*
- *Part 9: Estimation of measurement uncertainty for machine tool tests according to series 230, basic equations* [Technical Report]

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The following parts are under preparation:

— *Part 8: Determination of vibration levels* [Technical Report]

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Introduction

The purpose of ISO 230 is to standardize methods for testing the accuracy of machine tools, excluding portable power tools.

This part of ISO 230 specifies test procedures used to determine the accuracy and repeatability of positioning numerically controlled axes. The tests are designed to measure the relative displacements between the component that holds the tool and the component that holds the workpiece.

Since measurement uncertainty needs to be stated with the measurement results, a description of the estimation of the measurement uncertainty for the determination of the accuracy and repeatability of positioning has been added as Annex A.

It is believed that, with this addition, the relevant contributors to the measurement uncertainty are able to be recognized more easily and reduced more efficiently.

The supplier/manufacturer should provide thermal specifications for the environment in which the machine can be expected to perform with the specified accuracy. The machine user is responsible for providing a suitable test environment by meeting the supplier/manufacturer's thermal guidelines or otherwise accepting reduced performance. An example of environmental thermal guidelines is given in ISO 230-3:— [1], Annex C.

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A relaxation of accuracy expectations is required if the thermal environment causes excessive uncertainty or variation in the machine tool performance and does not meet the supplier/manufacturer's thermal guidelines. If the machine does not meet performance specifications, the analysis of the uncertainty due to the compensation of the machine tool temperature, given in A.2.4 of this part of ISO 230, and the uncertainty due to the environmental variation error, given in A.2.5, can help in identifying sources of problems.

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Test code for machine tools —

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

1 Scope

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

When several axes are simultaneously under test, the methods do not apply.

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

The methods involve repeat measurements at each position. The related parameters of the test are defined and calculated. Their uncertainties are estimated as described in ISO/TR 230-9:2005, Annex C [2].

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Annex A presents the estimation of the measurement uncertainty.

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Annex B describes the application of an optional test cycle — the step cycle. The results from this cycle are not to be used either in the technical literature with reference to this part of ISO 230, nor for acceptance purposes, except under special written agreements between supplier/manufacturer and user. Correct reference to this part of ISO 230 for machine acceptance always refers to the standard test cycle.

2 Terms and definitions

For the purposes of this document, 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

NOTE For rotary axes exceeding 360°, there may not be a clearly defined maximum length of travel.

2.2
measurement travel
part of the axis travel, used for data capture, selected so that the first and the last target positions can be approached bi-directionally

See Figure 1.

2.3
target position
P_i (i = 1 to m)
position to which the moving part is programmed to move

NOTE The subscript i identifies the particular position among other selected target positions along or around the axis.

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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

NOTE The symbol ↑ signifies a parameter derived from a measurement made after an approach in the positive direction, and ↓ one in the negative direction, e.g. $x_{ij}\uparrow$ or $x_{ij}\downarrow$.

2.7
bi-directional
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

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2.8
expanded uncertainty
quantity defining an interval about the result of a measurement that can be expected to encompass a large fraction of the distribution of values

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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 bi-directional 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

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

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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

$$B = \max.\left[\left|B_i\right|\right]$$

2.14
mean reversal value of an axis
$\bar{B}$
arithmetic mean of the reversal values B_i at all target positions along or around the axis

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

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2.15
estimator for the unidirectional axis repeatability 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

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

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 estimator for the unidirectional axis repeatability of positioning at a position P_i using a coverage factor of 2

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

and

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

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2.17
bi-directional repeatability of positioning at a position
R_i

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

2.18
unidirectional repeatability of positioning
$R\uparrow$ **or** $R\downarrow$
maximum value of the repeatability of positioning at any position P_i along or around the axis

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

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

2.19
bi-directional repeatability of positioning of an axis
R
maximum value of the repeatability of positioning at any position P_i along or around the axis

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

2.20
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.

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

and

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

2.21
bi-directional systematic positional deviation of an axis
E
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

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

2.22
mean bi-directional positional deviation of an axis
M
difference between the algebraic maximum and minimum of the mean bi-directional positional deviations $\bar{x}_i$ at any position P_i along or around the axis

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

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2.23
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 for axis repeatability of unidirectional positioning using a coverage factor of 2

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

and

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

2.24
bi-directional accuracy of positioning of an axis
A
range derived from the combination of the bi-directional systematic deviations and the estimator for axis repeatability of bi-directional positioning using a coverage factor of 2

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

3 Test conditions

3.1 Environment

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It is recommended that the supplier/manufacturer offer guidelines regarding the kind of thermal environment 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 or the workpiece/tool holding part of the machine tool and the test equipment shall be applied to yield results corrected to 20 °C. This condition might require temperature measurement of the representative part of the machine as well as the test equipment and a mathematical correction with the relevant thermal expansion coefficients. The NDE correction might also be achieved automatically, if the representative part of the machine tool and the test equipment have the same temperature and the same thermal expansion coefficient.

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 minimum range value for the resulting uncertainty is 2 µm/(m·°C) (see annexes A and C). Therefore, the actual temperatures shall be stated in the test report.

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

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3.2 Machine to be tested

The machine shall be completely assembled and fully operational. If 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 report.

3.3 Warm-up

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

If no conditions are specified, the warm-up operations may take the form of a “preliminary dummy run” of the accuracy test without gathering data; or the preliminary movements may be restricted to those necessary for setting up the measuring instruments. The warm-up operation chosen shall be stated in the test report.

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.

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4 Test programme

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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 to be reached, 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 the nominal interval based on a uniform spacing of target points over the measurement travel;

r is a random number within ± the amplitude of possible periodic errors (such as errors caused by the pitch of the ballscrew, and pitch of linear or rotary scales), used to ensure that these periodic errors are adequately sampled, and where, if no information on possible periodic errors is available, r shall be within ± 30 % of p.

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4.3 Measurements

4.3.1 Set-up 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.

If mathematical NDE correction is applied, the position of the temperature sensor(s) on the machine components, the expansion coefficients used for NDE correction and the type of compensation routine shall be stated on the test sheet.

4.3.2 Tests for linear axes up to 2 000mm

On machine axes of travel up to 2 000 mm, a minimum of five target positions per metre and 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.

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

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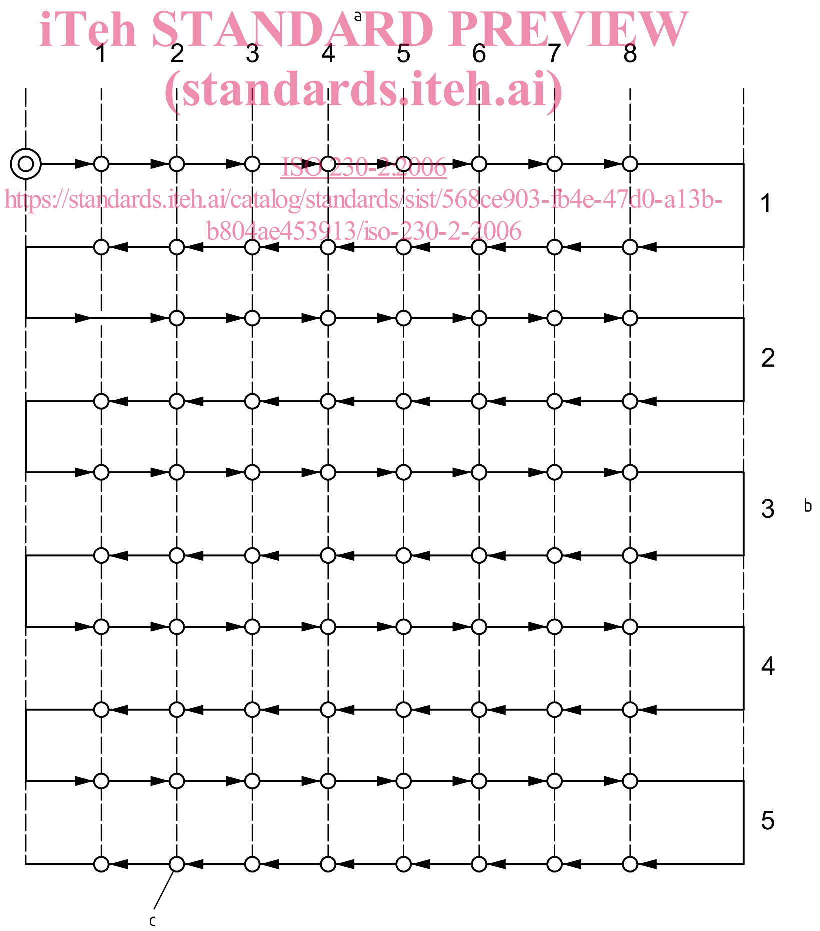

[a] Position $i (m = 8)$.
[b] Cycle $j (n = 5)$.
[c] Target points.

Figure 1 — Standard test cycle