INTERNATIONAL STANDARD

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Test code for machine tools —

Part 7:
Geometric accuracy of axes of rotation

Code d'essai des machines-outils —

Partie 7: Exactitude géométrique des axes de rotation

Reference number
ISO 230-7:2006(E)

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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 230-7 was prepared by Technical Committee ISO/TC 39, *Machine tools*, Subcommittee SC 2, *Test conditions for metal cutting machine tools*.

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 quasi-static 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]

The following part is under preparation:

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

Test code for machine tools —

Part 7: Geometric accuracy of axes of rotation

1 Scope

This part of ISO 230 is aimed at standardizing methods of specification and test of the geometric accuracy of axes of rotation used in machine tools. Spindles, rotary heads and rotary and swivelling tables of machine tools constitute axes of rotation, all having unintended motions in space as a result of multiple sources of errors.

This part of ISO 230 covers the following properties of spindles:

— axis of rotation error motion;

— speed-induced axis shifts.

The other important properties of spindles, such as thermally induced axis shifts and environmental temperature variation-induced axis shifts, are dealt with in ISO 230-3.

This part of ISO 230 does not cover the following properties of spindles:

— angular positioning accuracy (see ISO 230-1 and ISO 230-2);

— runout of surfaces and components (see ISO 230-1);

— tool holder interface specifications;

— inertial vibration measurements (see ISO 230-8);

— noise measurements (see ISO 230-5);

— rotational speed range and accuracy (see ISO 10791-6 and ISO 13041-6);

— balancing measurements or methods (see ISO 1940-1 and ISO 6103);

— idle run loss (power loss);

— thermal drift (see ISO 230-3).

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*

ISO 230-2:2006, *Test code for machine tools — Part 2: Determination of accuracy and repeatability of positioning numerically controlled axes*

ISO 230-3:— [1)], *Test code for machine tools — Part 3: Determination of thermal effects*

ISO 841:2001, *Industrial automation systems and integration — Numerical control of machines — Coordinate system and motion nomenclature*

3 Terms and definitions

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

NOTE They are presented in this sequence to help the user develop an understanding of the terminology of axes of rotation. The alphabetical cross-references for these definitions are given in Annex G.

3.1 General concepts

3.1.1
spindle unit
device which provides an axis of rotation

NOTE Other devices such as rotary tables, trunnions and live centres are included within this definition.

3.1.2
spindle
rotor
rotating element of a spindle unit

3.1.3
spindle housing
stator
stationary element of a spindle unit

3.1.4
bearing
element of a spindle unit that supports the spindle (rotor) and enables rotation between the spindle and the spindle housing

3.1.5
axis of rotation
line segment about which rotation occurs

See Figure 1 a).

NOTE In general, during rotation this line segment translates (in radial and axial directions) and tilts within the reference coordinate frame due to inaccuracies in the bearings and bearing seats, structural motion or axis shifts, as shown in Figure 1 a) and b).

1) To be published. (Revision of ISO 230-3:2001)

3.1.6
reference coordinate axes
mutually perpendicular X, Y, and Z-axes, fixed with respect to a specified object

See Figure 1 a).

NOTE The specified object can be fixed or rotating.

3.1.7
positive direction
in accordance with ISO 841, the direction of a movement that causes an increasing positive dimension of the workpiece

3.1.8
perfect spindle
spindle having no error motion of its axis of rotation relative to its axis average line

3.1.9
perfect workpiece
rigid body having a perfect surface of revolution about a centreline

3.1.10
axis average line
straight line segment located with respect to the reference coordinate axes representing the mean location of the axis of rotation

See Figure 1 a).

NOTE 1 The axis average line is a useful term to describe changes in location of an axis of rotation in response to load, temperature or speed changes.

NOTE 2 Unless otherwise specified, the axis average line should be determined by calculating the least-squares centre of two data sets of radial error motion taken at axially separated locations (see 3.4).

NOTE 3 ISO 841 defines the Z axis of a machine as being "parallel to the principal spindle of the machine". This implies that the machine Z axis is parallel to the axis average line of the principal spindle. However, since axis average line definition applies to other spindles and rotary axes as well, in general not all axes of rotation are parallel to the machine Z axis. An axis average line should be parallel to the machine Z axis only if it is associated with the principal spindle of the machine.

3.1.11
axis shift
quasi-static relative displacement, between the tool and the workpiece, of the axis average line due to a change in conditions

See Figure 1 c).

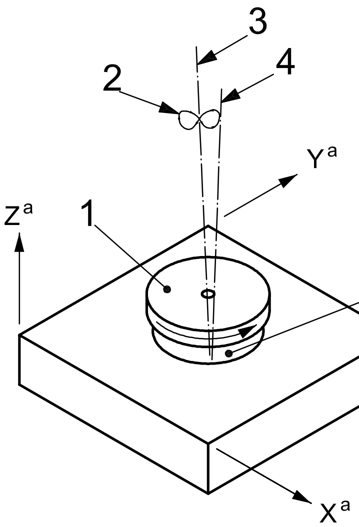
NOTE Causes of axis shift include thermal drift, load changes, and speed changes.

3.1.12
displacement sensor
device that measures displacement between two specified objects

EXAMPLE Capacitance gage, linear variable differential transformer (LVDTs), eddy current probe, laser interferometer, dial indicator.

3.1.13
structural loop
assembly of components which maintains the relative position between two specified objects

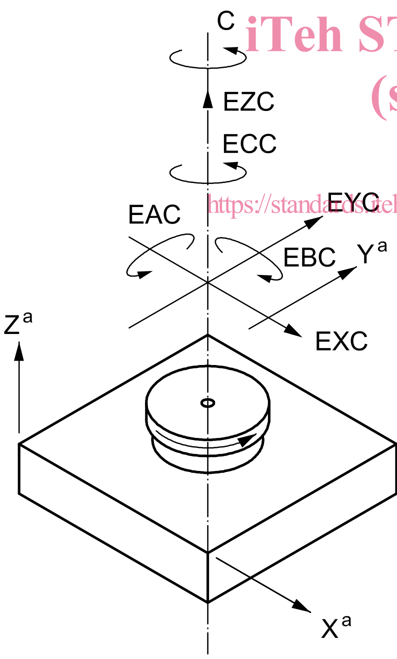
NOTE A typical pair of specified objects is a cutting tool and a workpiece: the structural loop would include the spindle, bearings and spindle housing, the machine head stock, the machine slideways and frame, and the tool and work holding fixtures.

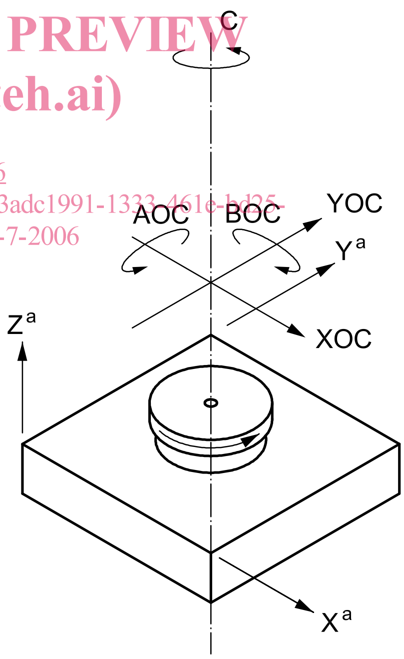


Key

1 spindle (rotor)
2 error motion of axis of rotation (prior to angle C)
3 axis average line
4 axis of rotation (at angle C)
5 spindle housing (stator)

a) Reference coordinate axes, axis of rotation, axis average line, and error motion of a spindle





Key

EXC radial motion in X direction
EYC radial motion in Y direction
EZC axial motion
EAC tilt motion around X
EBC tilt motion around Y axis
ECC angular positioning error

Key

XOC X position of C
YOC Y position of C
AOC squareness of C to Y
BOC squareness of C to X

[a] Reference axis.

b) Error motions of axis of rotation

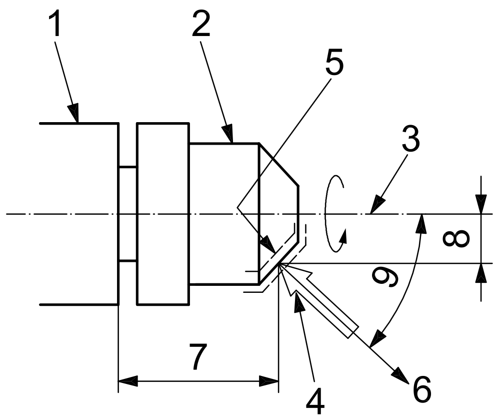
c) Location errors (axis shift) of axis average line

Figure 1 — Reference coordinate axes, axis of rotation, axis average line and error motion of a spindle shown for a C spindle or a C rotary axis

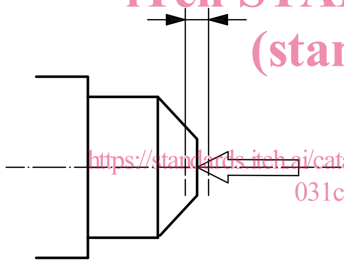
3.1.14
sensitive direction
direction perpendicular to the perfect workpiece surface through the instantaneous point of machining or measurement

See Figure 2.

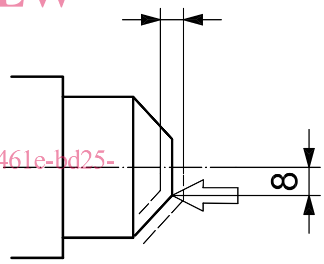
NOTE For a fixed sensitive direction, the results of the measurement of the relative displacement between the tool and the workpiece correspond to the shape error of the manufactured surface of a workpiece.



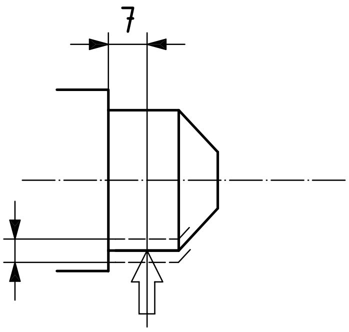
a) General case of error motion



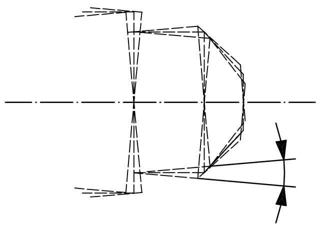
b) Axial error motion



c) Face error motion



d) Radial error motion



e) Tilt error motion

Key

1 spindle
2 perfect workpiece
3 axis average line
4 displacement sensor
5 error motion
6 sensitive direction
7 axial location
8 radial location
9 direction angle

Figure 2 — General case of error motion and axial, face, radial and tilt error motions for fixed sensitive direction

3.1.15
non-sensitive direction
any direction perpendicular to the sensitive direction

3.1.16
fixed sensitive direction
sensitive direction where the workpiece is rotated by the spindle and the point of machining or measurement is fixed

3.1.17
rotating sensitive direction
sensitive direction where the workpiece is fixed and the point of machining or measurement rotates with the spindle

NOTE A lathe has a fixed sensitive direction, a jig borer has a rotating sensitive direction.

3.1.18
runout
total displacement measured by a displacement sensor sensing against a moving surface or moved with respect to a fixed surface

NOTE 1 For runout of a component at a given section, see ISO 230-1:1996, 5.611.4.

NOTE 2 The terms “TIR” (total indicator reading) and “FIM” (full indicator movement) are equivalent to runout.

3.1.19
stationary point runout
total displacement measured by a displacement sensor sensing against a point on a rotating surface which has negligible lateral motion with respect to the sensor when both the sensor and the surface rotate together

See Figure 3.

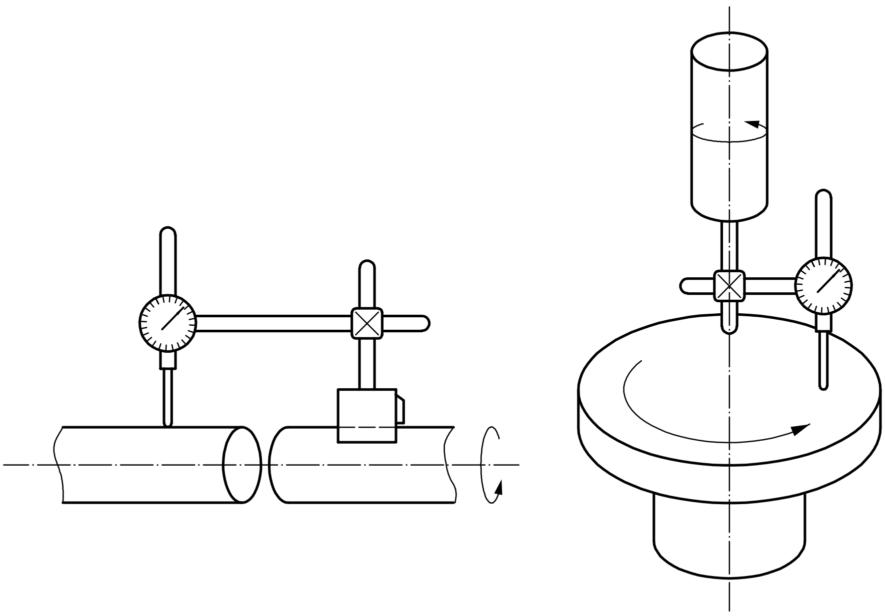


Figure 3 — Schematics of sample applications for use of stationary point runout (radial test for concentricity and face test for parallelism)

3.1.20
squareness
perpendicularity
angular relationship between two planes, two straight lines, or a straight line and a plane in which the angular deviation from 90 degrees does not exceed a given value

NOTE A plane surface is “square” to an axis of rotation if coincident polar profile centres are obtained for an axial and a face motion polar plot or for two face motion polar plots at different radii. *Perpendicularity of motion* refers, for machine tools, to the successive positions on the trajectory of a functional point on a moving part of the machine in relation to a plane (support or slideway), a straight line (axis or intersection of two planes) or the trajectory of a functional point on another moving part. See ISO 230-1:1996, 5.5.

3.1.21
play
condition of zero stiffness over a limited range of displacement due to clearance between elements of a structural loop

3.1.22
hysteresis
linear (or angular) displacement between two objects resulting from the sequential application and removal of equal forces (or moments) in opposite directions.

NOTE Hysteresis is caused by mechanisms, such as drive train clearance, guideway clearance, mechanical deformations, friction and loose joints.

3.1.22.1
setup hysteresis
hysteresis of various components in a test setup, normally due to loose mechanical connections

3.1.22.2
machine hysteresis
hysteresis of the machine structure when subjected to specific loads

3.2 Error motion

⟨axis of rotation⟩ unintended relative displacement in the sensitive direction between the tool and the workpiece

NOTE Error motions are specified as location and direction as shown in Figure 2 a) and do not include motions due to axis shifts associated with changes in temperature, load or rotational speed.

3.2.1
axis of rotation error motion
changes in position and orientation of axis of rotation relative to its axis average line as a function of angle of rotation of the spindle

NOTE This error motion may be measured as motions of the surface of a perfect cylindrical or spherical test artefact with its centreline coincident with the axis of rotation.

3.2.2
structural error motion
error motion due to internal or external excitation and affected by elasticity, mass and damping of the structural loop

See 3.6

3.2.3
bearing error motion
error motion due to imperfect bearing

NOTE See Annex A.

3.2.4
total error motion
complete error motion as recorded, composed of the synchronous and asynchronous components of the spindle and structural error motions

3.2.5
static error motion
special case of error motion in which error motion is sampled with the spindle at rest at a series of discrete rotational positions

NOTE This is used to measure error motion exclusive of any dynamic influences.

3.2.6
synchronous error motion
portion of the total error motion that occurs at integer multiples of the rotation frequency

NOTE It is the mean contour of the total error motion polar plot averaged over the number of revolutions.

3.2.7
fundamental error motion
portion of the total error motion that occurs at the rotational frequency of the spindle

3.2.8
residual synchronous error motion
portion of the synchronous error motion that occurs at integer multiples of the rotation frequency other than the fundamental

3.2.9
asynchronous error motion
portion of the total error motion that occurs at frequencies other than integer multiples of the rotation frequency

NOTE 1 Asynchronous error motion is the deviations of the total error motion from the synchronous error motion.

NOTE 2 Asynchronous error motion comprises those components of error motion that are

a) not periodic,

b) periodic but occur at frequencies other than the spindle rotational frequency and its integer multiples, and

c) periodic at frequencies that are subharmonics of the spindle rotational frequency.

3.2.10
radial error motion
error motion in a direction perpendicular to the axis average line and at a specified axial location

See Figure 2 d).

NOTE 1 This error motion may be measured as the motions, in the radial direction, of the surface of a perfect cylindrical or spherical test artefact with its centreline coincident with the axis of rotation.

NOTE 2 The term “radial runout” has an accepted meaning, which includes errors due to centring and workpiece out-of-roundness, and hence is not equivalent to radial error motion.

3.2.11
pure radial error motion
error motion in which the axis of rotation remains parallel to the axis average line and moves perpendicular to it in the sensitive direction

NOTE Pure radial error motion is just the concept of radial error motion in the absence of tilt error motion. There should be no attempt to measure it.

3.2.12
tilt error motion
error motion in an angular direction relative to the axis average line

See Figure 2 e).

NOTE 1 This motion may be evaluated by simultaneous measurements of the radial error motion in two radial planes separated by a distance along the axis average line.

NOTE 2 “Coning,” “wobble,” “swash”, “tumbling” and “towering” errors are non-preferred terms for tilt error motion.

NOTE 3 The term “tilt error motion” rather than “angular motion” was chosen to avoid confusion with rotation about the axis or with angular positioning error of devices such as rotary tables.

3.2.13
axial error motion
error motion coaxial with the axis average line

See Figure 2 b).

NOTE 1 This error motion may be measured as the motions, in the axial direction along the axis average line, of the surface of a perfect flat disk or spherical test artefact with its centreline coincident with the axis of rotation.

NOTE 2 “Axial slip”, “end-camming”, “pistoning” and “drunkenness” are non-preferred terms for axial error motion.

3.2.14
face error motion

error motion parallel to the axis average line at a specified radial location

See Figure 2 c).

NOTE Face error motion is a combination of axial and tilt error motions. The term “face runout” has an accepted meaning analogous to “radial runout” and hence is not equivalent to face error motion.

3.2.15
error motion measurement
measurement record of error motion, which includes all pertinent information regarding the machine, instrumentation and test conditions

3.3 Error motion polar plot

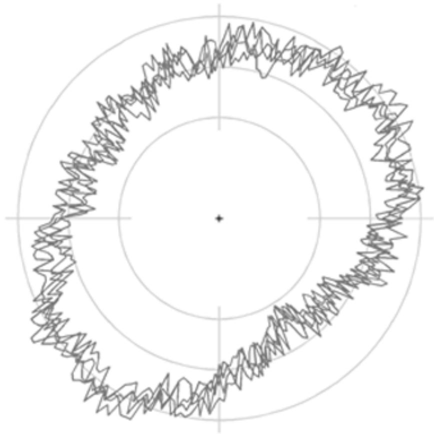
representation of error motions of axes of rotation generated by plotting displacement versus the angle of rotation of the spindle

See Figure 4.

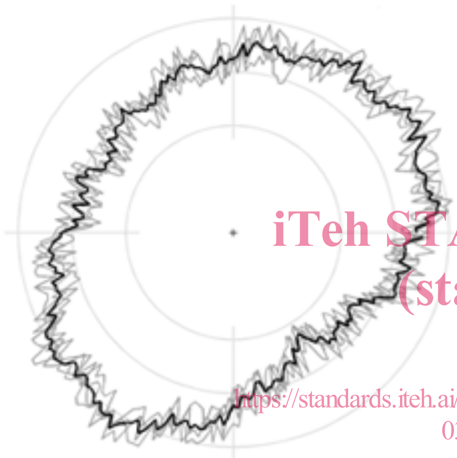
3.3.1
total error motion polar plot
polar plot of the complete error motion as recorded

3.3.2
synchronous error motion polar plot
polar plot of the error motion components having frequencies that are integer multiples of the rotation frequency

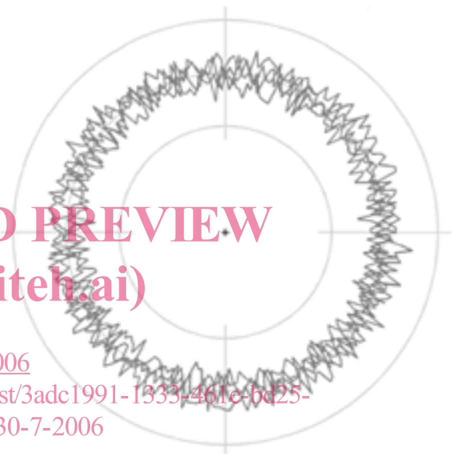
NOTE It is acceptable to create the synchronous error polar plot by averaging the total error motion polar plot.



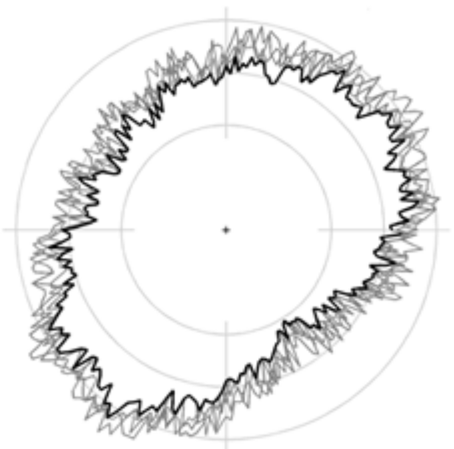
a) Total error motion



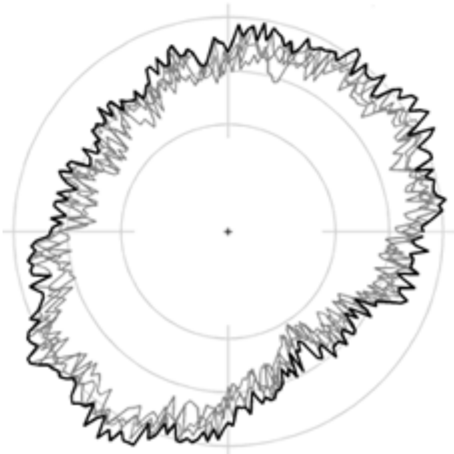
b) Synchronous error motion



c) Asynchronous error motion



d) Inner error motion



e) Outer error motion

Figure 4 — Error motion polar plots

3.3.3
asynchronous error motion polar plot
polar plot of that portion of the total error motion that occurs at frequencies that are not integer multiples of the rotational frequency

3.3.4
fundamental error motion polar plot
best-fit circle passed through the synchronous axial or face error motion polar plot about a specified polar profile centre

3.3.5
axial error motion polar plot
polar plot of the axial error motion, including the fundamental, synchronous residual and asynchronous axial error motions

3.3.6
residual synchronous error motion polar plot
polar plot of the portion of the synchronous error motion that occurs at frequencies other than the fundamental

NOTE The division of synchronous error motion into fundamental and residual components is only applicable to axial and face error motions. In the radial and tilt directions, fundamental error motion does not exist — the measured value that occurs at the fundamental frequency is not a characteristic of the axis of rotation.

3.3.7
inner error motion polar plot
contour of the inner boundary of the total error motion polar plot

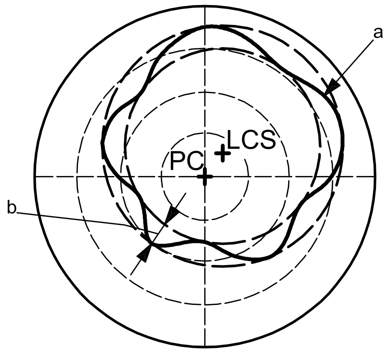
3.3.8
outer error motion polar plot
contour of the outer boundary of the total error motion polar plot

3.4 Error motion centre

centre defined for the assessment of error motion polar plots

See Figure 5.

NOTE Table 1 provides the preferred centres for the assessment of error motion values. If the centre is not specified, the preferred centre is to be assumed.



a Error motion polar plot.

b Error motion value for LSC centre.

Figure 5 — Error motion polar plot, PC (polar chart) centre and LSC (least-square circle) centre and error motion value for LSC centre

