INTERNATIONAL STANDARD

ISO 230-4

Second edition
2005-04-01

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

Reference number
ISO 230-4:2005(E)

ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

Published in Switzerland

Contents

Page

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 230-4 was prepared by Technical Committee ISO/TC 39, *Machine tools*, Subcommittee SC 2, *Test conditions for metal cutting machine tools*.

This second edition cancels and replaces the first edition (ISO 230-4:1996), of which it constitutes a technical revision. The main changes are

— the replacement of circular hysteresis H by bi-directional circular deviation G(b), because of the difficulty of evaluating circular hysteresis H by commonly available metrology instruments, and because bi-directional circular deviation G(b) contains similar information,

— the introduction of the mean bi-directional radial deviation, D,

— addition of the word “counter-clockwise”, the US variant of “anticlockwise”, for purposes of clarity where US usage is the norm,

— mention of measurement and test uncertainty,

— the inclusion of parameters G(b) and D in Annex A, and

— modification of the wording of 3.8 and B.3.1.

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 machine tools*

— *Part 3: Determination of thermal effects*

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

— *Part 5: Determination of the 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]

The following parts are under preparation:

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

Test code for machine tools —

Part 4: Circular tests for numerically controlled machine tools

1 Scope

This part of ISO 230 specifies methods of testing and evaluating the bi-directional circular deviation, the mean bi-directional radial deviation, the circular deviation and the radial deviation of circular paths that are produced by the simultaneous movements of two linear axes. Relevant measuring instruments are described in ISO 230-1:1996, 6.63.

The objective of this part of ISO 230 is to provide a method for the measurement of the contouring performance of a numerically controlled machine tool.

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 230-1:1996, *Test code for machine tools — Part 1: Geometric accuracy of machines operating under no-load or finishing conditions.*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
nominal path
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°

3.2
actual path
path produced by the machine tool when programmed to move on the nominal path

3.3
bi-directional circular deviation
$G(\mathrm{b})$
minimum radial separation of two concentric circles (minimum zone circles) enveloping two actual paths, where one path is carried out by a clockwise contouring motion and the other one by an anticlockwise (counter-clockwise) contouring motion

See Figure 1.

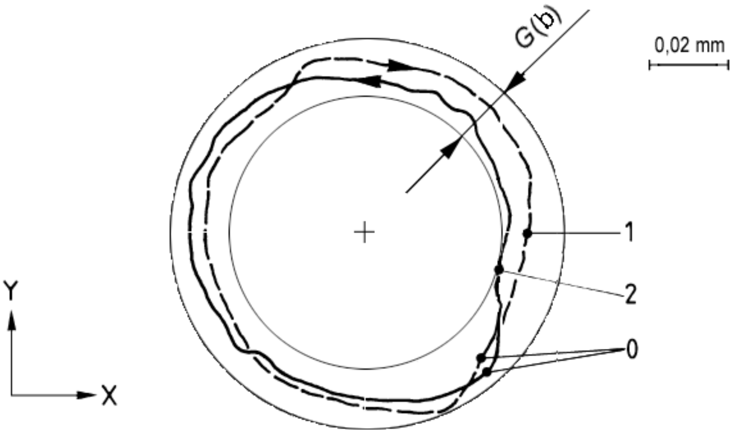
NOTE 1 The bi-directional circular deviation G(b) may be evaluated as the maximum radial range of deviations around the least squares circle. The least squares circle is calculated from 2 paths, i.e. the clockwise and the anticlockwise (counter-clockwise) path.

NOTE 2 Bi-directional circular deviation G(b) does not include set-up errors, i.e. centring errors of the measuring instrument.

NOTE 3 Bi-directional circular deviation 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 deviation F and mean bi-directional radial deviation value D require test equipment with both calibrated length and calibrated displacement (see Annex A).

NOTE 4 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 and also ISO 230-1:1996, 6.61).

NOTE 5 Designation G(b) is for measurements with external measurement equipment only, e.g. as described in ISO 230-1:1996, 6.63. Results from circular tests using a feed back signal are designated as "bi-directional circular deviation using feed back signal, $G(\mathrm{b})_\mathrm{f}$," see Annex E.



Key

+ centre of least squares circle of the two actual parts

0 starting point

1 actual path, clockwise

2 actual path, anticlockwise (counter-clockwise)

bi-directional circular deviation $G(\mathrm{b})_{XY}$ = 0,015 mm

Figure 1 — Evaluation of bi-directional deviation G(b)

3.4
circular deviation

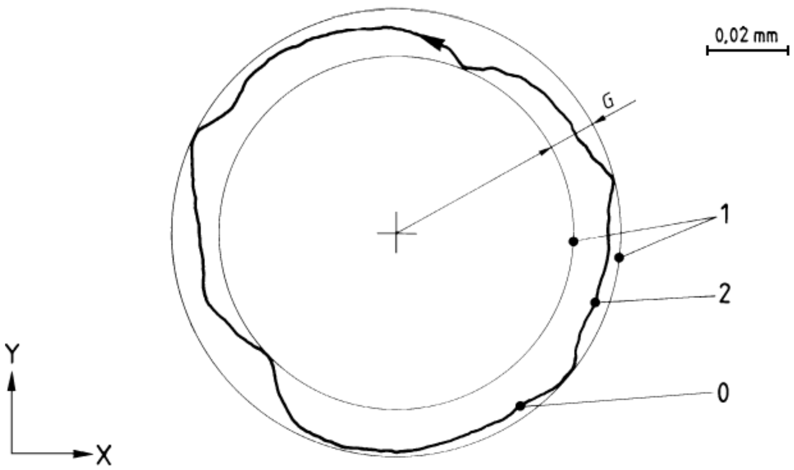
G

minimum radial separation of two concentric circles enveloping the actual path (minimum zone circles) of a clockwise or anticlockwise (counter-clockwise) contoured path and which may be evaluated as the maximum radial range around the least squares circle

See Figure 2.

NOTE 1 The notes for bi-directional circular deviation G(b) apply for circular deviation G. For differences between the circular deviation G and the radial deviation F, see Annex A.

NOTE 2 Designation G is for measurements with external measurement equipment, e.g. described in ISO 230-1, 6.63, only. Results from circular tests using feed back signal shall be designated circular deviation using feed back signal G_f, see Annex D.



Key

+ centre of least squares circle of the two actual parts
0 starting point
1 minimum zone circles
2 actual path

circular deviation G_{XY} = 0,012 mm

Figure 2 — Evaluation of circular deviation *G*

3.5
radial deviation
F
deviation between the actual path and the nominal path, where the centre of the nominal path is obtained either

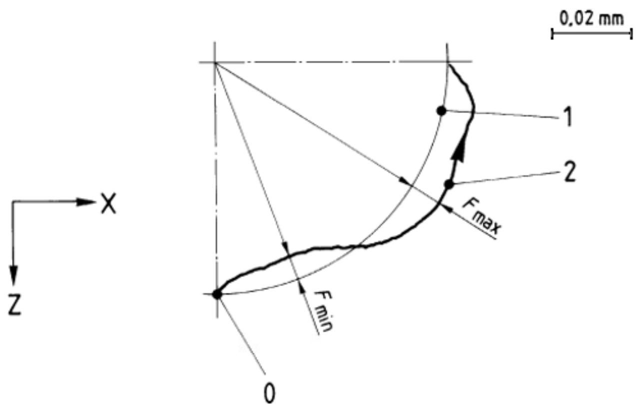
a) from the centring of the measuring instruments on the machine tool, or

b) from the least squares centring analysis for a full circle only.

NOTE 1 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 deviation is given by the maximum value, F_{max}, and the minimum value, F_{min}.

NOTE 2 Set-up errors may be included in the radial deviation *F*; this is applicable only to a) above.

NOTE 3 For differences between the radial deviation *F* and the circular deviation *G*, see Annex A.



Key

+ centre of nominal circles
0 starting point
1 nominal path
2 actual path

radial deviation: $F_{ZX, max}$ = +0,008 mm
$F_{ZX, min}$ = −0,006 mm

Figure 3 — Evaluation of radial deviation *F*

3.6
mean bi-directional radial deviation
D
deviation between the radius of the nominal path and the radius of the least squares circle of two full circle actual paths, where one path is carried out by a clockwise contouring motion and the other one by a anticlockwise (counter-clockwise) contouring motion

NOTE For differences between mean bi-directional radial deviation *D* and bi-directional circular deviation *G*(b), see Annex A.

3.7
identification of axes
designation of the axes which are moved to produce the actual path

3.8
sense of contouring
⟨clockwise/anticlockwise (counter-clockwise) contouring⟩ sequence of indices denoting the direction of contouring

NOTE The order of the indices matches the order in which the circular arc crosses the positive extreme of each axis. For example GXY denotes the anticlockwise (counter-clockwise) circular deviation, because an anticlockwise (counter-clockwise) arc in the XY plane crosses the X+ axis immediately followed by the Y+ axis. In the case of a bi-directional result, the indices denote the direction of the first arc.

4 Test conditions

4.1 Test environment

Where the temperature of the environment can be controlled, it shall be set at 20 °C. Otherwise, the output of the measuring instrument and the machine nominal readings shall be adjusted to yield results corrected to 20 °C (for radial deviation measurements only).

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

4.2 Machine to be tested

The machine shall be completely assembled and fully operational. All necessary levelling operations and functional checks shall be completed before starting the tests.

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

4.3 Machine warm-up

The tests shall be preceded by an appropriate warm-up procedure, as specified by the manufacturer of the machine and/or agreed between the supplier/manufacturer and the user.

If no other conditions are specified, the preliminary movements shall be restricted to only those necessary to set up the measuring instrument.

4.4 Test parameters

Parameters of the test are the following:

a) diameter (or radius) of the nominal path;

b) contouring feed;

c) sense of contouring — clockwise or anticlockwise (counter-clockwise) according to 3.8;

d) machine axes moved to produce the actual path;

e) location of the measuring instrument in the machine tool working zone;

f) temperature (environment temperature, measuring instrument temperature, machine temperature) and expansion coefficient (of machine tool, of measuring instrument) used for compensation for mean bi-directional radial deviation D *and* radial deviation F measurement only;

g) data acquisition method (data capture range if different from 360°, starting and stop points of the actual movement, number of measuring points taken for digital data acquisition, and whether a data smoothing process is applied or not);

h) any machine compensation routines used during the test cycle;

i) positions of slides or moving elements on the axes which are not being tested.

4.5 Test instrument calibration

For the checking of the mean bi-directional radial deviation D and the radial deviation F, the reference dimension of the test instrument shall be known.

NOTE For circular tests using a feed back signal, see Annex D.

4.6 Test uncertainty

The main contributors to the test uncertainty for the bi-directional circular deviation G(b) and the circular deviation G are the

— measurement uncertainty of the test equipment;

— repeatability of the machine tool, checked, for example, by repetition of the circular test;

— temperature drift of the machine tool and/or the test equipment, checked, for example, by a drift test according to ISO/TR 16015.

The main contributors to the test uncertainty for the mean bi-directional radial deviation D and the radial deviation F are the

— contributors for the deviations G(b) and G (see above);

— uncertainty of the temperature measurement of the machine tool and the test equipment [caused by the uncertainty of the temperature sensor(s) and the uncertainty due to the location of the temperature sensor(s)];

— uncertainty of the thermal expansion coefficients of the machine tool and the test equipment (used for the compensation to 20 °C).

5 Test procedure

To determine bi-directional circular deviation G(b) and mean bi-directional radial deviation D, two actual paths have to be measured consecutively: one in a clockwise sense of contouring and the other in an anticlockwise (counter-clockwise) sense of contouring.

All measured data corresponding to the actual path (including any peaks at reversal points) shall be used in the evaluation.

For radial deviation, F, of a partial circle, set-up errors should be minimized.

6 Presentation of results

A graphical method of presenting results is preferred with the following test result data specified numerically:

a) bi-directional circular deviation G(b);

b) mean bi-directional radial deviation D, corrected to 20 °C;

c) circular deviations G, for clockwise and/or anticlockwise (counter-clockwise) contouring;

d) radial deviations, F_{max} and F_{min}, for clockwise and anticlockwise (counter-clockwise) contouring, corrected to 20 °C.

Typical examples of presentation of test results are shown in Figures 4, 5 and 6.

NOTE For better clarity, the presentation of results is shown in three figures in this part of ISO 230. In a test report, the three figures can be combined into one figure.

The test report shall give the following:

— date of test;

— name of machine;

— measuring equipment;

— test parameters (see 4.4).

Magnification scale of the graphical presentation shall be stated.

The test uncertainty should be stated.

7 Points to be agreed between supplier/manufacturer and user

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

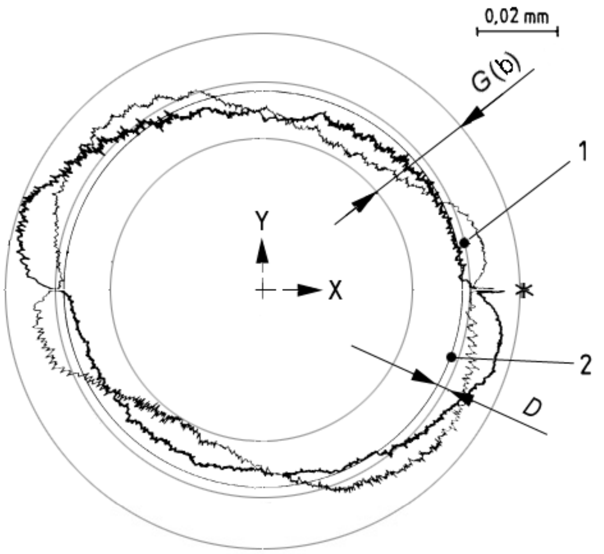
a) warm-up procedure prior to testing the machine (see 4.3);

b) test parameters (see 4.4);

c) which test result data for the bi-directional circular deviation G(b), the mean bi-directional radial deviation D, the circular deviation G and/or the radial deviation F [from 6 a) to d)] are required and are to be presented.

Date of test: yy/mm/dd Name of machine: xyz
Measuring instrument: abc

Test parameters	
diameter of nominal path:	40 mm
contouring feed:	500 mm/min
contouring direction:	—
machine axes under test (X, Y, Z):	XY
Location of measuring instrument	
— centre of circle (X/Y/Z):	250/250/100 mm
— offset to tool reference (X/Y/Z):	0/0/– 80 mm
— offset to workpiece reference (X/Y/Z):	0/0/30 mm
Data acquisition method	
— starting point:	4th quadrant
— stop point:	4th quadrant
— number of measuring points (digital only):	1 500
— data smoothing process:	none
Compensation used:	none
Positions of axes not under test	Z = 150 mm



Key

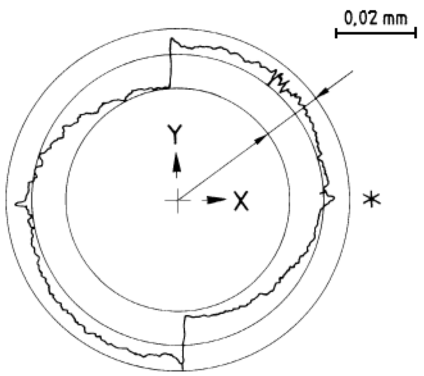
+ centre of least squares circle of the two actual paths
* starting point
heavy trace actual path, from + Y to + X
light trace actual path, from + X to + Y

bi-directional circular deviation $G(\mathrm{b})_{XY}$ = 0,028 mm
mean bi-directional radial deviation D_{XY} = 0,001mm

Figure 4 — Example of data presentation for bi-directional circular deviation G(b) and mean bi-directional radial deviation *D*

Date of test: yy/mm/dd Name of machine: xyz
Measuring instrument: abc

Test parameters	
diameter of nominal path:	250 mm
contouring feed:	1 000 mm/min
contouring direction:	+ X to + Y
machine axes under test (X, Y, Z):	XY
Location of measuring instrument	
— centre of circle (X/Y/Z):	250/250/300 mm
— offset to tool reference (X/Y/Z):	0/0/– 80 mm
— offset to workpiece reference (X/Y/Z):	0/0/230 mm
Data acquisition method	
— starting point:	4th quadrant
— stop point:	4th quadrant
— number of measuring points (digital only):	1 800
— data smoothing process:	none
Compensation used:	none
Positions of axes not under test	Z = 350 mm



Key

+ centre of minimum zone circles
* starting point

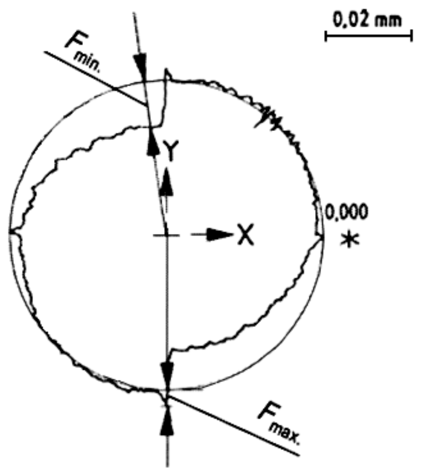
circular deviation G_{XY} = 0,018 mm

Figure 5 — Example of data presentation for circular deviation G

Date of test: yy/mm/dd Name of machine: xyz

Measuring instrument: abc

Test parameters	
diameter of nominal path:	150 mm
contouring feed:	300 mm/min
contouring direction:	+ Y to + X
machine axes under test (X, Y, Z):	XY
Location of measuring instrument	
— centre of circle (X/Y/Z):	250/250/100 mm
— offset to tool reference (X/Y/Z):	0/0/− 80 mm
— offset to workpiece reference (X/Y/Z):	0/0/30 mm
Temperature	
— environment temperature:	22 °C
— temperature of the measuring instrument:	22 °C
— machine temperature:	22 °C
Data acquisition method	
— starting point:	4th quadrant
— stop point:	4th quadrant
— number of measuring points (digital only):	1 800
— data smoothing process:	none
Compensation used:	temperature
Positions of axes not under test:	Z = 150 mm



Key

+	centre of least circles
*	starting point
0,000	nominal path
radial deviation:	$F_{XY,max}$ = +0,005 mm
	$F_{XY,min}$ = −0,013 mm

Figure 6 — Example of data presentation for radial deviation *F*

Annex A
(informative)

Differences between circular deviations G and G(b) and radial deviations F and D

Table A.1 shows the differences between circular deviations G and G(b) and radial deviations F and D.

Table A.1

Influences	Circular deviations G and G(b)	Radial deviation F and D
Deviation of form [a]	Included	Included
Deviation of diameter [b]	Not included, as the diameters of the minimum zone circles are not evaluated.	Included
Deviation of position [c]	Not included, as the position of the minimum zone circles is defined by the actual path only.	Included in F for a partial circle, not included in F for a full circle and not included in D.

[a] Deviation between a circle and the shape of the actual path (e.g. elliptical form deviation).

[b] Deviation between the diameter of the nominal path and the diameter of the actual path.

[c] Deviation between the position of the centre of the nominal path and the centre of the actual path (e.g. deviations in the X and Y positions).

Annex B
(informative)

Influences of typical machine deviations on circular paths

B.1 General

This annex points to the principal influences of typical machine deviations on circular motion. In general, these individual deviations show a combined influence on actual measured circular paths. Therefore, the information in this annex alone is not sufficient for a detailed analysis of circular measurements.

Circular paths that are produced by two linear axes on numerically controlled machines are influenced by geometric deviations of the two axes and by deviations caused by the numerical control and its drives.

B.2 Influence of geometric deviations

B.2.1 Influence of a progressive linear positioning deviation

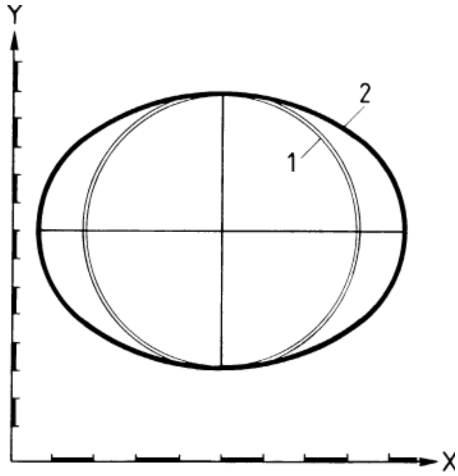
When the X-axis movement is long, for example, due to a scale deviation, the circular path is changed to an ellipse with its major diameter parallel to the X-axis. If the Y-axis is assumed to be deviation free, the diameter of the path parallel to Y is not changed, i.e. the diameter is equal to the nominal diameter [see Figure B.1 a)].

When the X-axis movement is short and the Y-axis is still assumed to be without deviations, the circular path is changed to an ellipse with its major diameter parallel to Y. That diameter is again equal to the nominal diameter [see Figure B.1 b)].

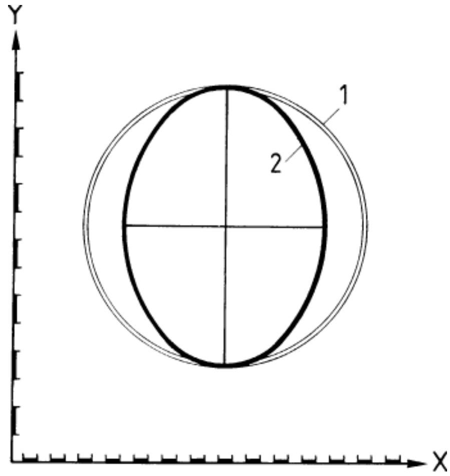
B.2.2 Influence of non-perpendicularity of axes

When axes X and Y are not square and the angle between the two axes is larger than 90°, the circular path is changed to an ellipse with its principal axes at ± 45°. The major diameter of the ellipse is at – 45° [see Figure B.2 a)]. In addition, it is assumed that deviation from squareness is the only deviation in the XY plane.

When the angle between the two axes is smaller than 90°, the circular path is again changed to an ellipse with its principal axes at ± 45°, but with the major diameter at + 45° [see Figure B.2 b)].



a) X movement long



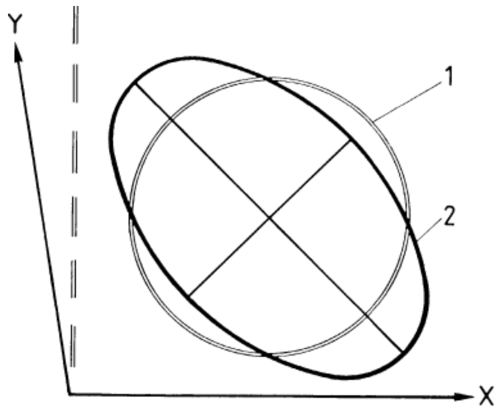
b) X movement short

Key

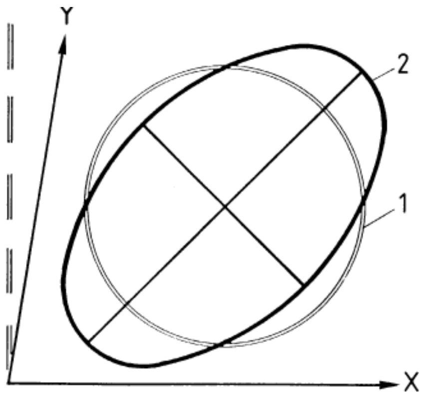
1 nominal path

2 actual path

Figure B.1 — Influence of short and long movements of an axis on circular paths



a) Angle larger than 90°



b) Angle less than 90°

Key

1 nominal path

2 actual path

Figure B.2 — Influence of non-perpendicularity of axes on circular paths

B.2.3 Influence of periodic deviations

Periodic deviations also influence circular paths. The deviation from the circular path is non-elliptic. Figure B.3 shows changes to the path if a periodic positioning deviation of Z is assumed.

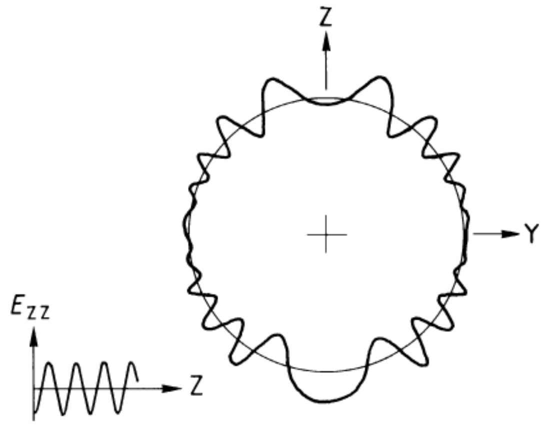


Figure B.3 — Influence of periodic deviations of Z

B.3 Influence of the numerical control and its drives

B.3.1 General

A circular path that is produced by two linear and numerically controlled axes gives information on the behaviour of the numerical control and its drives. The movement for each axis is quite complicated, with travel, velocity and acceleration of each axis changing, according to a sine or to a cosine if the feed rate on the circular path is kept constant.

B.3.2 Influence of reversal error

When axial reversal error is present, “steps” will occur at the points of reversal. Figure B.4 shows typical backlash reversal error occurring at the four quadrature points (from both axes) giving four quadrants with different centres. For normal backlash, the figure shows the shape produced by anticlockwise (counter-clockwise) contouring.

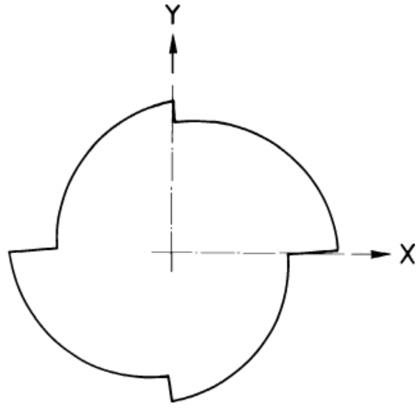


Figure B.4 — Quadrature reversal steps

When recovery of the reversal error occurs (whether by the use of scales for the feed back or by use of reversal compensation in the CNC), time delay effects will cause peaks or “spikes” at the reversal points (see Figure B.5). The magnitude of these “spikes” will depend on the mechanical backlash and the time delay.

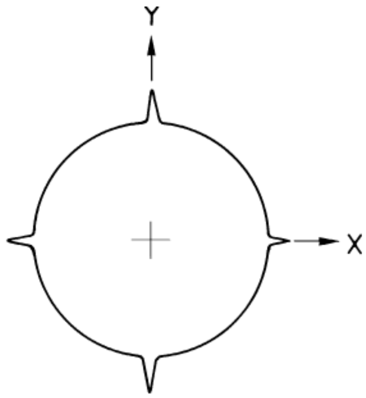


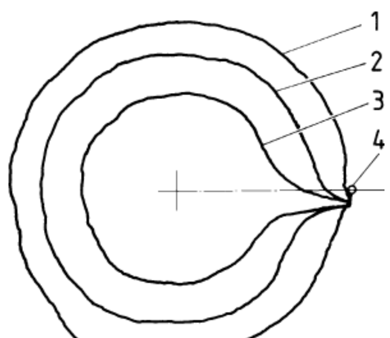
Figure B.5 — Quadrature reversal spikes

Note that the “steps” and “spikes” at reversal points are actually distorted “flats” and will show up on machined circles, but do not appear on standard checks of the accuracy and repeatability of positioning of linear axis (e.g. according to ISO 230-2), because the measurements are taken only after the machine movement has stopped, in accordance with these standard checks.

In practice, both “spikes” and “steps” can occur together by different amounts. If, in addition, reversal error compensation and/or friction compensation is applied that does not exactly match the existing error, then quite complex shapes can occur at quadrature, including “negative spikes” and “negative steps.”

B.3.3 Influence of acceleration of axes

If the feed rate for the circular path is increased, the acceleration of the axes increases accordingly. The drive of an axis can behave in such a way that the amplitude of the movement decreases at a higher frequency at higher feed rates. This results in paths that are smaller in diameter than the nominal circular path (see Figure B.6).



Key

Actual paths of circular movements with

1 low contouring feed

2 medium contouring feed

3 high contouring feed

4 starting and stop points

Figure B.6 — Influence of acceleration of axes

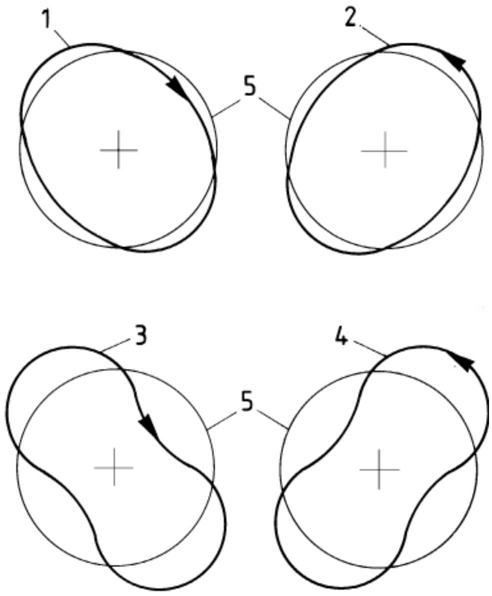
Special control algorithms in the numerical control of the machine (e.g. proportional-integral control loop) may produce larger circles than the nominal circular path at higher feed rates, thus compensating the influence of the acceleration of respective axes.

B.3.4 Influence of different following errors (mismatch of position loop gain)

If the following errors of the two axes involved are different, the circular path is changed to an elliptical one. The principal axes of the ellipse are at ± 45°.

Depending on the contouring direction [clockwise or anticlockwise (counter-clockwise)], the major diameter is at + 45° or at – 45° (see Figure B.7).

When the feed rate is increased, the elliptical deviation from the circle increases accordingly.



Key

Actual paths with

1 low contouring feed clockwise

2 low contouring feed anticlockwise (counter-clockwise)

3 high contouring feed clockwise

4 high contouring feed anticlockwise (counter-clockwise)

5 nominal path

Figure B.7 — Influence of different following errors

Annex C
(informative)

Adjustment of diameter and contouring feed

The diameter of the nominal path and the contouring feed are specified by agreement between supplier and customer or by the relevant machine standards.

When the diameter or the contouring feed are chosen differently from the specified values, they should be adjusted according to the following formula in order to keep the axes' acceleration constant:

$$V_1 = V_2 \sqrt{d_1 / d_2}$$

where

V_1 is the calculated contouring feed;

V_2 is the specified contouring feed;

d_1 is the test diameter of nominal path;

d_2 is the specified diameter of nominal path.

The change of the diameter should be kept to a minimum, as

— the influence of geometric deviations of the machine tool increases with increasing diameter of the nominal path and

— the influence of different following errors increases with an increase in contouring feed.

EXAMPLE When

— the specified diameter, d_2, is 100 mm,

— the specified contouring feed, V_2, is 500 mm/min and

— the test diameter, d_1, is 125 mm,

— the calculated contouring feed, V_1, is calculated as follows:

$$500\sqrt{125/100} = 559 \text{ mm/min}$$

Annex D
(informative)

Circular tests using feedback signal

Circular tests that are carried out without external measuring equipment, for example, as described in of ISO 230-1:1996, 6.63, but using the internal feed back signal of the machine axes drives, shall be referred to as "circular tests using feed back signal".

Bi-directional circular deviation values and circular deviation values from circular tests using feed back signal shall be referenced as

— bi-direction circular deviation using feed back signal $G(\mathrm{b})_\mathrm{f}$,

— circular deviation using feed back signal G_f.

Circular tests using feed back signal shall not be used to specify radial deviation values or mean bi-directional radial deviation values.

On machine tools with linear scales, circular tests using feed back signal can be used to recognize, for example, the influence of periodic deviations (as described in B.2.3), influence of reversal error (B.3.2), influence of acceleration of axes (B.3.3), influence of different following errors (B.3.4).

Bibliography

[1] ISO/TR 16015:2003, *Geometrical product specification (GPS) — Systematic errors and contributions to measurement uncertainty of length measurement due to thermal influences*

[2] ISO 230-2:1997, *Test code for machine tools — Part 2: Determination of accuracy and repeatability of positioning of numerically controlled machine tools*

[3] ANSI/ASME B5.54-1992, *Methods for Performance, Evaluation of Computer Numerically Controlled Machining Centers*

[4] BRYAN, J.B. A simple method for testing measuring machines and machine tools; Part 1: *Precision Engineering* April 4 2 (1982), p. 61; Part 2: *Precision Engineering* July 4 3 (1982), p. 125

[5] BURDEKIN, M. and PARK, J. CONTISURE. *A Computer Aided System for assessing the contouring accuracy of NC machine tools*, MATADOR Conference, April 1988, p. 197

[6] KAKINO, Y., IHARA, Y. and SHINOHARA, A. *Accuracy Inspection of NC Machine Tools by Double Ball*

[7] Bar Method, Carl-Hanser Verlag, 1993; in German: Carl-Hanser Verlag, 1993; in Japanese: Realize, Inc., 1989

[8] KNAPP, W. and HROVAT, S. The Circular Test for Testing NC Machine Tools, S. HROVAT, Trottenstr. 79, CH-8037 Zürich, 1987, ISBN 3-906391-03-5

in French: S. HROVAT, Trottenstr. 79, CH-8037. Zürich, 1986, ISBN 3-906391-02-7

in Russian: NPO ENIMS, 5th Donskoi pr. 21-b, 117926 Moscow, Russia, 1992

in German: S. HROVAT, Trottenstr. 79, CH-8037 Zürich, 1986. ISBN 3-906391-01-9

in Japanese: Nachi-Fujikoshi, World Trade Centre Building, 2-4-1, Hamamatsu-cho, Minato-ku, Tokyo 105.

[9] NAKAZAWA, H. and ITO, K. *Measurement System of Contouring Accuracy on NC Machine Tools*, Bull. Japan Soc. Prec. Eng., 12 4 (Dec. 1978), p. 189.

ICS 25.040.20

Price based on 17 pages