



BSI Standards Publication

Test code for machine tools

Part 4: Circular tests for numerically controlled machine tools

National foreword

This British Standard is the UK implementation of ISO 230-4:2022. It supersedes BS ISO 230-4:2005, which is withdrawn.

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A list of organizations represented on this committee can be obtained on request to its committee manager.

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Test code for machine tools —

Part 4: Circular tests for numerically controlled machine tools

Code d'essai des machines-outils —

*Partie 4: Essais de circularité des machines-outils à
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.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document 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 230-4:2005), which has been technically revised.

The main changes are as follows:

- introduction of circular tests with rotary axes;
- application of definitions from ISO 230-1;
- inclusion of precautions when measuring rotary axes in [Annex C](#).

A list of all parts in the ISO 230 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Test code for machine tools —

Part 4:

Circular tests for numerically controlled machine tools

1 Scope

This document provides methods for the determination of the contouring performance of numerically controlled machine tools.

This document specifies methods of testing and evaluating the bi-directional circular error, the mean bi-directional radial error, the circular error and the radial error of circular paths that are produced by the simultaneous movements of two linear axes.

This document also specifies methods of testing the deviations of the circular or constant radius trajectories generated by any combination of simultaneously controlled (coordinated) linear and rotary axes. The basic principle of these tests is to coordinate the multiple axes of motion (combination of rotary and linear axes) to keep the relative position between the tool and the workpiece constant.

This document describes differences between circular errors and radial errors ([Annex A](#)), influences of typical machine errors on circular paths executed with two linear axes ([Annex B](#)), precautions for test set-ups for circular tests with rotary axes ([Annex C](#)), an example of adjustment of diameter and contouring speed for circular tests ([Annex D](#)), and circular tests using feedback signal ([Annex E](#)).

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 230-1:2012, *Test code for machine tools — Part 1: Geometric accuracy of machines operating under no-load or quasi-static conditions*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 230-1 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org/>

3.1

nominal path

<circular interpolation> numerically controlled and programmed circular path defined by its diameter (or radius), the position of its centre and its orientation in the working zone of the machine tool and which may be either a full circle or a partial circle of at least 90°

Note 1 to entry: Linear interpolation (G01) or circular interpolation (G02 or G03) or other types of interpolation may be used to generate nominal circular path.

3.2

actual path

path produced by the machine tool when programmed to move on the *nominal path* (3.1)

3.3

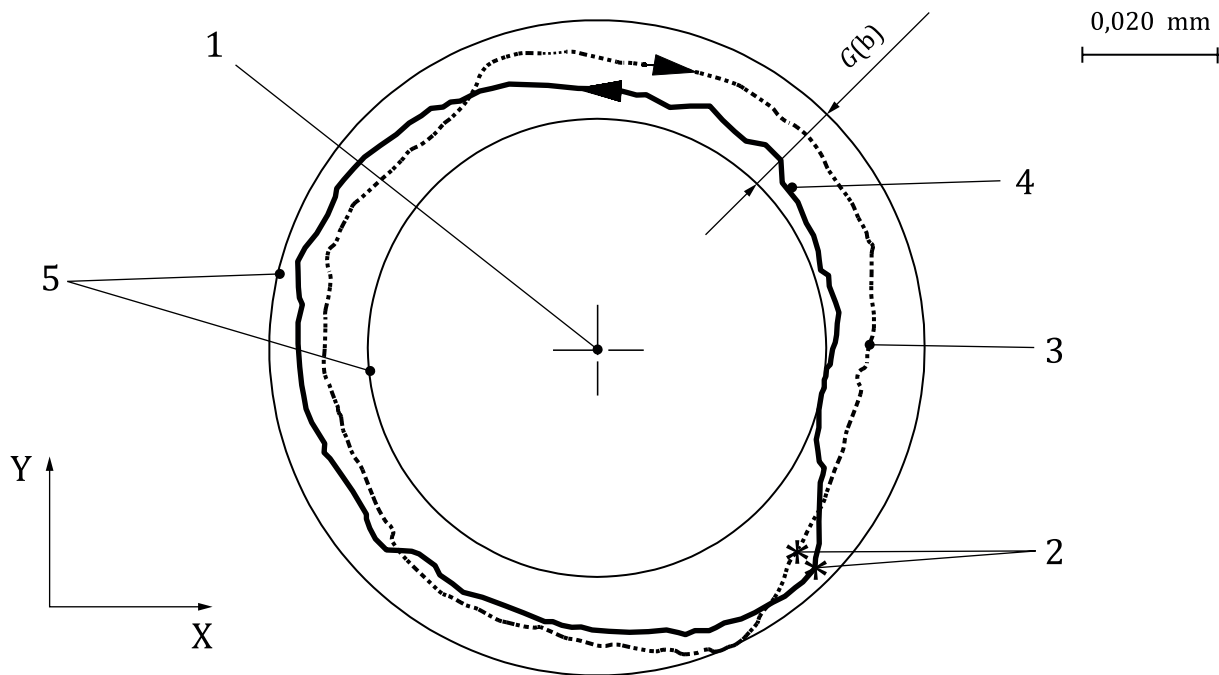
bi-directional circular error

bi-directional circular deviation

$G(b)$

minimum radial separation of two concentric circles (minimum zone circles) enveloping two *actual paths* (3.2), where one path is carried out by a clockwise contouring motion and the other one by an anticlockwise (counter-clockwise) contouring motion

Note 1 to entry: See Figure 1, where bi-directional circular error $G(b)_{XY} = 0,015$ mm. The indices identify the axes moved during the circular test (see 3.7).



Key

- 1 centre of least squares circle of the two actual paths according to Note 2 to entry
- 2 starting points
- 3 actual path, clockwise
- 4 actual path, anticlockwise (counter-clockwise)
- 5 concentric circles enveloping the actual paths

Figure 1 — Evaluation of bi-directional error $G(b)$ using least squares circle

Note 2 to entry: The bi-directional circular error $G(b)$ can be evaluated as the maximum radial range of deviations around the least squares circle. The least squares circle is calculated from two paths, i.e. the clockwise and the anticlockwise (counter-clockwise) paths.

Note 3 to entry: Bi-directional circular error $G(b)$ does not include set-up errors, i.e. centring errors of the measuring instrument.

Note 4 to entry: Bi-directional circular error $G(b)$ measurement requires the use of test equipment only with calibrated displacement measurements (no need for calibrated length measurements for path diameter). The measurements of *radial error* F (3.5) and *mean bi-directional radial error value* D (3.6) require test equipment with both calibrated length and calibrated displacement (see Annex A).

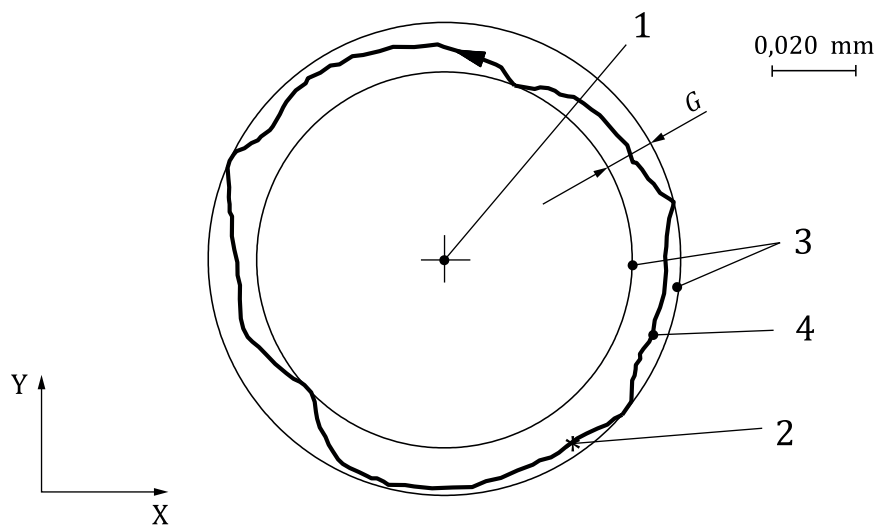
Note 5 to entry: A line situated in a plane is said to be circular when all its points are contained between two concentric circles whose radial separation does not exceed a given value (see [Figure 2](#)).

Note 6 to entry: Designation $G(b)$ is for measurements with external measurement equipment only, for example as described in ISO 230-1:2012, 11.3.4. Results from circular tests using a feedback signal are designated as “bi-directional circular error using feedback signal $G(b)_f$ ” (see [Annex E](#)).

3.4 circular error circular deviation G

minimum radial separation of two concentric circles enveloping the *actual path* ([3.2](#)) (minimum zone circles) of a clockwise or anticlockwise (counter-clockwise) contoured path

Note 1 to entry: See [Figure 2](#), where circular error $G_{XY} = 0,012$ mm. The sequence of indices denotes the direction of contouring (see [3.8](#)).



Key

- 1 centre of least squares circle of the actual path according to Note 2 to entry
- 2 starting point
- 3 concentric circles enveloping the actual path
- 4 actual path

Figure 2 — Evaluation of circular error G using least squares circle

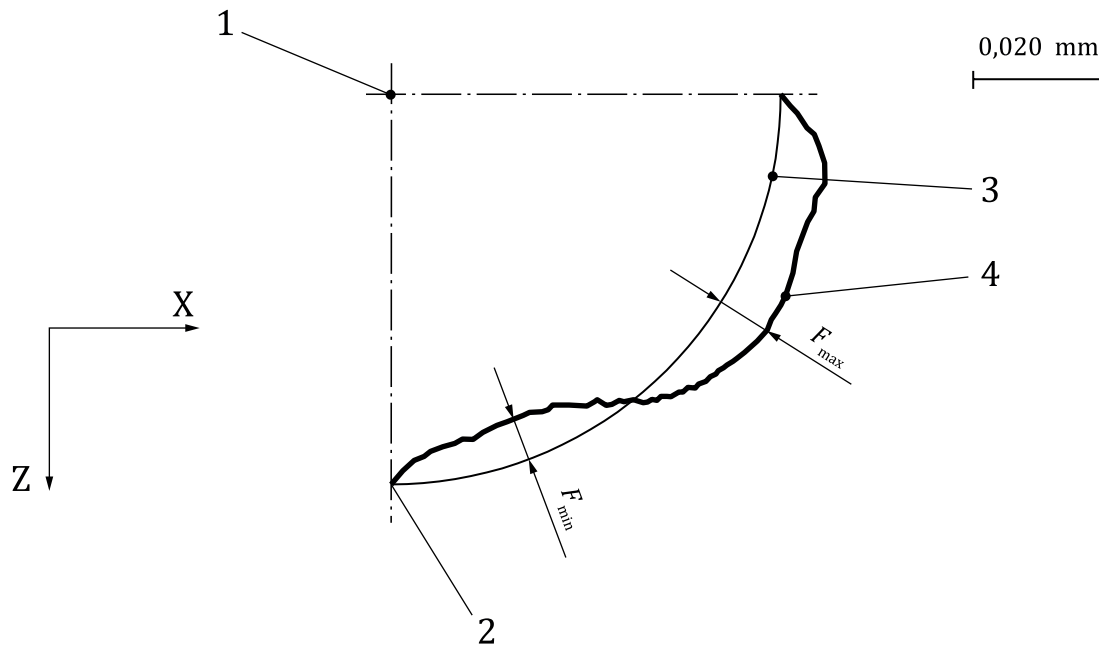
Note 2 to entry: Note 2 to entry to Note 6 to entry for *bi-directional circular error $G(b)$* ([3.3](#)) apply for circular error G . For differences between the circular error G and the *radial error F* ([3.5](#)), see [Annex A, Table A.1](#).

Note 3 to entry: Designation G is for measurements with external measurement equipment, for example as described in ISO 230-1:2012, 11.3.4, only. Results from circular tests using feedback signal shall be designated circular error using feedback signal G_f , see [Annex E](#).

3.5 radial error radial deviation F

deviation between the *actual path* ([3.2](#)) and the *nominal path* ([3.1](#)), where the centre of the nominal path is obtained either a) from the centring of the measuring instruments on the machine tool or b) from the least squares centring analysis for a full circle only

Note 1 to entry: See [Figure 3](#), where radial error $F_{ZX, \max} = +0,008$ mm and radial error $F_{ZX, \min} = -0,006$ mm. The sequence of indices denotes the direction of contouring (see [3.8](#)).



Key

- 1 centre of nominal circle
- 2 starting point
- 3 nominal path
- 4 actual path

Figure 3 — Evaluation of radial error F

Note 2 to entry: Positive deviations are measured away from the centre of the circle and negative ones towards the centre of the circle (see [Figure 3](#)). The radial error is given by the maximum value, $F_{\max}$, and the minimum value, $F_{\min}$.

Note 3 to entry: Set-up errors can be included in the radial error F ; this is applicable only where the centre of the nominal path is obtained from the centring of the measuring instrument on the machine tool [option a) of the definition].

Note 4 to entry: For differences between the radial error F and the *circular error* G ([3.4](#)), see [Annex A, Table A.1](#).

3.6

mean bi-directional radial error mean bi-directional radial deviation

D

difference between the radius of the least squares circle of two full circle *actual paths* ([3.2](#)), where one path is carried out by a clockwise contouring motion and the other one by an anticlockwise (counter-clockwise) contouring motion, and the radius of the *nominal path* ([3.1](#))

Note 1 to entry: For differences between mean bi-directional radial error D and *bi-directional circular error* $G(b)$ ([3.3](#)), see [Annex A, Table A.1](#).

3.7

identification of axes

designation of the axes which are moved to produce the *actual path* ([3.2](#))

3.8

sense of contouring for circular tests with linear axes

<clockwise/anticlockwise (counter-clockwise) contouring> sequence of indices denoting the direction of contouring

Note 1 to entry: The order of the indices matches the order in which the circular arc crosses the positive extreme of each axis. For example, G_{XY} denotes the anticlockwise (counter-clockwise) *circular error* (3.4), because an anticlockwise (counter-clockwise) arc in the XY plane crosses the X+ axis immediately followed by the Y+ axis. Similarly, G_{YX} denotes the clockwise *circular error* (3.4), because a clockwise arc in the XY plane crosses the Y+ axis immediately followed by the X+ axis. In the case of a bi-directional result, the indices denote the direction of the first arc.

3.9

contouring interpolation error

contouring interpolation deviation

E_{int}

range of deviations of the tool centre point trajectory from the fixed point in the *workpiece coordinate system* (3.11), when a rotary axis (or axes) is (are) driven, synchronously with interpolated circular motion with linear axes, such that the tool centre point nominally stays at this fixed point in the *workpiece coordinate system* (3.11)

Note 1 to entry: Typical test methods are described in ISO 230-1:2012, 11.3.5. Typical measuring instruments are described in ISO/TR 230-11:2018, 12.2.1, 12.3.3 and 12.3.4.

Note 2 to entry: If the length-measuring device (ball bar, linear displacement sensor or nest of three linear displacement sensors) is rotated with a rotary axis, the measurements are taken in the coordinate system attached to the rotary axis, i.e. in radial, tangential and/or axial direction. This is specified by $E_{int,radial}$, $E_{int,tangential}$ and $E_{int,axial}$.

Note 3 to entry: If the length-measuring device (ball bar, linear displacement sensor or nest of three linear displacement sensors) is not rotated with a rotary axis, the measurements are taken in X, Y and Z directions of the *machine coordinate system* (3.10). This is specified by $E_{int,X}$, $E_{int,Y}$ and $E_{int,Z}$.

Note 4 to entry: The axes moved are specified by giving the nomenclature of the axes. For example, a measurement with linear axes X and Y and rotary axis C in radial direction is specified by $E_{int,radial,XYC}$. A measurement with three linear axes X, Y, Z and two rotary axes A, C in radial direction corresponds to a spherical test according to ISO 230-1:2012, 11.5 and is specified by $E_{int,radial,XYZAC}$.

Note 5 to entry: Clockwise or anticlockwise (counter-clockwise) movement is defined by the rotary axes if there is just one rotary axis moved. If two rotary axes are moved, clockwise and anticlockwise (counter-clockwise) are defined by the axis that moves over a larger range, generally the axis that moves over 360°. Clockwise is specified by CW, anticlockwise (counter-clockwise) is specified by CCW. For a clockwise measurement with the axes X, Y and C in radial direction the specification is $E_{int,radial,XYC}(CW)$.

Note 6 to entry: Precautions for test set-ups for circular tests with rotary axes are given in [Annex C](#).

3.10

machine coordinate system

MCS

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

Note 1 to entry: The machine coordinate system is prescribed by ISO 841 for many machine tools.

[SOURCE: ISO 230-1:2012, 3.2.1, modified — figure deleted and Note 1 to entry added.]

3.11

workpiece coordinate system

WCS

Cartesian coordinates fixed on the workpiece

Note 1 to entry: When a machine tool has the rotary axis (axes) on the workpiece side, the workpiece coordinate system is rotated with the rotary axis (axes).