INTERNATIONAL STANDARD

ISO 230-1

Third edition
2012-03-01

Test code for machine tools —

Part 1:
Geometric accuracy of machines operating under no-load or quasi-static conditions

Code d'essai des machines-outils —

Partie 1: Exactitude géométrique des machines fonctionnant à vide ou dans des conditions quasi-statiques

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Contents

Page

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ISO 230-1:2012
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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 230-1 was prepared by Technical Committee ISO/TC 39, *Machine tools*, Subcommittee SC 2, *Test conditions for metal cutting machine tools*.

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This third edition cancels and replaces the second edition (ISO 230-1:1996), which has been technically revised.

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

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

— *Part 2: Determination of accuracy and repeatability of positioning of 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 8: Vibrations* [Technical Report]

— *Part 9: Estimation of measurement uncertainty for machine tool tests according to series ISO 230, basic equations* [Technical Report]

— *Part 10: Determination of the measuring performance of probing systems of numerically controlled machine tools*

The following part is under preparation:

— *Part 11: Measuring instruments and their application to machine tool geometry tests* [Technical Report].

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Introduction

ISO/TC 39/SC 2 decided to revise and restructure this part of ISO 230 for the following reasons:

a) some subclauses of the previous edition overlapped with other newly specified test codes;

b) for practical reasons, it was necessary to modify the definitions of parallelism error and squareness error in order to exclude straightness error when looking at machine tool motion;

NOTE These definitions are not intended to be used for describing parallelism and perpendicularity errors of components and features. For components and features, this part of ISO 230 directly complies with the parallelism error and perpendicularity error definitions derived from other International Standards (e.g. ISO 1101).

c) a clear separation was desired among error motions of a trajectory and imperfections of functional surfaces and workpieces;

d) there was a need to address advances in machine tool technologies, measurement methods and measurement instruments.

e) Annex A of the second edition became wider, as new measuring methods/apparatus have been developed and introduced for higher accuracy and faster measurements. Therefore, it was separated from the main body to become a future Part 11 (Technical Report).

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f) furthermore, to align this part of ISO 230 with ISO 14253 (all parts), subclauses related to the uncertainty of measurement have been introduced.

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Test code for machine tools —

Part 1:
Geometric accuracy of machines operating under no-load or quasi-static conditions

1 Scope

This part of ISO 230 specifies methods for testing the accuracy of machine tools, operating either under no-load or under quasi-static conditions, by means of geometric and machining tests. The methods can also be applied to other types of industrial machines.

This part of ISO 230 covers power-driven machines, which can be used for machining metal, wood, etc., by the removal of chips or swarf material or by plastic deformation. It does not cover power-driven portable hand tools.

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This part of ISO 230 relates to the testing of geometric accuracy. It is not applicable to the operational testing of the machine tool (vibrations, stick-slip motion of components, etc.) or to the checking of characteristics (speeds, feeds).

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This part of ISO 230 does not cover the geometric accuracy of high-speed machine motions where machining forces are typically smaller than acceleration forces.

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 1, *Geometrical Product Specifications (GPS) — Standard reference temperature for geometrical product specification and verification*

ISO 230-2, *Test code for machine tools — Part 2: Determination of accuracy and repeatability of positioning of numerically controlled axes*

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

ISO 230-6, *Test code for machine tools — Part 6: Determination of positioning accuracy on body and face diagonals (Diagonal displacement tests)*

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

ISO/TR 230-8, *Test code for machine tools — Part 8: Vibrations*

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

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ISO 1101, *Geometrical Product Specifications (GPS) — Geometrical tolerancing — Tolerances of form, orientation, location and run-out*

ISO 12181-1:2011, *Geometrical product specifications (GPS) — Roundness — Part 1: Vocabulary and parameters of roundness*

ISO 12780-1:2011, *Geometrical product specifications (GPS) — Straightness — Part 1: Vocabulary and parameters of straightness*

ISO 12781-1:2011, *Geometrical product specifications (GPS) — Flatness — Part 1: Vocabulary and parameters of flatness*

ISO 14253-1, *Geometrical Product Specifications (GPS) — Inspection by measurement of workpieces and measuring equipment — Part 1: Decision rules for proving conformance or non-conformance with specifications*

3 Terms and definitions

3.1 General

For the purposes of this document, the terms and definitions given in ISO 230-2, ISO 230-4, ISO 230-7, ISO 841, ISO 12181-1, ISO 12780-1 and ISO 12781-1 and the following apply.

This part of ISO 230 uses metrological definitions, which take into account actual motions, real lines and surfaces accessible to measurement taking into account the limitations introduced by the construction or the practicality of geometric verification.

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NOTE 1 In some cases, geometric definitions (definitions of run-out, etc.) have been retained in this part of ISO 230, in order to eliminate any confusion and to clarify the language used. However, when describing test methods, measuring instruments and tolerances, metrological definitions are taken as the basis.

NOTE 2 For the alphabetical list of terms and definitions, see the index.

3.2 Terms for machine coordinate system and motion nomenclature

3.2.1
machine coordinate system
right-hand rectangular system with the three principal axes labelled X, Y and Z, with rotary axes about each of these axes labelled A, B and C, respectively

See Figure 1.

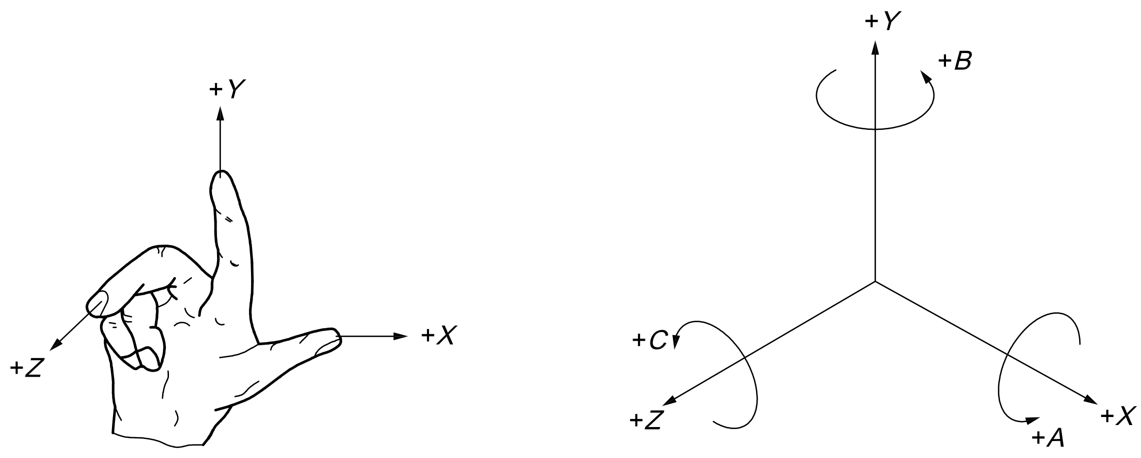

Figure 1 — Right-hand rectangular machine coordinate system

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3.3 Terms for static compliance and hysteresis

3.3.1
structural loop
assembly of components, which maintains the relative position between two specified objects

[ISO 230-7:2006, definition 3.1.13]

NOTE A typical pair of specified objects is a cutting tool and a workpiece, in which case the structural loop includes the spindle, bearings and spindle housing, the machine head stock, the machine slideways and frame, and the fixtures for holding the tool and workpiece. For large machines, the foundation can also be part of the structural loop.

3.3.2
static compliance
linear (or angular) displacement per unit static force (or moment) between two objects, specified with respect to the structural loop, the location and direction of the applied forces, and the location and direction of the displacement of interest

NOTE 1 Static compliance is reciprocal to static stiffness. Static compliance is preferred because of its additive properties.

NOTE 2 The term "cross compliance" is used when displacement and force are not measured in the same direction.

3.3.3
play
condition of zero stiffness over a limited range of displacement due to clearance between the components of a structural loop

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[ISO 230-7:2006, definition 3.1.21]

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3.3.4
hysteresis
linear (or angular) displacement between two objects resulting from the sequential application and removal of equal forces (or moments) in opposite directions

[ISO 230-7:2006, definition 3.1.22]

3.3.5
setup hysteresis
hysteresis of the various components in a test setup, normally due to loose mechanical connections

[ISO 230-7:2006, definition 3.1.22.1]

3.3.6
machine hysteresis
hysteresis of the machine structure when subjected to specific loads

[ISO 230-7:2006, definition 3.1.22.2]

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3.4 Terms for linear axes

3.4.1 General

In this part of ISO 230, many definitions and tests address errors in the relative motion between the component of the machine that carries the cutting tool and the component that carries the workpiece. These errors are defined and measured at the position or trajectory of the functional point.

3.4.2
functional point
cutting tool centre point or point associated with a component on the machine tool where cutting tool would contact the part for the purposes of material removal

See Figure 2.

NOTE 1 The functional point is a single point that can move within the machine tool working volume. This part of ISO 230 and related machine tool-specific standards, typically recommend to perform tests of geometrical characteristics applying test setups that are representative of the relative position between a (moving) tool of estimated average length and the hypothetical centre of a (moving) workpiece assumed to be located near the centre travel of the machine tool axes.

NOTE 2 To improve readability, definitions and tests of this part of ISO 230 use the expression: “functional point on a moving component” instead of the formally more accurate expression: “moving point representing the relative position between a (moving) tool and a (moving) workpiece”.

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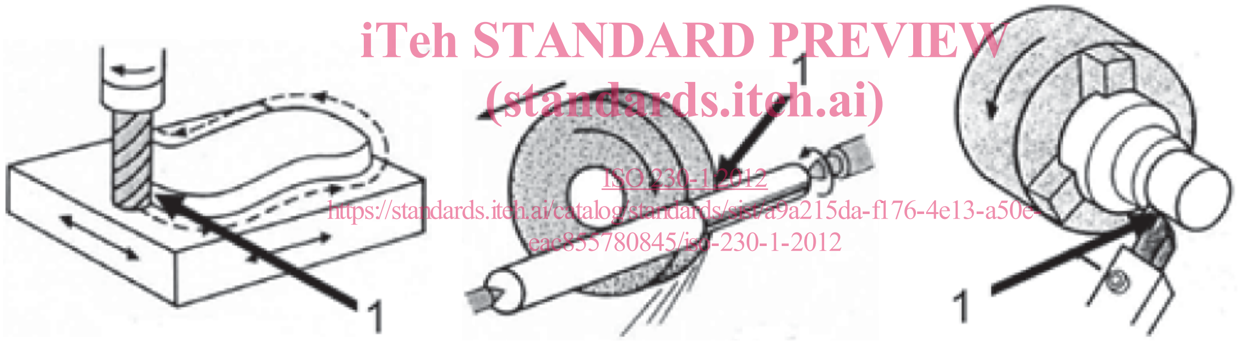

Key

1 functional point

Figure 2 — Examples of functional points

3.4.3
error motions of a linear axis
unwanted linear and angular motions of a component commanded to move along a (nominal) straight-line trajectory

See Figure 3.

NOTE 1 Error motions are identified by the letter E followed by a subscript, where the first letter is the name of the axis corresponding to the direction of the error motion and the second letter is the name of the axis of motion (see Figure 3 and Annex A).

NOTE 2 Linear error motions are defined in 3.4.4; angular error motions are defined in 3.4.16.

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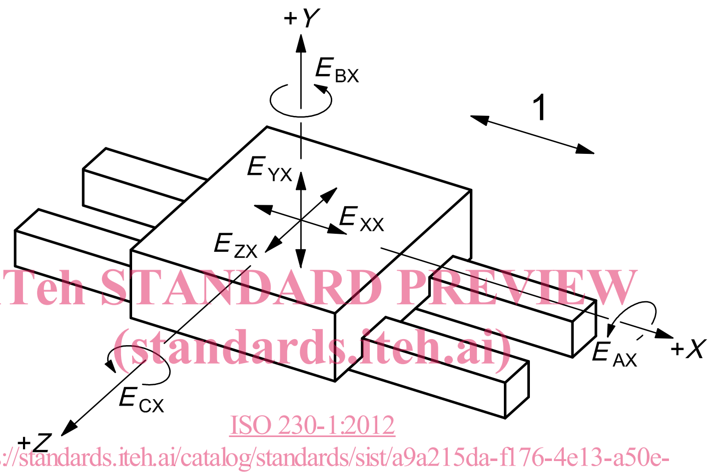
3.4.4
linear error motions of a linear axis
three translational error motions of the functional point of a moving component commanded to move along a (nominal) straight-line trajectory, the first one being along the direction of the (nominal) motion and the other two being along two directions orthogonal to this direction

NOTE 1 The linear error motion along the direction of motion is called **linear positioning error motion** (3.4.5). The other two translational error motions are called **straightness error motions** (3.4.8).

NOTE 2 The linear error motions measured at the functional point include the effects of angular error motions. The effects of these angular error motions are different when the location of a measurement point on the moving component is different from the functional point. In such cases, angular error motions are taken into account to determine the deviations of the trajectory of the functional point.

NOTE 3 If the moving component cannot be regarded as a rigid body, e.g. in the case of a large moving table, tests are carried out for more than one point on the moving component.



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Key

1 X-axis commanded linear motion
E_{AX} angular error motion around A-axis (roll)
E_{BX} angular error motion around B-axis (yaw)
E_{CX} angular error motion around C-axis (pitch)
E_{XX} linear positioning error motion of X-axis; positioning deviations of X-axis
E_{YX} straightness error motion in Y-axis direction
E_{ZX} straightness error motion in Z-axis direction

Figure 3 — Angular and linear error motions of a component commanded to move along a (nominal) straight-line trajectory parallel to the X-axis

3.4.5
linear positioning error motion
unwanted motion along the direction of motion that results in the actual local position reached by the moving component at the functional point differing from the local commanded position along the direction of motion

See Figure 4.

NOTE 1 The positive sign of the positioning error motion is in the direction of the positive direction of the motion (according to ISO 841).

NOTE 2 Linear positioning error motion is associated with imperfections of the moving component and its guiding system. It is not associated with the dynamic response of the moving component and its positioning servo control system.

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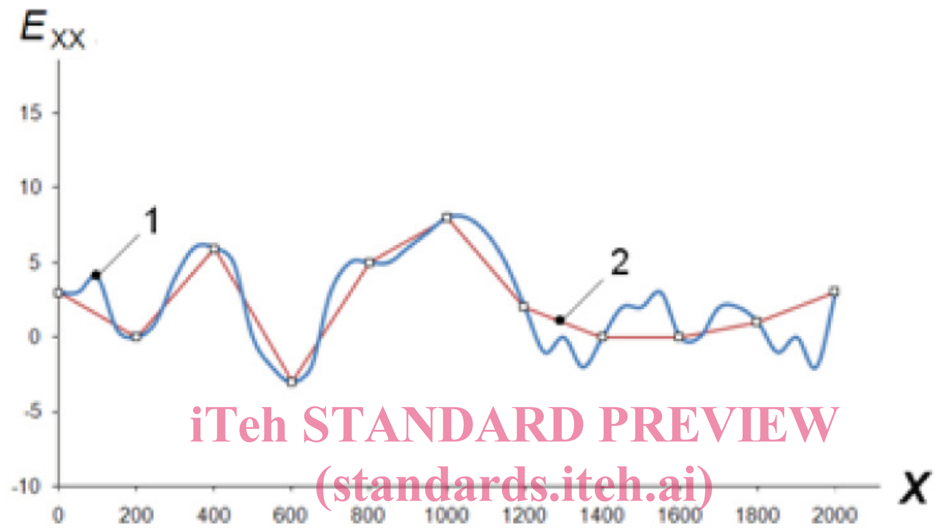
3.4.6
linear positioning deviation
position reached by the functional point on the moving component minus the target position

NOTE 1 Adapted from ISO 230-2:2006, definition 2.5.

NOTE 2 Positioning deviations are measured at specified discrete intervals in accordance with the requirements of ISO 230-2, to determine positioning accuracy and repeatability of numerically controlled axes.

NOTE 3 Positioning deviations, measured in accordance with the requirements of ISO 230-2, constitute a limited representation of positioning error motion (see Figure 4).



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ISO 230-1:2012
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Key

X X-axis coordinates (mm)

E_{XX} X-axis positioning deviation and positioning error motion (µm)

1 plot of the actual positioning error motion of the X-axis

2 plot of the measured positioning deviations of the X-axis

Figure 4 — Example of linear positioning error motion and measured linear positioning deviations of the linear motion of a functional point along the X-axis

3.4.7
linear positioning error
linear positioning accuracy
accuracy of linear positioning
value of the largest positive linear positioning deviation added to the absolute value of the largest negative positioning deviation, evaluated in accordance with specified conventions

NOTE 1 This definition only applies to axes that are not continuously numerically controlled. Accuracy of linear positioning of continuous numerically controlled axes is established and determined in accordance with the requirements of ISO 230-2.

NOTE 2 A convention for linear positioning error evaluation can be to position a linear axis manually over 100 mm, ten times forward, ten times backward and evaluate for each positioning the linear positioning deviation.

3.4.8
straightness error motion
unwanted motion in one of the two directions orthogonal to the direction of a linear axis commanded to move along a (nominal) straight-line trajectory

See Figures 5 and 6.

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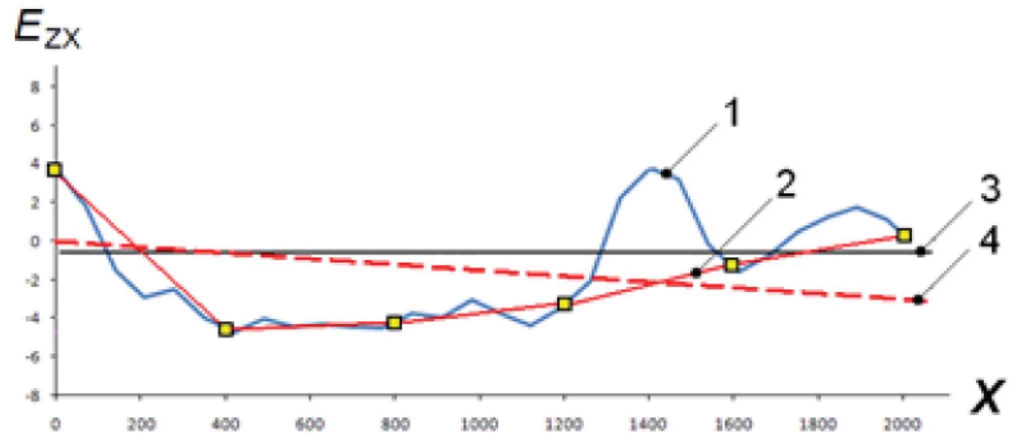

Key

X X-axis coordinates (mm)

E_{ZX} straightness deviations of X in Z-axis direction (µm)

1 plot of the actual linear error motion of X in Z-axis direction

2 plot of the measured straightness error motion

3 mean minimum zone reference straight line associated with actual linear error motion

4 mean minimum zone reference straight line associated with measured straightness error motion

Figure 5 — Example of straightness error motion in Z-direction and measured straightness error motion of the functional point trajectory for X-axis motion

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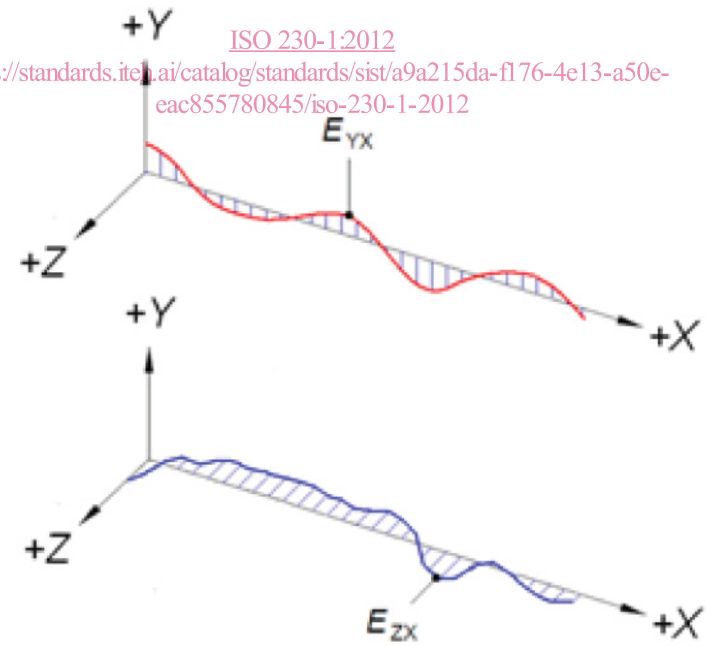

Key

E_{YX} straightness deviations of X in Y-axis direction

E_{ZX} straightness deviations of X in Z-axis direction

Figure 6 — Representation of straightness deviations of X-axis in Y- and Z-axis direction

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3.4.9
straightness deviation
distance of the functional point from the **reference straight line** (3.4.12) fitting its trajectory, measured in one of the two directions orthogonal to the direction of a commanded (nominal) straight-line trajectory

See Figure 6.

NOTE 1 Straightness deviations are measured at low speed (or when the axis under test has stopped) in order to avoid dynamic cross-talk.

NOTE 2 Straightness deviations, measured at discrete intervals (400 mm in the example of Figure 5), constitute a limited representation of the actual straightness error motion.

NOTE 3 The positive sign of the straightness deviation is in the positive direction of the associated principal axis according to ISO 841.

3.4.10
straightness error of a linear axis
value of the largest positive straightness deviation added to the absolute value of the largest negative straightness deviation (with respect to any previously defined reference straight line)

NOTE The minimum straightness error is obtained by using the minimum zone reference straight line.

3.4.11
straightness
property of a straight line

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[ISO 12780-1:2011, definition 3.1.1]

NOTE The actual trajectory of the functional point of a moving component, commanded to move along a nominal straight-line trajectory, is not a straight line.

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3.4.12
reference straight line
general direction of the line
associated straight line fitting the measured trajectory of a functional point in accordance with specified conventions, to which the straightness deviations and the straightness error are referred

NOTE 1 The reference straight line is computed from the measured deviations in two orthogonal planes (see Figure 6), within the boundary of the measurement being performed.

NOTE 2 The previous edition of this part of ISO 230 used the expressions “representative line”; it is a non-preferred expression for “reference straight line”.

NOTE 3 The mean minimum zone **reference straight line** (3.4.13), or the **least squares reference straight line** (3.4.14), or the **end-point reference straight line** (3.4.15) can be used (see Figures 7, 8 and 9).

NOTE 4 The minimum straightness error is typically evaluated by using the mean minimum zone reference straight line. However, since software for minimum zone calculation has limited availability, straightness error is evaluated as the minimum error resulting from using the least squares reference straight line or using the end-point reference straight line.

3.4.13
mean minimum zone reference straight line
arithmetic mean of two parallel straight lines in the straightness plane enclosing the measured straightness deviations and having the least separation

See Figure 7.

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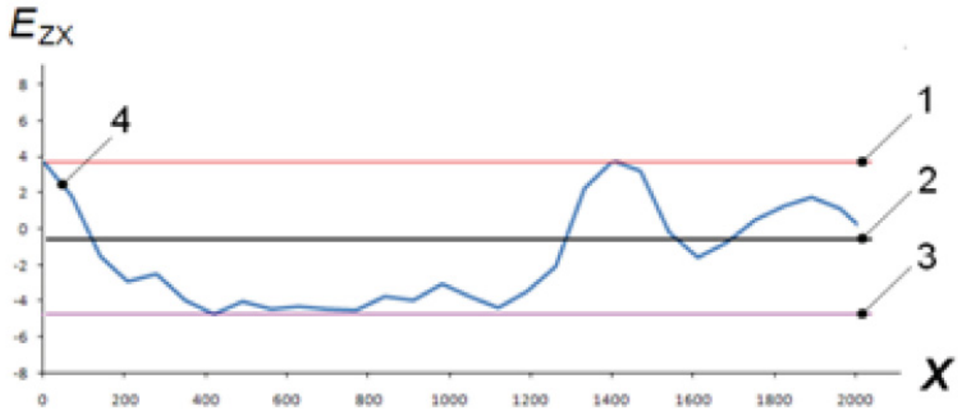

Key

X X-axis coordinates (mm)

E_{ZX} straightness deviations of X in Z-axis direction (µm)

1 upper minimum zone reference straight line at positive E_{ZX}

2 mean minimum zone reference straight line

3 lower minimum zone reference straight line at negative E_{ZX}

4 measured straightness deviations

Figure 7 — Example of minimum zone reference straight lines for straightness of X in the ZX plane

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3.4.14
least squares reference straight line
straight line, where the sum of the squares of the measured straightness deviations is minimum

See Figure 8.

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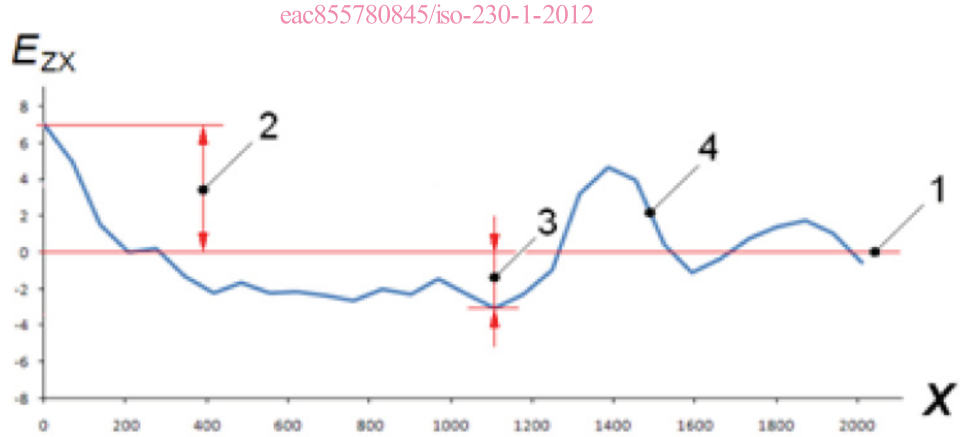

Key

X X-axis coordinates (mm)

E_{ZX} straightness deviations of X in Z-axis direction (µm)

1 least squares reference straight line

2 largest positive straightness deviation E_{ZX}

3 largest negative straightness deviation E_{ZX}

4 measured straightness deviations

Figure 8 — Example of least squares reference straight line for straightness of X in ZX plane

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