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Geometrical product specifications (GPS) — Acceptance and reverification tests for coordinate measuring machines (CMM) —

Part 7:
CMMs equipped with imaging probing systems

Spécification géométrique des produits (GPS) — Essais de réception et de vérification périodique des machines à mesurer tridimensionnelles (MMT) —

Partie 7: MMT équipées de systèmes de palpage imageurs

Reference number
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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 10360-7 was prepared by Technical Committee ISO/TC 213, *Dimensional and geometrical product specifications and verification*.

ISO 10360 consists of the following parts, under the general title *Geometrical product specifications (GPS) — Acceptance and reverification tests for coordinate measuring machines (CMM)*:

— *Part 1: Vocabulary*

— *Part 2: CMMs used for measuring linear dimensions*

— *Part 3: CMMs with the axis of a rotary table as the fourth axis*

— *Part 4: CMMs used in scanning measuring mode*

— *Part 5: CMMs using single and multiple stylus contacting probing systems*

— *Part 6: Estimation of errors in computing of Gaussian associated features*

— *Part 7: CMMs equipped with imaging probing systems*

— *Part 9: CMMs with multiple probing systems*

The following part is under preparation:

— *Part 8: CMMs with optical distance sensors*

Introduction

This part of ISO 10360 is a geometrical product specification (GPS) standard and is to be regarded as a general GPS standard (see ISO/TR 14638). It influences chain link 5 of the chains of standards on size, distance, radius, angle, form, orientation, location, run-out and datums. For more detailed information on the relation of this part of ISO 10360 to other standards and the GPS matrix model, see Annex E.

The tests of this part of ISO 10360 have two technical objectives:

a) to test the error of indication of a calibrated test length using an imaging probing system;

b) to test the errors in the imaging probing system.

The benefits of these tests are that the measured result has a direct traceability to the unit length, the meter, and that it gives information on how the CMM will perform on similar length measurements.

The structure of this part of ISO 10360 parallels that of ISO 10360-2, which is for CMMs equipped with contact probing systems. The testing methodology between these two parts of ISO 10360 is intentionally similar. The differences that exist may be eliminated in future revisions of either this part of ISO 10360 or ISO 10360-2.

All the definitions in Clause 3 will appear in the revision of ISO 10360-1:2000.

Geometrical product specifications (GPS) — Acceptance and reverification tests for coordinate measuring machines (CMM) —

Part 7: CMMs equipped with imaging probing systems

1 Scope

This part of ISO 10360 specifies the acceptance tests for verifying the performance of a coordinate measuring machine (CMM) used for measuring linear dimensions as stated by the manufacturer. It also specifies the reverification tests that enable the user to periodically reverify the performance of the CMM.

The acceptance and reverification tests given in this part of ISO 10360 are applicable only to Cartesian CMMs using imaging probing systems of any type operating in the discrete-point probing mode.

This part of ISO 10360 does not explicitly apply to:

— non-Cartesian CMMs; however, parties may apply this part of ISO 10360 to non-Cartesian CMMs by mutual agreement;

— CMMs using other types of optical probing; however, parties may apply this approach to other optical CMMs by mutual agreement;

— CMMs using contact probing systems (see ISO 10360-2 for contact probing systems).

This part of ISO 10360 specifies performance requirements that can be assigned by the manufacturer or the user of a CMM, the manner of execution of the acceptance and reverification tests to demonstrate the stated requirements, rules for proving conformance, and applications for which the acceptance and reverification tests can be used.

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 10360-1:2000, *Geometrical Product Specifications (GPS) — Acceptance and reverification tests for coordinate measuring machines (CMM) — Part 1: Vocabulary*

ISO 10360-2:2009, *Geometrical product specifications (GPS) — Acceptance and reverification tests for coordinate measuring machines (CMM) — Part 2: CMMs used for measuring linear dimensions*

ISO 14253-1:1998, *Geometrical Product Specifications (GPS) — Inspection by measurement of workpieces and measuring equipment — Part 1: Decision rules for proving conformance or non-conformance with specifications*

ISO 14660-1:1999, *Geometrical Product Specifications (GPS) — Geometrical features — Part 1: General terms and definitions*

ISO/TS 23165:2006, *Geometrical product specifications (GPS) — Guidelines for the evaluation of coordinate measuring machine (CMM) test uncertainty*

ISO/IEC Guide 99, *International vocabulary of metrology — Basic and general concepts and associated terms (VIM)*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 10360-1, ISO 10360-2, ISO 14253-1, ISO 14660-1, ISO/TS 23165, ISO/IEC Guide 99 and the following apply.

3.1
imaging probing system
probing system which creates measurement points through the use of an imaging system

NOTE 1 This part of ISO 10360 is primarily concerned with imaging probing systems that enable measurements in the lateral direction to the probing system axis.

NOTE 2 A video or vision probing system is an imaging probing system.

3.2
imaging probe CMM
CMM equipped with an imaging probing system

3.3
field of view
FOV
area viewed by the imaging probing system

See Figure 1.

NOTE The measuring limits, or size, of the FOV are stated as the limits of the object space that is reproduced in the final image.

3.4
measuring window
region of interest in the FOV that is used in the determination of the measured point(s)

See Figure 1.

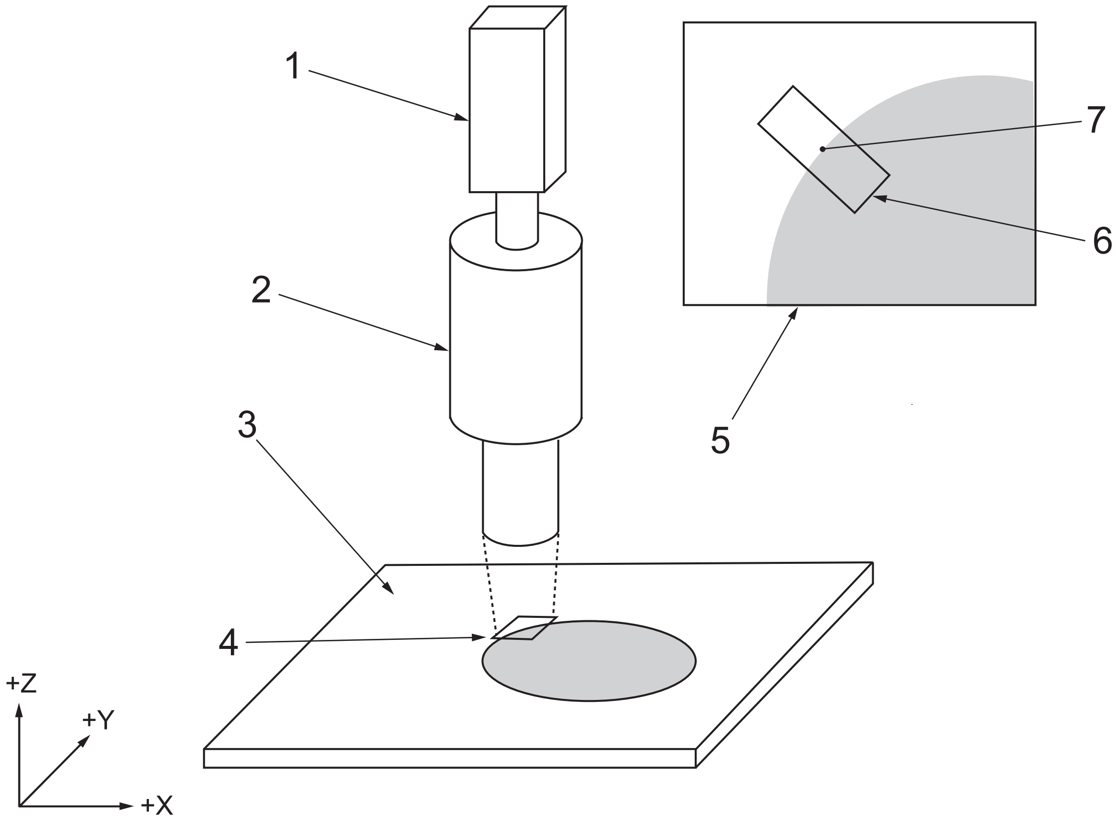
NOTE Configurations of measuring windows may vary widely between various imaging probe CMMs and for different measuring applications on the same imaging probe CMM.

3.5
measuring plane (of the imaging probing system)
two-dimensional plane defined by the FOV of an imaging probing system

3.6
coefficient of thermal expansion
CTE
α
linear thermal expansion coefficient of a material at 20 °C

3.7
normal CTE material
material with a CTE between 8×10^{-6}/°C and 13×10^{-6}/°C

3.8
test circle
circular material standard used for acceptance test and reverification test



Key

1 camera or other device for capturing an image of the measured object
2 various optical elements of the imaging probing system
3 measured object
4 FOV (object)
5 FOV (image)
6 measuring window
7 measured point

Figure 1 — Imaging probing system

3.9
bidirectional length measurement error
E_B
error of indication when measuring a calibrated bidirectional test length using an imaging probe CMM with a single probing point (or equivalent) at each end of the calibrated test length

NOTE E_B is applicable only to imaging probe CMMs that are capable of three-dimensional spatial measurements, which may not always be the case.

3.10
repeatability range of the bidirectional length measurement error
R_B
range (largest minus smallest) of three repeated length measurement errors measured by a CMM when measuring a calibrated bidirectional test length

3.11
unidirectional length measurement error
E_U
error of indication when measuring a calibrated unidirectional test length using an imaging probe CMM with a single probing point (or equivalent) at each end of the calibrated test length

NOTE E_U is applicable only to imaging probe CMMs that are capable of three-dimensional spatial measurements, which may not always be the case.

3.12
repeatability range of the unidirectional length measurement error
R_U
range (largest minus smallest) of three repeated length measurement errors measured by a CMM when measuring a calibrated unidirectional test length

3.13
Z bidirectional length measurement error
E_{BZ}
error of indication when measuring a calibrated bidirectional test length that is nominally perpendicular to the measuring plane of the imaging probe using a single probing point (or equivalent) at each end of the calibrated test length

NOTE In this part of ISO 10360, it is assumed that the machine Z-axis is nominally perpendicular to the measuring plane of the imaging probe. If that is not the case, alternative nomenclature should be used (e.g. E_{BX} or E_{BY}).

3.14
Z unidirectional length measurement error
E_{UZ}
error of indication when measuring a calibrated unidirectional test length that is nominally perpendicular to the measuring plane of the imaging probe using a single probing point (or equivalent) at each end of the calibrated test length

NOTE In this part of ISO 10360, it is assumed that the machine Z-axis is nominally perpendicular to the measuring plane of the imaging probe. If that is not the case, alternative nomenclature should be used (e.g. E_{UX} or E_{UY}).

3.15
XY bidirectional length measurement error
E_{BXY}
error of indication when measuring a calibrated bidirectional test length that is nominally parallel to the measuring plane of the imaging probe using a single probing point (or equivalent) at each end of the calibrated test length

NOTE In this part of ISO 10360, it is assumed that the machine XY plane is nominally parallel to the measuring plane of the imaging probe. If that is not the case, alternative nomenclature should be used (e.g. E_{BXZ} or E_{BYZ}).

3.16
XY unidirectional length measurement error
E_{UXY}
error of indication when measuring a calibrated unidirectional test length that is nominally parallel to the measuring plane of the imaging probe using a single probing point (or equivalent) at each end of the calibrated test length

NOTE In this part of ISO 10360, it is assumed that the machine XY plane is nominally parallel to the measuring plane of the imaging probe. If that is not the case, alternative nomenclature should be used (e.g. E_{UXZ} or E_{UYZ}).

3.17
squareness error
E_{SQ}
error of indication of the combined influence of the straightness and squareness (perpendicularity of motion) measured between the axis of motion of the imaging probe CMM that is nominally perpendicular to the measuring plane of the imaging probe and the plane of motion that is nominally parallel to the measuring plane of the imaging probe

NOTE The expected usage is where the Z-axis is nominally perpendicular to the measuring plane of the imaging probe and the XY plane is nominally parallel to the measuring plane of the imaging probe.

3.18
imaging probe bidirectional length measurement error
E_{BV}
error of indication of a calibrated bidirectional test length measured in any position within the field of view of the imaging probe, nominally parallel to the measuring plane of the imaging probe, and using a single probing point (or equivalent) at each end of the calibrated test length

NOTE 1 Testing E_{BV} does not involve motion of the imaging probe CMM.

NOTE 2 E_{BV} is applicable only to imaging probe CMMs that are capable of making measurements in the field of view of the imaging probe, which may not always be the case.

3.19
imaging probe unidirectional length measurement error
E_{UV}
error of indication of a calibrated unidirectional test length measured in any position within the field of view of the imaging probe, nominally parallel to the measuring plane of the imaging probe, and using a single probing point (or equivalent) at each end of the calibrated test length

NOTE 1 Testing E_{UV} does not involve motion of the imaging probe CMM.

NOTE 2 E_{UV} is applicable only to imaging probe CMMs that are capable of making measurements in the field of view of the imaging probe, which may not always be the case.

3.20
probing error
P_{F2D}
error of indication within which the range of radii can be determined by a least-squares fit of points measured on a circular material standard of size, the measurements being taken on the test circle located anywhere in the measuring volume by an imaging probe CMM in the discrete-point probing mode using motion of the CMM between all successive points and with all points evenly distributed across the usable field of view of the imaging probe

3.21
probing error of the imaging probe
P_{FV2D}
error of indication within which the range of radii can be determined by a least-squares fit of point measured on a circular material standard of size, the measurements being taken on the test circle by an imaging probe CMM in the discrete-point probing mode using no motion of the CMM and with all points distributed across the usable field of view of the imaging probe

NOTE P_{FV2D} is applicable only to imaging probe CMMs that are capable of making measurements in the field of view of the imaging probe, which may not always be the case.

3.22
maximum permissible error of bidirectional length measurement
$E_{B, MPE}$
extreme value of the bidirectional length measurement error, E_B, permitted by specifications

3.23
maximum permissible limit of the bidirectional repeatability range
$R_{B, MPL}$
extreme value of the repeatability range of the bidirectional length measurement error, R_B, permitted by specifications

3.24
maximum permissible error of unidirectional length measurement
$E_{U, MPE}$
extreme value of the unidirectional length measurement error, E_U, permitted by specifications

3.25
maximum permissible limit of the unidirectional repeatability range
$R_{U, MPL}$
extreme value of the repeatability range of the unidirectional length measurement error, R_U, permitted by specifications

3.26
maximum permissible error of Z bidirectional length measurement
$E_{BZ, MPE}$
extreme value of the Z bidirectional length measurement error, E_{BZ}, permitted by specifications

3.27
maximum permissible error of Z unidirectional length measurement
$E_{UZ, MPE}$
extreme value of the Z unidirectional length measurement error, E_{UZ}, permitted by specifications

3.28
maximum permissible error of the XY bidirectional length measurement
$E_{BXY, MPE}$
extreme value of the XY bidirectional length measurement error, E_{BXY}, permitted by specifications

3.29
maximum permissible error of the XY unidirectional length measurement
$E_{UXY, MPE}$
extreme value of the XY unidirectional length measurement error, E_{UXY}, permitted by specifications

3.30
maximum permissible squareness error
$E_{SQ, MPE}$
extreme value of the squareness error, E_{SQ}, permitted by specifications

3.31
maximum permissible error of imaging probe bidirectional length measurement
$E_{BV, MPE}$
extreme value of the imaging probe bidirectional length measurement error, E_{BV}, permitted by specifications

3.32
maximum permissible error of imaging probe unidirectional length measurement
$E_{UV, MPE}$
extreme value of the imaging probe unidirectional length measurement error, E_{UV}, permitted by specifications

3.33
maximum permissible probing error
$P_{F2D, MPE}$
extreme value of the probing error, P_{F2D}, permitted by specifications

3.34
maximum permissible probing error of the imaging probe
$P_{FV2D, MPE}$
extreme value of the probing error of the imaging probe, P_{FV2D}, permitted by specifications

4 Symbols

For the purposes of this part of ISO 10360, the symbols of Table 1 apply.

Table 1 — Symbols

Symbol	Meaning
E_{B}	bidirectional length measurement error
R_{B}	repeatability range of the bidirectional length measurement error
E_{U}	unidirectional length measurement error
R_{U}	repeatability range of the unidirectional length measurement error
E_{BZ}	Z bidirectional length measurement error
E_{UZ}	Z unidirectional length measurement error
E_{BXY}	XY bidirectional length measurement error
E_{UXY}	XY unidirectional length measurement error
E_{BX}	X bidirectional length measurement error
E_{UX}	X unidirectional length measurement error
E_{BY}	Y bidirectional length measurement error
E_{UY}	Y unidirectional length measurement error
E_{SQ}	squareness error
E_{BV}	imaging probe bidirectional length measurement error
E_{UV}	imaging probe unidirectional length measurement error
P_{F2D}	probing error
P_{FV2D}	probing error of the imaging probe
$E_{\mathrm{B,\ MPE}}$	maximum permissible error of bidirectional length measurement
$R_{\mathrm{B,\ MPL}}$	maximum permissible limit of bidirectional repeatability range
$E_{\mathrm{U,\ MPE}}$	maximum permissible error of unidirectional length measurement
$R_{\mathrm{U,\ MPL}}$	maximum permissible limit of unidirectional repeatability range
$E_{\mathrm{BZ,\ MPE}}$	maximum permissible error of Z bidirectional length measurement
$E_{\mathrm{UZ,\ MPE}}$	maximum permissible error of Z unidirectional length measurement
$E_{\mathrm{BXY,\ MPE}}$	maximum permissible error of XY bidirectional length measurement
$E_{\mathrm{UXY,\ MPE}}$	maximum permissible error of XY unidirectional length measurement
$E_{\mathrm{BX,\ MPE}}$	maximum permissible error of X bidirectional length measurement
$E_{\mathrm{UX,\ MPE}}$	maximum permissible error of X unidirectional length measurement
$E_{\mathrm{BY,\ MPE}}$	maximum permissible error of Y bidirectional length measurement
$E_{\mathrm{UY,\ MPE}}$	maximum permissible error of Y unidirectional length measurement
$E_{\mathrm{SQ,\ MPE}}$	maximum permissible squareness error
$E_{\mathrm{BV,\ MPE}}$	maximum permissible error of imaging probe bidirectional length measurement
$E_{\mathrm{UV,\ MPE}}$	maximum permissible error of imaging probe unidirectional length measurement
$P_{\mathrm{F2D,\ MPE}}$	maximum permissible probing error
$P_{\mathrm{FV2D,\ MPE}}$	maximum permissible probing error of the imaging probe

NOTE See Clause 9 for the indications of these symbols in product documentation, drawings, data sheets, etc.

5 Environmental and metrological requirements

5.1 Environmental conditions

Limits for permissible environmental conditions, such as temperature conditions, air humidity, vibration and ambient lighting at the site of installation, that influence the measurements shall be specified by:

— the manufacturer, in the case of acceptance tests;

— the user, in the case of reverification tests.

In both cases, the user is free to choose the environmental conditions under which the ISO 10360-7 testing will be performed within the specified limits (as supplied in the data sheet of the manufacturer).

The user is responsible for providing the environment enclosing the CMM, as specified by the manufacturer in the data sheet.

If the environment does not meet the specifications, then verification of the maximum permissible errors and limits cannot be required.

5.2 Operating conditions

The CMM shall be operated using the procedures given in the manufacturer's operating manual when conducting the tests given in Clause 6.

Specific areas in the manufacturer's manual to be adhered to are, for example:

a) machine start-up/warm-up cycles,

b) cleaning procedures,

c) probing system qualification,

d) thermal stability of the probing system before calibration,

e) probing approach direction,

f) ambient illumination,

g) illumination system,

h) location, type, number of thermal sensors,

i) imaging probe set-up and magnification,

j) image processing filters and algorithms.

5.3 Requirements for various configuration imaging probe CMMs

5.3.1 General

This part of ISO 10360 recognizes the various configurations of imaging probe CMMs and allows manufacturer's specifications and the required testing procedure some amount of flexibility for that reason.

5.3.2 Length measurement errors

Some imaging probe CMMs are designed and intended for three-dimensional measurements while some are not capable of making three-dimensional measurements. In order to allow some flexibility in specifications, but still ensure all necessary requirements for metrological characteristics are met, variations of specifications using the defined MPEs are allowed.

a) For imaging probe CMMs that are capable of spatial (three-dimensional) measurements anywhere in the imaging probe CMM volume, this part of ISO 10360 allows for two different testing approaches: the component approach and the composite approach.

   1) The composite approach includes a single maximum permissible error (MPE) for length measurement errors, i.e.

      either $E_{\mathrm{B,\ MPE}}$ or $E_{\mathrm{U,\ MPE}}$.

   2) The component approach includes the following three MPE values:

      i) either $E_{\mathrm{BXY,\ MPE}}$ or $E_{\mathrm{UXY,\ MPE}}$;

      ii) either $E_{\mathrm{BZ,\ MPE}}$ or $E_{\mathrm{UZ,\ MPE}}$;

      iii) $E_{\mathrm{SQ,\ MPE}}$.

   The MPE values from the composite and component approaches cannot necessarily be directly compared.

b) For imaging probe CMMs that can move in three axes but are only capable of making measurements in a two-dimensional plane (nominally parallel to the measuring plane of the imaging probe, whereby measured features may be in different planes but are projected into a single plane for measurement), there are two MPE values for length measurement errors:

   1) $E_{\mathrm{SQ,\ MPE}}$;

   2) either $E_{\mathrm{BXY,\ MPE}}$ or $E_{\mathrm{UXY,\ MPE}}$.

c) For imaging probe CMMs that are only capable of making measurements in any two-dimensional plane (nominally parallel to the measuring plane of the imaging probe, but where all features measured at any given time are always nominally in a single plane and not projected from the plane of measurement), there is one MPE value for length measurement errors:

   either $E_{\mathrm{BXY,\ MPE}}$ or $E_{\mathrm{UXY,\ MPE}}$.

In addition, for machines capable of measurements in the field of view without machine motion, specification of either $E_{\mathrm{BV,\ MPE}}$ or $E_{\mathrm{UV,\ MPE}}$ is allowed, but not required.

The maximum permissible errors for the length measurement errors can be specified, at the discretion of the manufacturer, using either unidirectional or bidirectional test lengths.

NOTE 1 Measuring machines with optical probing systems are sometimes used for the task of line scale pitch measurement. For this measurement task, a unidirectional length MPE specification may be appropriate.

NOTE 2 Limited availability of suitable bidirectional length artefacts with low calibration uncertainty may significantly increase the MPE for bidirectional length measurements compared to unidirectional length measurements.

The length measurement errors shall not exceed the respective maximum permissible errors as stated by:

— the manufacturer, in the case of acceptance tests,

— the user, in the case of reverification tests.

The length measurement errors and the maximum permissible errors of length measurement are expressed in micrometres.

5.3.3 Probing errors

$P_{\text{F2D, MPE}}$ is required for all machine configurations. The test procedure for the probing error, P_{F2D}, shall include both machine motion and the full usable portion of the field of view.

For machines capable of measurements in the field of view without machine motion, specification of $P_{\text{FV2D, MPE}}$ is allowed, but not required.

The probing errors, P_{F2D} and P_{FV2D}, shall not exceed the respective maximum permissible error, $P_{\text{F2D, MPE}}$ and $P_{\text{FV2D, MPE}}$ as stated by:

— the manufacturer, in the case of acceptance tests,

— the user, in the case of reverification tests.

The probing error and the maximum permissible error of the probing error are expressed in micrometres.

5.3.4 Repeatability range of the length measurement error, R_{B} or R_{U}

When $E_{\text{B, MPE}}$ or $E_{\text{U, MPE}}$ is specified then the corresponding $R_{\text{B, MPL}}$ or $R_{\text{U, MPL}}$ shall also be specified.

The repeatability range of the length measurement errors (R_{B} or R_{U} values) shall not exceed the respective maximum permissible limit of the repeatability range, $R_{\text{B, MPL}}$ or $R_{\text{U, MPL}}$, as stated by:

— the manufacturer, in the case of acceptance tests;

— the user, in the case of reverification tests.

The repeatability range of the length measurement error (R_{B} or R_{U} values) and the maximum permissible limit of the repeatability range, $R_{\text{B, MPL}}$ or $R_{\text{U, MPL}}$, are expressed in micrometres.

5.3.5 Workpiece loading effects

The length measurement errors shall not exceed the respective maximum permissible errors as stated by the manufacturer when the CMM is loaded with up to the maximum workpiece mass for which the CMM performance is rated. Testing of the length measurement errors may be conducted under any workpiece load (from zero up to the rated maximum workpiece load), selected by the user subject to the following conditions.

— The physical volume of the load supplied for testing shall lie within the measuring volume of the CMM and the load shall be free-standing.

— The manufacturer may specify a limit on the maximum load per unit area (kg/m^2) on the CMM support (i.e. table) surface or on individual point loads (kg/cm^2), or on both; for point loads, the load at any specific contact point shall be no greater than twice the load of any other contact point.

— Unless otherwise specified by the manufacturer, the load shall be located approximately centrally and approximately symmetrically at the centre of the CMM table.

The user and manufacturer should arrange for the availability of the load.

The user and the manufacturer should discuss the loading of the CMM table since access to measurement positions may be impaired by the load.

6 Acceptance tests and reverification tests

6.1 General

Acceptance tests are executed according to the manufacturer's specifications and procedures that are in compliance with this part of ISO 10360. The manufacturer may choose the artefact representing the calibrated test length from those described in Annex B and Annex D.

The user may supply the artefact if there is mutual agreement between the user and manufacturer; in this case, the measurement uncertainty, artefact material, and cost should be carefully considered.

Reverification tests are executed according to the user's specifications and the manufacturer's procedures.

For all tests, supplementary measurements may be required for artefact alignment purposes. It is recommended that the alignment method used be consistent with the procedures used for the artefact calibration.

The manufacturer should clearly specify on the data sheet the imaging probing configuration that will be used for all tests. If the manufacturer does not specify the imaging probing configuration, the user is free to choose the configuration from any components supplied with the CMM.

For all tests, the probing system shall be set up and qualified in accordance with the manufacturer's normal procedures (see 5.2). All probing system qualifications shall be performed using the artefact supplied by the manufacturer for probe qualifications in the normal use of the CMM and shall not make use of any test artefact or other artefacts.

NOTE Changing the imaging probing system or measuring conditions may significantly change the test results.

The algorithms and parameters used in testing should be those used for normal workpiece measurement on the machine. No additional filtering or other optimization should be used.

6.2 Length measurement errors

6.2.1 General

The principle of the assessment method is to use a calibrated test length, traceable to the metre, to establish whether the CMM is capable of measuring within the stated maximum permissible error of length measurement for a CMM.

The assessment shall be performed by comparison of the indicated values of five different calibrated test lengths, each measured three times, relative to their calibrated values. The indicated values are calculated by point-to-point length measurements projected onto the alignment direction. Each point shall be measured through the use of a single measuring window following the recommendations of the manufacturer. The dimensions of the measuring window shall be no larger than 10 % of the field of view.

To compare the length measured by a CMM to the calibrated value of the test length, it is necessary to align the test length properly. If the calibration certificate of the test length supplies instructions for alignment, then those instructions should be followed prior to the length measurements. In the absence of alignment instructions in the calibration certificate, the manufacturer may decide the alignment procedure.

Each of the three repeated measurements is to be arranged in the following manner: if one end of the calibrated test length is labelled “A” and the other end “B” then the measurement sequence is either A_1 B_1, A_2 B_2, A_3 B_3 or A_1 B_1, B_2 A_2, A_3 B_3. Other sequences such as A_1 A_2 A_3, B_1 B_2 B_3 are not permitted. Each of the three repeated measurements shall have its own unique measured points. That is, in general, B_1, B_2 and B_3 shall be different actual points of the same target point B. Once the measurement sequence for a test length has begun no additional probing points shall be measured other than those required to measure its length; for instance, no alignment points are permitted between the measurement A_1 and B_3.

For CMMs without workpiece thermal expansion compensation, the uncorrected differential thermal expansion between the CMM and the calibrated test length can produce a significant error; hence this part of ISO 10360 also requires the disclosure of the test length CTE.

For CMMs with workpiece thermal expansion compensation, this thermally induced error is greatly reduced. For these CMMs, a significant portion of the residual thermal error is due to the uncertainty in the test length's CTE (i.e. resulting in imperfect thermal expansion correction); hence this part of ISO 10360 requires the disclosure of the uncertainty in the CTE of the test length.

For some CMMs, the thermal correction system requires the user to input values of the artefact's CTE and temperature as part of its automatic thermal compensation system as described in its operating documentation. This is permitted provided it is the CMM software that performs the thermal compensation. Manual thermal compensation by the user is not permitted.

6.2.2 Measuring equipment

The longest calibrated test length for each position shall be at least 66 % of the maximum travel of the CMM along a measurement line through the calibrated test length. Hence the minimum allowable longest calibrated test length positioned along a body diagonal will be longer than the minimum allowable longest calibrated test length positioned along an axis direction. Each calibrated test length shall differ significantly from the others in length. Their lengths shall be well distributed over the measurement line. In general, the five calibrated test lengths used in one position may differ in their lengths from those used in another position, for example due to the extent of CMM travel along different measurement lines.

EXAMPLE 1 An example of well-distributed calibrated test lengths over a 1 m measurement line is: 100 mm, 200 mm, 400 mm, 600 mm, 800 mm.

The optional test for E_{BV} or E_{UV} allows no motion of the CMM; in this case, the maximum travel is the maximum measurable length in the image of the field of view of the imaging probe.

The manufacturer shall state the upper, and optionally lower, limits of the CTE of the calibrated test length. The manufacturer may calibrate the CTE of a calibrated test length. The manufacturer shall specify the maximum permissible ($k = 2$) uncertainty of the CTE of the calibrated test length. In the case where the calibrated test length is composed of a unidirectional length and a short bidirectional length (see Annex B), the CTE shall be considered to be that of the unidirectional length. The default for a calibrated test length is a normal CTE material unless the manufacturer's specifications explicitly state otherwise.

If the calibrated test length is not a normal CTE material, then the corresponding maximum permissible errors are designated with an asterisk (*) and an explanatory note shall be provided describing the CTE of the calibrated test length.

EXAMPLE 2

$E_{B,\ MPE}$*

* Artefact is super-invar with a CTE no greater than $0{,}5 \times 10^{-6}$/°C and with a CTE expanded uncertainty ($k = 2$) no greater than $0{,}3 \times 10^{-6}$/°C.

For E_B, E_U, E_{BXY}, and E_{UXY}, if the manufacturer's specification states that the calibrated test lengths will be a non-normal CTE material *and* the CTE is less than 2×10^{-6}/°C, then perform an additional measurement as described in 6.2.3.3 and 6.2.5.3.

A low CTE test length can be mathematically adjusted to give the apparent behaviour of a normal CTE material test length subject to the requirements of Annex D; however, this calibrated test length is still considered to have a low CTE and is subject to the requirement of 6.2.3.3 and 6.2.5.3.

See Annex B for examples of a calibrated test length.

6.2.3 Length measurement error, E_B or E_U

6.2.3.1 Measurement positions

Five different calibrated test lengths shall be placed in each of seven different positions (locations and orientations) in the measuring volume of the CMM, and each length shall be measured three times, for a total of 105 measurements. Four of the seven positions shall be the space diagonals, as shown in Table 2. The user may specify the remaining three positions; the default positions are parallel to each of the CMM axes, as shown in Table 2.

The manufacturer may, at his discretion, specify the maximum permissible error of bidirectional or unidirectional length measurement for each CMM axis, i.e. positions 5, 6 and 7.

- For bidirectional length measurements, the notation shall be
  - E_{BX} and $E_{BX, MPE}$,
  - E_{BY} and $E_{BY, MPE}$, and
  - E_{BZ} and $E_{BZ, MPE}$.
- For unidirectional length measurements, the notation shall be
  - E_{UX} and $E_{UX, MPE}$,
  - E_{UY} and $E_{UY, MPE}$, and
  - E_{UZ} and $E_{UZ, MPE}$.

Table 2 — Orientation in the measuring volume

Position number	Orientation in the measuring volume	Required or default
1	Along the diagonal in space from point (1, 0, 0) to (0, 1, 1)	Required
2	Along the diagonal in space from point (1, 1, 0) to (0, 0, 1)	Required
3	Along the diagonal in space from point (0, 1, 0) to (1, 0, 1)	Required
4	Along the diagonal in space from point (0, 0, 0) to (1, 1, 1)	Required
5	Parallel to the machine scales from point (0, 1/2, 1/2) to (1, 1/2, 1/2)	Default
6	Parallel to the machine scales from point (1/2, 0, 1/2) to (1/2, 1, 1/2)	Default
7	Parallel to the machine scales from point (1/2, 1/2, 0) to (1/2, 1/2, 1)	Default
NOTE For specifications in this table, opposite corners of the measuring volume are assumed to be (0, 0, 0) and (1, 1, 1) in coordinates (X, Y, Z).		

For CMMs with a high aspect ratio between the length of the axes, it is recommended that the manufacturer and the user, upon mutual agreement, add two additional measurement positions. A high aspect ratio CMM occurs when the length of the longest axis is at least three times the length of the intermediate axis. The recommended positions, each consisting of five calibrated test lengths, each measured three times, are the two (corner-to-corner) diagonals in a plane perpendicular to the longest axis, i.e. if X is the longest axis, then the two diagonals are in the Y-Z plane and located approximately at the midpoint of the X-axis.

6.2.3.2 Measurement procedure

For each of the five calibrated test lengths, obtain three measurement results. See Annex B for details regarding the measurement procedure for specific types of test lengths. Repeat for all seven measurement positions for a total of 105 measurement results from the calibrated test lengths.

6.2.3.3 Low CTE case

For the case where the manufacturer's specification for $E_{B,\ MPE}$ or $E_{U,\ MPE}$ requires $\alpha < 2 \times 10^{-6}$/°C (thus being a non-normal CTE), an additional measurement shall be performed on a normal CTE material calibrated test length. The normal CTE material test length shall be greater than the lesser of 0,5 m or 50 % of the longest CMM axis travel. This measurement shall be performed in the centre of the CMM measuring volume and parallel to one of the CMM axes. The measurement shall be repeated three times. The manufacturer may calibrate the CTE of this test length.

NOTE 1 When a laser interferometer is used to produce the calibrated test lengths, as described in Annex B, the laser interferometer is considered a low CTE material and hence requires the measurement of a normal CTE calibrated test length.

NOTE 2 When using a laser interferometer, it is good practice to measure the normal CTE artefact along a measurement line that was previously measured using the laser interferometer. The consistency of the errors of indication from the laser interferometer and from the normal CTE artefact serves as a quick check to see if the compensation for the workpiece CTE and the compensation for the index of refraction have been correctly implemented.

6.2.3.4 Derivation of test results

For all 105 measurements, and (if required) the three additional measurements of 6.2.3.3, calculate each length measurement error, E_B or E_U, by calculating the difference between the indicated value and the calibrated value of each test length (where the calibrated value is taken as the conventional true value of the length). The indicated value of a particular measurement of a calibrated test length may be corrected by the CMM to account for systematic errors, or thermally induced errors (including thermal expansion) if the CMM has accessory devices for this purpose. Manual correction of the results obtained from the computer output to account for temperature or other corrections shall not be allowed when the environmental conditions satisfy the conditions of 5.1.

Plot all length measurement errors on a diagram, as indicated on the figure (Figure 12, Figure 13 or Figure 14 of ISO 10360-1:2000) that matches the expressed form of the MPE.

6.2.4 Z length measurement error, E_{BZ} or E_{UZ}

6.2.4.1 Measurement positions

Five different calibrated test lengths shall be oriented nominally perpendicular to the measuring plane of the imaging probe. The user may specify the location.

6.2.4.2 Measurement procedure

For each of the five calibrated test lengths, obtain three measurement results for a total of 15 measurement results from the calibrated test lengths; see Annex B for details regarding the measurement procedure for specific types of test lengths.

6.2.4.3 Derivation of test results

For all 15 measurements, calculate each length measurement error, E_{BZ} or E_{UZ}, by calculating the difference between the indicated value and the calibrated value of each test length (where the calibrated value is taken as the conventional true value of the length). The indicated value of a particular measurement of a calibrated test length may be corrected by the CMM to account for systematic errors, or thermally induced errors (including thermal expansion) if the CMM has accessory devices for this purpose. Manual correction of the results obtained from the computer output to account for temperature or other corrections shall not be allowed when the environmental conditions satisfy the conditions of 5.1.

Plot all length measurement errors on a diagram, as indicated on the figure (Figure 12, Figure 13 or Figure 14 of ISO 10360-1:2000) that matches the expressed form of the MPE.

6.2.5 XY length measurement error, E_{BXY} or E_{UXY}

6.2.5.1 Measurement positions

Five different calibrated test lengths shall be placed in each of four different positions (locations and orientations) nominally parallel to the measuring plane of the imaging probe. Two of the four positions shall be the planar face diagonals. The user may specify the remaining two positions; the default positions are nominally parallel to each of the CMM axes, X and Y. The four different positions may be in different, but nominally parallel, planes.

6.2.5.2 Measurement procedure

For each of the five calibrated test lengths, obtain three measurement results. See Annex B for details regarding the measurement procedure for specific types of test lengths. Repeat for all four measurement positions for a total of 60 measurement results from the calibrated test lengths.

6.2.5.3 Low CTE case

For the case where the manufacturer's specification for $E_{BXY,\ MPE}$ or $E_{UXY,\ MPE}$ requires $\alpha < 2 \times 10^{-6}$/°C (thus being a non-normal CTE), an additional measurement shall be performed on a normal CTE material calibrated test length. The normal CTE material test length shall be greater than the lesser of 0,5 m or 50 % of the longest CMM axis travel in X or Y. This measurement shall be performed in the centre of the CMM measuring volume and parallel to either the X or Y CMM axis. The measurement shall be repeated three times. The manufacturer may calibrate the CTE of this test length.

NOTE 1 When a laser interferometer is used to produce the calibrated test lengths, as described in Annex B, the laser interferometer is considered a low CTE material and hence requires the measurement of a normal CTE calibrated test length.

NOTE 2 When using a laser interferometer, it is good practice to measure the normal CTE artefact along a measurement line that was previously measured using the laser interferometer. The consistency of the errors of indication from the laser interferometer and from the normal CTE artefact serves as a quick check to see if the compensation for the workpiece CTE and the compensation for the index of refraction have been correctly implemented.

6.2.5.4 Derivation of test results

For all 60 measurements, and (if required) the three additional measurements of 6.2.5.3, calculate each length measurement error, E_{BXY} or E_{UXY}, by calculating the difference between the indicated value and the calibrated value of each test length (where the calibrated value is taken as the conventional true value of the length). The indicated value of a particular measurement of a calibrated test length may be corrected by the CMM to account for systematic errors, or thermally induced errors (including thermal expansion) if the CMM has accessory devices for this purpose. Manual correction of the results obtained from the computer output to account for temperature or other corrections shall not be allowed when the environmental conditions satisfy the conditions of 5.1.

Plot all length measurement errors on a diagram, as indicated on the figure (Figure 12, Figure 13 or Figure 14 of ISO 10360-1:2000) that matches the expressed form of the MPE.

6.2.6 Imaging probe length measurement error, E_{BV} or E_{UV}

6.2.6.1 Measurement positions

Five different calibrated test lengths shall be placed in each of four different positions (locations and orientations) nominally parallel to the measuring plane of the imaging probe CMM. Two of the four positions shall be the field of view diagonals. The user may specify the remaining two positions; the default positions are nominally parallel to each of the CMM axes, X and Y, in the centre of the field of view.

NOTE This test does not involve machine motion; therefore, all measurement positions are within the field of view of the imaging probing system.

6.2.6.2 Measurement procedure

For each of the five calibrated test lengths, obtain three measurement results. See Annex B for details regarding the measurement procedure for specific types of test lengths. Repeat for all four measurement positions for a total of 60 measurement results from the calibrated test lengths.

6.2.6.3 Derivation of test results

For all 60 measurements, calculate each length measurement error, E_{BV} or E_{UV}, by calculating the difference between the indicated value and the calibrated value of each test length (where the calibrated value is taken as the conventional true value of the length). The indicated value of a particular measurement of a calibrated test length may be corrected by the CMM to account for systematic errors, or thermally induced errors (including thermal expansion) if the CMM has accessory devices for this purpose. Manual correction of the results obtained from the computer output to account for temperature or other corrections shall not be allowed when the environmental conditions satisfy the conditions of 5.1.

Plot all length measurement errors on a diagram, as indicated on the figure (Figure 12, Figure 13 or Figure 14 of ISO 10360-1:2000) that matches the expressed form of the MPE.

6.3 Squareness error, E_{SQ}

6.3.1 General

If the test method described in the following is not practical or suitable, the alternative method given in Annex C may be used upon mutual agreement between the two parties.

The principle of the assessment method is to use a calibrated mechanical square, traceable to the meter, to establish whether the imaging probe CMM is capable of measuring within the stated maximum permissible error of squareness, $E_{SQ,\ MPE}$, for both the YZ and ZX planes of motion of the CMM.

The assessment method shall be performed by measuring six different locations (a zero point plus five measurement points) on a square and comparing the results to the calibration values of the square. The indicated values are measured relative to the reference surface of the square, which must be properly aligned to the XY plane of motion of the CMM.

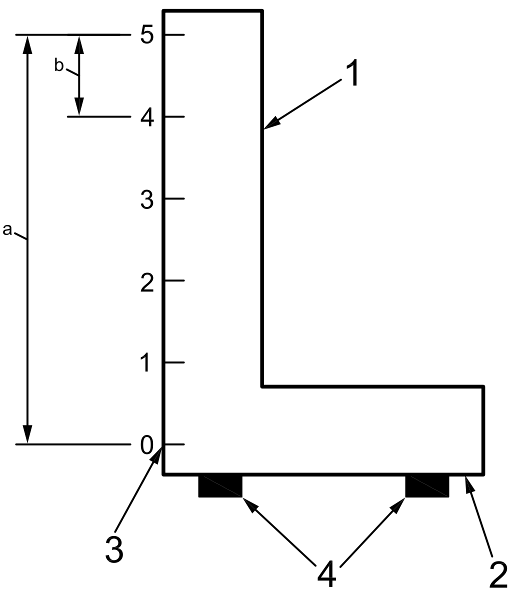
The measurement of the square will normally require the use of some type of indicator, or indicating gauge head, to be attached to the CMM. If required, this external indicator shall be supplied by the tester.

6.3.2 Measuring equipment

The squareness measurements shall be taken over at least 66 % of the maximum travel of the CMM Z-axis of motion. The distance between the measurement locations, parallel to the Z-axis, shall be at least 10 % of the maximum travel of the Z-axis. Each location to be measured on the square shall be calibrated relative to the reference surface of the square. The requirements for the size and measurement locations on the square are shown in Figure 2.

NOTE Squares are available in many shapes and configurations. The one shown in Figure 2 is just an example.

The maximum workpiece mass for which the CMM performance is rated should be considered in the selection of the square.



Key

1 precision mechanical square

2 reference surface of square

3 zero point of square

4 fixturing for placing square on reference points (if appropriate)

[a] The minimum length of measuring line is 66 % of Z travel.

[b] The minimum distance between points is 10 % of Z travel.

Figure 2 — Square for checking squareness error, E_S

6.3.3 Measuring positions

The calibrated square shall be placed in each of two different measuring positions. The first position shall be nominally parallel to the ZX plane of motion of the CMM. The second position shall be nominally parallel to the YZ plane of motion of the CMM.

6.3.4 Measuring procedure

6.3.4.1 External indicator

If an external indicator is required, it shall be rigidly mounted to the Z-axis such that the measuring point of the indicator is as close as possible to the measuring point of the imaging probing system. It shall be set up to measure deviations parallel to the measuring plane of the imaging probe in either the X or Y directions depending on whether the ZX or YZ plane, respectively, is being tested.

If an external indicator is not required, then the imaging probing system shall be set up and qualified in accordance with the manufacturer's normal procedures (see 5.2).

6.3.4.2 Alignment

The calibrated square shall be placed in the first measuring position with the reference surface of the square nominally parallel to the XY plane of motion of the CMM.

The reference surface of the square shall be used for alignment purposes; the reference surface of the square shall therefore either be mechanically aligned to be parallel to the XY plane of motion of the CMM or appropriate software tools must be used to create a measurement coordinate system to correct for the misalignment. Supplementary measurements may be required for artefact alignment purposes. It is recommended that the alignment method used be consistent with the procedures used for the artefact calibration.

The alignment method will typically involve measuring a plane on the reference surface of the square. The location of the measuring points on the plane should be based on the calibration of the square.

Riser blocks, or other fixturing, may be used to position the square or raise the square off the work surface of the CMM. This may be important to align the square in the same manner in which it was calibrated. See Figure 2.

Alignment and measurement of the square using an external indicator may be impossible or problematic on some imaging probe CMMs as the imaging probe is not being used in the measurement. Additional errors may also result if the use of the external indicator prohibits the proper functioning of any error compensation routines within the CMM. It is recommended that users consult with the manufacturer prior to performing this performance test.

6.3.4.3 Measurement points

Once the square is aligned, measurement points are taken on the square by moving the imaging probe CMM in the +Z direction. The first measurement point is the zero, or reference, point. The zero point is shown in Figure 2.

It is recommended that the zero point be consistent with the calibration of the square.

For each of the five measurement locations, a single measurement result on the calibrated surface of the square is then obtained by moving in the +Z direction. In the first position of the square, parallel to the ZX plane, the readings will be in the X direction.

The calibrated square is then placed in the second measurement position, parallel to the YZ plane. The external indicator set-up and alignment, as required, is repeated, and the measurement of the zero point and the five measurement points on the square are completed. The readings will be in the Y direction.

6.3.5 Derivation of test results

For all 10 measurements, the difference between each measurement result and the corresponding measurement result for the zero point of the square is calculated. These differences are the indicated values of the square. The squareness measurement error, E_{SQ}, is then calculated as the difference between the indicated value for each measurement point and the calibrated value of each measured point on the square. (The calibrated value is taken as the conventional true value of the measured point on the square.)

If the measured zero point does not correspond to the zero point indicated on the calibration certificate of the square, then appropriate corrections to the calibrated values of the square should be done.

The indicated value of a particular measurement of the calibrated square may be corrected by the CMM to account for systematic errors, or thermally induced errors (including thermal expansion) if the CMM has accessory devices for this purpose. Manual correction of the results obtained from the computer output to account for temperature or other corrections shall not be allowed when the environmental conditions satisfy the conditions of 5.1.

Plot all the errors of indication on a diagram, as indicated on the figure (Figure 12, Figure 13 or Figure 14 of ISO 10360-1:2000) that matches the expressed form of the MPE.

6.4 Repeatability range of the length measurement error, R_B or R_U

For each set of three repeated measurements in 6.2.3, calculate the corresponding repeatability range, R_B or R_U, by evaluating the range of the three repeated length measurements.

Plot all the repeatability range values on a diagram, as indicated on the figure (Figure 12, Figure 13 or Figure 14 of ISO 10360-1:2000) that matches the expressed form of the maximum permissible limit (MPL).

6.5 Probing performance (P_{F2D})

6.5.1 Principle

The principle of the assessment method for the probing error is to establish whether the CMM is capable of measuring within the stated maximum permissible probing error, $P_{F2D,\ MPE}$, by determining the range of distances of the measured points from the centre of the Gaussian associated circle.

6.5.2 Measuring equipment

The test circle shall have a nominal diameter at least 150 % of the smallest axis of the field of view but no greater than 51 mm.

The form of the test circle shall be calibrated, since form deviation influences the test result, and shall be taken into account when proving conformance or non-conformance with the specification.

6.5.3 Procedure

6.5.3.1 The user is free to choose the imaging probing system configuration and location of the mounting of the test circle within the specified limits.

6.5.3.2 Set up and qualify the probing system in accordance with the manufacturer's normal procedures.

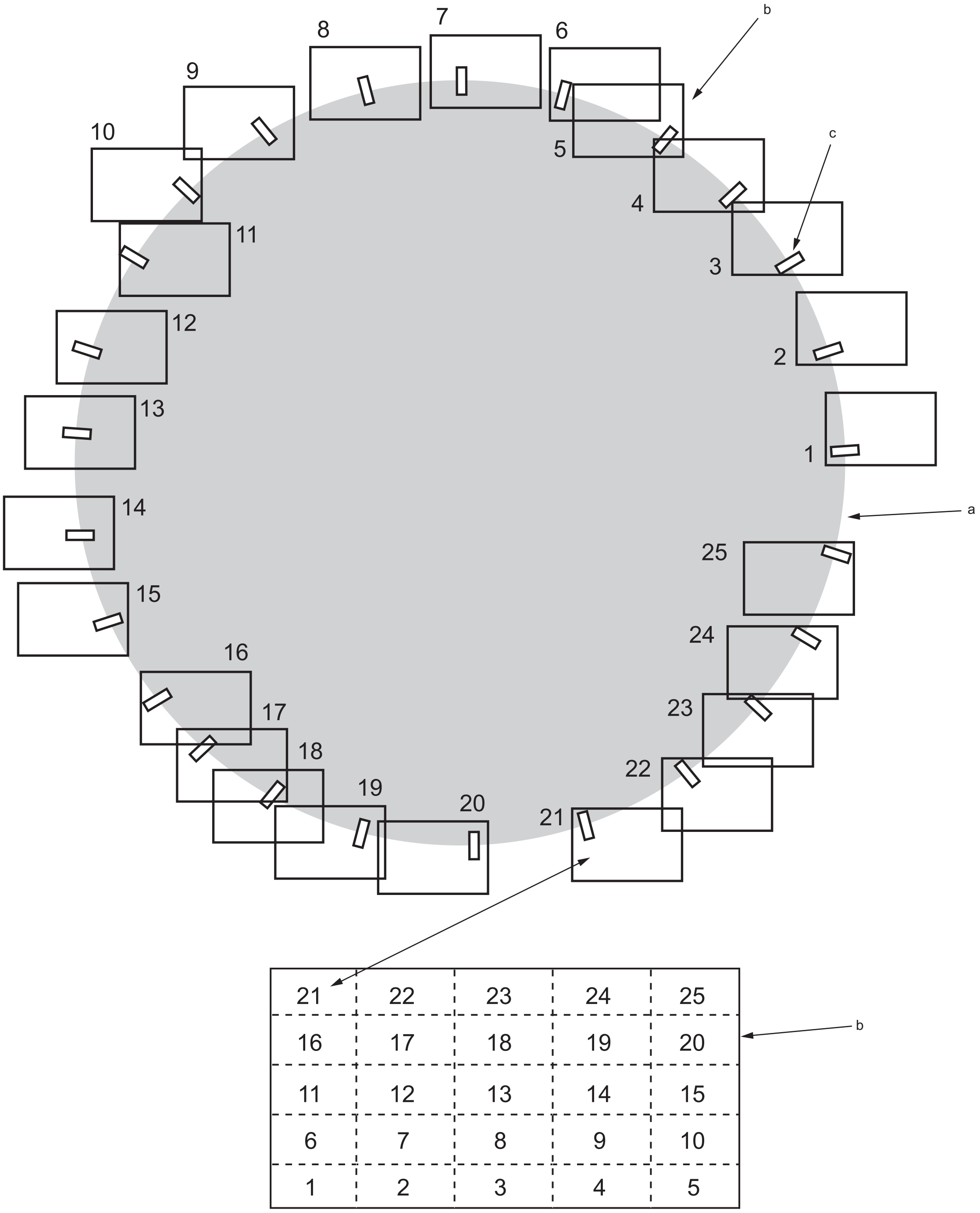
6.5.3.3 Position the test circle to be nominally parallel to the focal plane of the imaging probe.

6.5.3.4 Measure and record 25 points. The points shall be approximately evenly distributed around the full circle (approximately every 14,4 degrees). Each point shall be taken with a single measuring window. The position of the points shall be at the discretion of the user, taking into account the following.

- The CMM shall move between all measured points for 25 different fields of view.
- Some overlap between fields of view is allowed, however, the measuring windows in the field of view shall not overlap.
- The 25 measuring windows shall be distributed across the entire field of view.
- Focusing between points is allowed.

Figure 3 shows one allowable pattern; this pattern is one of many possibilities that would meet the requirements of this clause and should not be considered a default nor required pattern.

NOTE In Figure 3, the relationship between the position of the field of view on the test circle and the position of the test window in the field of view is highlighted for point 21 (of the required 25 points).



a Test circle.

b Field of view.

c Measuring window.

Figure 3 — One allowable pattern and possible distribution of the 25 measurement points across the entire field of view for measuring P_{F2D} that meets the requirements of 6.5.3.4

6.5.4 Derivation of test results

Using all 25 measurements, compute the Gaussian associated circle. For each of the 25 measurements, calculate the Gaussian radial distance R.

Calculate the probing error, P_{F2D}, as the range of the 25 Gaussian radial distances, $R_{\mathrm{max}} - R_{\mathrm{min}}$.

6.6 Probing error of the imaging probe, P_{FV2D}

6.6.1 Principle

The principle of the assessment method for the probing error is to establish whether the CMM is capable of measuring within the stated maximum permissible probing error, $P_{\mathrm{FV2D,\ MPE}}$, by determining the range of distances of the measured points from the centre of the Gaussian associated circle.

6.6.2 Measuring equipment

The test circle shall have a nominal diameter between 10 % to 30 % of the smallest axis of the field of view.

The form of the test circle shall be calibrated, since form deviation influences the test result, and shall be taken into account when proving conformance or non-conformance with the specification.

6.6.3 Procedure

6.6.3.1 The user is free to choose the imaging probing system configuration and location of the mounting of the test circle within the specified limits.

6.6.3.2 Set up and qualify the probing system in accordance with the manufacturer's normal procedures.

6.6.3.3 Position the test circle to be nominally parallel to the focal plane of the imaging probe.

6.6.3.4 Measure and record 25 points. The points shall be approximately evenly distributed around the full circle (approximately every 14,4 degrees). The position of the points shall be at the discretion of the user, taking into account the following.

— The position of the test circle, within the image of the imaging probing system, is at the discretion of the user. Figure 4 shows one optional position. Only one position shall be chosen for the test. The position of the test circle in Figure 4 is one of many possibilities that would meet the requirements of this clause and should not be considered a default nor required position.

— The measuring windows in the field of view shall not overlap.

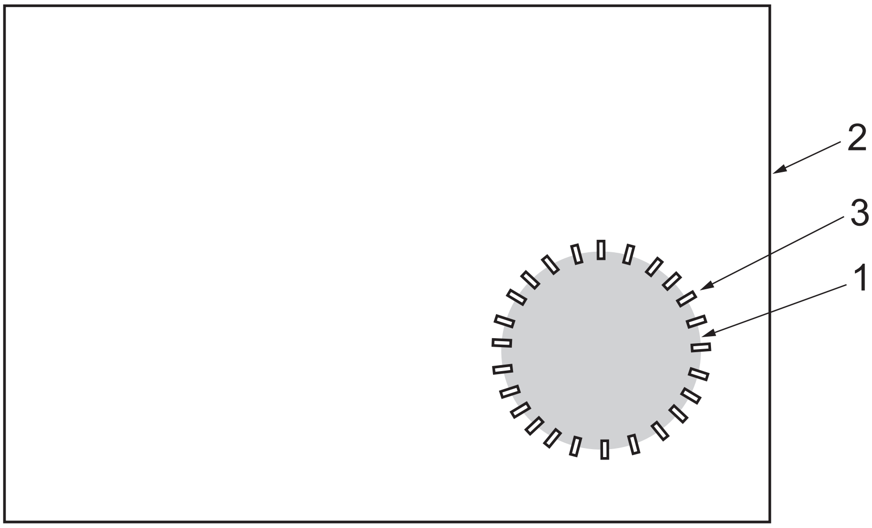
— 25 different measuring windows shall be used.

— The CMM shall not be moved between measurements points.

6.6.4 Derivation of test results

Using all 25 measurements, compute the Gaussian associated circle. For each of the 25 measurements, calculate the Gaussian radial distance R.

Calculate the probing error, P_{FV2D}, as the range of the 25 Gaussian radial distances, $R_{\mathrm{max}} - R_{\mathrm{min}}$.



Key

1 test circle

2 field of view

3 measuring windows

Figure 4 — Allowable position of the test circle within the field of view that meets the requirements of 6.6.3.4

7 Compliance with specifications

7.1 Acceptance test

7.1.1 Acceptance criteria

The performance of the CMM equipped with imaging probes is verified if

— the length measurement errors (E_B or E_U values) are within the respective maximum permissible error of length measurement, $E_{B,\ MPE}$ or $E_{U,\ MPE}$, as specified by the manufacturer when plotted on the appropriate diagram as indicated on Figure 12, Figure 13 or Figure 14 of ISO 10360-1:2000, and taking into account the uncertainty according to ISO 14253-1 and ISO/TS 23165,

and

— the corresponding repeatability range (R_B or R_U values) are within the respective maximum permissible limits of the repeatability range, $R_{B,\ MPL}$ or $R_{U,\ MPL}$, as specified by the manufacturer when plotted on the appropriate diagram as indicated on Figure 12, Figure 13 or Figure 14 of ISO 10360-1:2000, and taking into account the uncertainty according to ISO 14253-1 and ISO/TS 23165,

and

— the probing error (P_{F2D} values) are within the maximum permissible error of the probing error, $P_{F2D,\ MPE}$, as specified by the manufacturer when plotted on the appropriate diagram as indicated on Figure 12, Figure 13 or Figure 14 of ISO 10360-1:2000, and taking into account the uncertainty according to ISO 14253-1 and ISO/TS 23165, and, where specified,

— the probing error of the imaging probe (P_{FV2D} values) and the imaging probe length measurement error (E_{BV} or E_{UV} values) are within the respective maximum permissible errors as specified by the manufacturer when plotted on the appropriate diagram as indicated on Figure 12, Figure 13 or Figure 14 of ISO 10360-1:2000, and taking into account the uncertainty according to ISO 14253-1 and ISO/TS 23165.

The performance of the CMM equipped with imaging probes is also verified if:

— the XY length measurement errors (E_{BXY} or E_{UXY} values) are within the respective maximum permissible errors of length measurement, $E_{BXY,\ MPE}$ or $E_{UXY,\ MPE}$, as specified by the manufacturer when plotted on the appropriate diagram, as indicated on Figure 12, Figure 13 or Figure 14 of ISO 10360-1:2000, and taking into account the uncertainty according to ISO 14253-1 and ISO/TS 23165,

and, where relevant,

— the Z length measurement errors (E_{BZ} or E_{UZ} values) are within the respective maximum permissible errors of length measurement, $E_{BZ,\ MPE}$ or $E_{UZ,\ MPE}$, as specified by the manufacturer when plotted on the appropriate diagram as indicated on Figure 12, Figure 13 or Figure 14 of ISO 10360-1:2000, and taking into account the uncertainty according to ISO 14253-1 and ISO/TS 23165,

and, where relevant,

— the squareness errors (E_{SQ} values) are within the maximum permissible error of the squareness error, $E_{SQ,\ MPE}$, as specified by the manufacturer when plotted on the appropriate diagram as indicated on Figure 12, Figure 13 or Figure 14 of ISO 10360-1:2000, and taking into account the uncertainty according to ISO 14253-1 and ISO/TS 23165,

and

— the probing errors (P_{F2D} values) are within the maximum permissible error of the probing error, $P_{F2D,\ MPE}$, as specified by the manufacturer when plotted on the appropriate diagram as indicated on Figure 12, Figure 13 or Figure 14 of ISO 10360-1:2000, and taking into account the uncertainty according to ISO 14253-1 and ISO/TS 23165,

and, where specified,

— the probing error of the imaging probe (P_{FV2D} values) and the imaging probe length measurement error (E_{BV} or E_{UV} values) are within the respective maximum permissible errors as specified by the manufacturer when plotted on the appropriate diagram as indicated on Figure 12, Figure 13 or Figure 14 of ISO 10360-1:2000, and taking into account the uncertainty according to ISO 14253-1 and ISO/TS 23165.

For imaging probe CMMs with limited two- and three-dimensional measuring capability, the manufacturer's specifications may not include $E_{B,\ MPE}$, $E_{U,\ MPE}$, $E_{BZ,\ MPE}$, $E_{UZ,\ MPE}$ or $E_{SQ,\ MPE}$. In these cases, the verification of the imaging probe CMM does not require these tests (see 5.3.2).

7.1.2 Data rejection and repeated measurements

7.1.2.1 Length measurement errors

For E_B or E_U, a maximum of five of the 35 sets (or 36 sets if 6.2.3.3 is required) of three repeated measurements in accordance with 6.2.3 may have one (and no more than one) of the three values of the length measurement error outside the conformance zone.

For E_{BZ} or E_{UZ}, a maximum of one of the five sets of three repeated measurements in accordance with 6.2.4 may have one (and no more than one) of the three values of the length measurement error outside the conformance zone.

For E_{BXY} or E_{UXY}, a maximum of three of the 20 sets (or 21 sets if 6.2.5.3 is required) of three repeated measurements in accordance with 6.2.5 may have one (and no more than one) of the three values of the length measurement error outside the conformance zone.

For E_{BV} or E_{UV}, a maximum of three of the 20 sets of three repeated measurements in accordance with 6.2.6 may have one (and no more than one) of the three values of the length measurement error outside the conformance zone.

Each such measurement that is outside the conformance zone (according to ISO 14253-1) shall be re-measured three times at the relevant position.

If all the values of the errors of indication of a calibrated test length from the three repeated measurements are within the conformance zone (see ISO 14253-1), then the performance of the CMM is verified at that position.

7.1.2.2 Repeatability range of the length measurement error, R_B or R_U

For E_B or E_U, if a calibrated test length is re-measured according to 7.1.2.1, then the range of the three repeated measurements shall be used to determine the corresponding R_B or R_U at that position, and the three original measurements shall be discarded.

No additional repeated measurements (beyond that allowed by 7.1.2.1) shall be performed.

7.2 Reverification test

The performance of the CMM used for measuring linear dimensions is considered to have been reverified if all relevant test results, described in 6.2, 6.3, 6.4, 6.5 and 6.6, are not greater than the corresponding maximum permissible errors and maximum permissible limits, as determined in 7.1.

8 Applications

8.1 Acceptance test

In a contractual situation between a manufacturer and a user such as that described in a

— purchasing contract,

— maintenance contract,

— repair contract,

— renovation contract, or

— upgrading contract,

the acceptance test specified in this part of ISO 10360 may be used as a test for verifying the performance of the CMM equipped with imaging probes in accordance with the specification for the stated maximum permissible errors and maximum permissible limits as agreed upon by the manufacturer and the user.

The manufacturer is permitted to specify detailed limitations applicable to the stated maximum permissible errors and maximum permissible limits. If no such specification is given, the stated maximum permissible errors and maximum permissible limits apply for any location and orientation in the measuring volume of the CMM.

8.2 Reverification test

In an organization's internal quality assurance system, the performance verification described in this part of ISO 10360 can be used as a reverification test to verify the performance of the CMM used for measuring linear dimensions in accordance with the specification for the maximum permissible errors and maximum permissible limits as stated by the user. The user is permitted to state the values of, and to specify detailed limitation applicable to maximum permissible errors and maximum permissible limits.

NOTE 1 As the tester accounts for the test uncertainty according to the decision rules in ISO 14253-1, a reverification test (where, typically, the tester is the user) may have a different conformance zone than an acceptance test.

NOTE 2 In acceptance testing, the conformance zone is derived from the manufacturer's specifications. In reverification testing, the reverification limits may be derived from the user's metrological needs.

8.3 Interim check

In an organization's internal quality assurance system, a reduced performance verification may be used periodically to demonstrate the probability that the CMM conforms with specified requirements regarding the maximum permissible errors and maximum permissible limits. The extent of the performance verification as described in this part of ISO 10360 may be reduced by using fewer measurements and positions (see Annex A).

NOTE This part of ISO 10360 is primarily concerned with acceptance and reverification testing. Interim testing is often associated with quality assurance. See the ISO/TS 15530 series of documents for further discussion of the role of measurement uncertainty associated with CMM measurements.

9 Indication in product documentation and data sheets

The symbols of Clause 4 are not suitable for use in product documentation, drawings, data sheets, etc. Table 3 gives the corresponding indications which are allowed for that purpose.

Table 3 — Symbols and corresponding indication in product documentation, drawings, data sheets, etc.

Symbol used in this part of ISO 10360	Corresponding indication
E_{B}	*EB*
R_{B}	*RB*
E_{U}	*EU*
R_{U}	*RU*
E_{BZ}	*EBZ*
E_{UZ}	*EUZ*
E_{BXY}	*EBXY*
E_{UXY}	*EUXY*
E_{BX}	*EBX*
E_{UX}	*EUX*
E_{BY}	*EBY*
E_{UY}	*EUY*
E_{SQ}	*ESQ*
E_{BV}	*EBV*
E_{UV}	*EUV*
P_{F2D}	*PF2D*
P_{FV2D}	*PFV2D*
$E_{\mathrm{B,\ MPE}}$	MPE (*EB*)
$R_{\mathrm{B,\ MPL}}$	MPL (*RB*)
$E_{\mathrm{U,\ MPE}}$	MPE (*EU*)
$R_{\mathrm{U,\ MPL}}$	MPL (*RU*)
$E_{\mathrm{BZ,\ MPE}}$	MPE (*EBZ*)
$E_{\mathrm{UZ,\ MPE}}$	MPE (*EUZ*)
$E_{\mathrm{BXY,\ MPE}}$	MPE (*EBXY*)
$E_{\mathrm{UXY,\ MPE}}$	MPE (*EUXY*)
$E_{\mathrm{BX,\ MPE}}$	MPE (*EBX*)
$E_{\mathrm{UX,\ MPE}}$	MPE (*EUX*)
$E_{\mathrm{BY,\ MPE}}$	MPE (*EBY*)
$E_{\mathrm{UY,\ MPE}}$	MPE (*EUY*)
$E_{\mathrm{SQ,\ MPE}}$	MPE (*ESQ*)
$E_{\mathrm{BV,\ MPE}}$	MPE (*EBV*)
$E_{\mathrm{UV,\ MPE}}$	MPE (*EUV*)
$P_{\mathrm{F2D,\ MPE}}$	MPE (*PF2D*)
$P_{\mathrm{FV2D,\ MPE}}$	MPE (*PFV2D*)

Annex A
(informative)

Interim check

A.1 Interim check of the CMM

It is strongly recommended that the CMM be checked regularly during the periods between periodic reverification. The interval between checks should be determined from the environmental conditions and the measuring performance required. The CMM should be checked immediately after any significant event that can have affected CMM performance.

Artefacts other than those calibrated test lengths that are described in Annex B may also be used in the interim test. The measurements should be made directly after the performance verification test; the positions and orientations of the artefacts should be noted and subsequently repeated.

Depending on the measurement tasks for which the CMM is used, the most relevant of the following commonly used artefacts should be chosen; some examples are given below:

- a purpose-made test piece that has features representing typical geometrical shapes, is dimensionally stable, mechanically robust, and which has a surface finish that does not significantly affect the uncertainty of measurement;
- a ball plate;
- a grid plate;
- a ball bar;
- a line scale;
- a circular artefact (e.g. a ring gauge).

It is strongly recommended that the artefact material have a CTE similar to typical workpieces measured with the CMM. The method involving the mathematical adjustment to low CTE artefacts described in Annex D may be used in interim testing; however, it is crucial that the temperature of the low CTE artefact used for the adjustment be measured with an independent thermometer that is not part of the CMM.

A.2 Interim testing and the comparison to specifications

In some cases, it may be desirable to perform an interim test such that the results can be compared to the manufacturer's specifications. In this case, a calibrated test length, as described in Annex B, should be used and the measurement procedures described in this part of ISO 10360 followed.

In order to minimize the time to perform the interim test an abbreviated test procedure should focus on those test positions that most commonly reveal a problem with the CMM. For example, the measurement of a single long test length in each of the body diagonals will generally more readily reveal CMM errors than the measurements of five test lengths along a CMM axis.

Each of the errors of indication from the interim test should be less than the corresponding specification, e.g. $E_{B,\ MPE}$, provided the test is conducted according to the procedures of this part of ISO 10360 and the environmental conditions are within those stated by the manufacturer.

Annex B
(normative)

Artefacts that represent a calibrated test length

B.1 General

For reasons of economy, availability and practicality, it is the intent of this part of ISO 10360 to allow several types of artefacts to be used in testing a CMM provided they are appropriately adjusted (as described in this annex) to yield the same measurand, a calibrated test length.

A calibrated test length, as measured by the procedures of this part of ISO 10360, is designed to detect three categories of CMM errors:

a) geometrical and thermal errors associated with the CMM between the two endpoints of the test length;

b) errors associated with the imaging probing system;

c) repeatability problems as evaluated, in effect, by a single probing point on each end of the calibrated test length.

B.2, B.3 and B.4 describe common artefacts that may be used as a calibrated test length.

In some cases, these artefacts may not be available or sufficiently long, particularly when testing very large CMMs. In this case, both parties may agree to use other means to generate a calibrated test length. These might include length standards that are "stitched" together (i.e. overlapped end-to-end) to form a longer artefact, or other types of laser-based lengths, e.g. produced by multilateration. In the latter case, issues associated with the absence of contact probing shall be accounted for (see B.3 and B.4). In all such cases, the procedure shall be documented and the uncertainties associated with these techniques shall be considered carefully.

A laser interferometer that is corrected for the index of refraction of air has a zero CTE ($\alpha = 0$). Hence, if it is used to produce a calibrated test length, it is considered a low CTE material and is subject to the requirements of 6.2.3.3 or 6.2.5.3. Additionally, if the laser has a workpiece (material) temperature sensor, then the workpiece CTE in the laser's software shall be set to 0. If a laser is used on a temperature-compensated CMM, then the workpiece CTE in the CMM's software shall be set to 0.

When a laser interferometer is used to produce a calibrated test length, the CMM shall be positioned at a point described by nominal coordinates, without probing a surface. In this case, some CMMs may not arrive at the nominal position exactly. This does not necessarily result in an error of indication as long as the CMM reports the actual position. Consequently, for each test length, the spatial distance between the reported CMM coordinates of points A and B shall be evaluated and compared with the distance indicated by the laser interferometer. It has to be ensured that the CMM coordinates used for the calculation of the error include all compensations that would be considered during the probing process.

Some artefacts such as step gauges, line scales, multi-ball ball bars, ball plates, and laser interferometry can produce multiple lengths relative to a "reference zero". For example, a step gauge can measure lengths "A" to "B", "A" to "C", etc., or an interferometer can measure the displacement from an initial position to a series of subsequent positions (each of different length). In order to provide equivalency to gauge blocks, the reference position, i.e. the "zero", shall be re-measured each time a calibrated test length is produced. That is, the "A" to "B" length and the "A" to "C" length must each have its own "A" measured anew. Similarly, with interferometry, the initial position shall be re-measured for each displacement used to produce a calibrated test length.

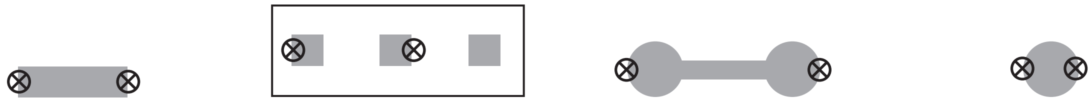
B.2 Bidirectional measurements

B.2.1 General

The measurement of a bidirectional test length involves probing a single point on each diametrically opposing end of an appropriate calibrated bidirectional gauge, and these probing points shall be approached from any direction allowed under normal operation of the CMM; see Figure B.1. Internal and external bidirectional test lengths shall not be mixed on a measurement line. Several possible bidirectional measurement methods are described below.

NOTE 1 The probing approach direction can influence the results of this test.

NOTE 2 It is advisable that each probing point be located at the calibrated gauging points of the artefact.



a) Gauge block or linewidth **b) Step gauge or linescale** **c) Ball bar (endpoint-to-endpoint measurement)** **d) Circle artefact**

Key

⊗ probing point

Figure B.1 — Examples of bidirectional test lengths, each probed with a single point on opposing ends of the gauge

B.2.2 Gauge blocks and linewidths (measured in a bidirectional manner)

A calibrated bidirectional test length may be produced using a calibrated gauge block or linewidth measured with a single-point-to-single-point method.

B.2.3 Step gauges or linescales (measured in a bidirectional manner)

A calibrated bidirectional test length may be produced using a calibrated step gauge or linescale measured with a single-point-to-single-point bidirectional method.

B.2.4 Ball bars/ball plates/multi-circle artefacts (measured in a bidirectional manner)

A calibrated bidirectional test length may be produced using a ball bar/ball plate or multi-circle artefact (sometimes called dot plates or dot grids) where the length is equal to the calibrated sphere/circle centre-to-centre length plus one half the calibrated diameter of each sphere/circle. The gauge is measured in a single-point-to-single-point, bidirectional manner.

B.2.5 Circle/sphere artefacts (measured in a bidirectional manner)

A calibrated bidirectional test length may be produced using a single sphere or circle artefact where the length is equal to the calibrated diameter of the sphere or circle. The gauge is measured in a single-point-to-single-point, bidirectional manner.

B.3 Unidirectional measurements

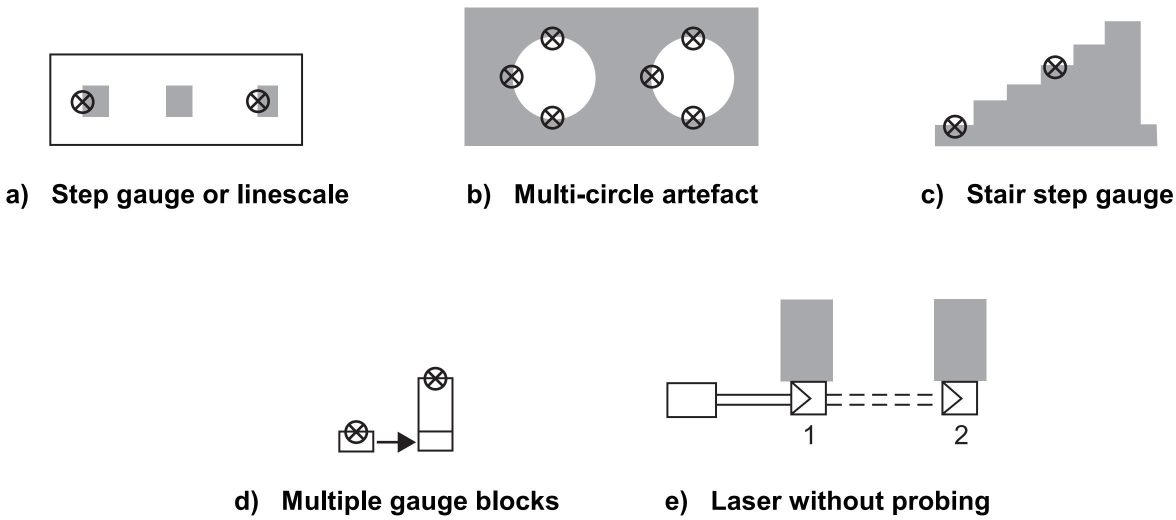
B.3.1 General

For the purposes of this part of ISO 10360, unidirectional test lengths are any test lengths that are not bidirectional. They include step gauges measured in a unidirectional manner, centre-to-centre distances of ball plates and ball bars, and some methods of laser interferometry (see Figure B.2). Several possible unidirectional measurement methods are described below.

When using imaging probe CMMs, the probing direction is usually independent of the surface being probed. For the purposes of this part of ISO 10360, the probing points shall be approached from any direction allowed under normal operation of the CMM.

NOTE 1 The probing approach direction can influence the results of this test.

NOTE 2 It is advisable that each probing point be located at the calibrated gauging points of the artefact.



Key

⊗ probing point

Figure B.2 — Examples of unidirectional measurements

B.3.2 Step gauges or linescales (measured in a unidirectional manner)

A calibrated unidirectional test length may be produced using a calibrated step gauge or linescale measured with a single-point-to-single-point unidirectional method.

B.3.3 Circle plates/dot plates (measured as the unidirectional distance between centres)

A calibrated unidirectional test length may be produced using a circle plate artefact where the length is equal to the calibrated circle centre-to-centre length. Each circle is measured using only three single probing points, 90 degrees apart, and such that only a single point is taken along the measurement line.

B.3.4 Stair step gauge

A calibrated unidirectional test length may be produced using a calibrated stair step gauge with a single-point-to-single-point unidirectional method.

NOTE The stair step gauge can be useful for testing E_{UZ}.

B.3.5 Multiple gauge blocks

A calibrated unidirectional test length may be produced by stacking (or wringing) two or more calibrated gauge blocks and measuring the accessible face of each block with a single point.

NOTE Multiple gauge blocks can be useful for testing E_{UZ}.

B.3.6 Laser interferometry without contact probing measured in a unidirectional manner

In some cases (particularly large CMMs) it may be convenient to replace the probing system with a retroreflector and to measure the displacement of the CMM using laser interferometry. Each laser displacement measurement is considered a unidirectional measurement.

For some CMMs tested with laser interferometry used without probing, the interferometric measurements might not appropriately implement the CMM compensation for geometrical errors. Consequently, this will yield an error of indication much larger than would be the case with probing. In such cases, a calibrated test length involving probing should be employed and an external trigger activating the error compensation may alleviate the problem.

B.4 Equivalent bidirectional measurements using unidirectional test lengths

B.4.1 General

For the purposes of this part of ISO 10360, the measurement of unidirectional test lengths can be combined with the measurement of bidirectional test lengths in order to produce test lengths equivalent to calibrated bidirectional test lengths. An equivalent calibrated bidirectional test length can be produced using the arithmetic sum of a calibrated unidirectional length and a calibrated bidirectional length.

NOTE 1 The procedure for measuring the unidirectional test lengths for use in equivalent bidirectional test lengths is different than that described in B.3. This is required for the test results to be equivalent to that of the point-to-point bidirectional test lengths.

NOTE 2 This procedure allows for more flexibility in testing, as unidirectional artefacts can be used for much of the bidirectional testing, if desired.

B.4.2 Short bidirectional test length

A single, short, calibrated bidirectional test length is required. The maximum default length of the bidirectional test length is 10 % of the maximum travel of either the X- or Y-axes. The minimum default length of the bidirectional test length is 10 % of the field of view of the imaging probing system. Details for specific types of bidirectional test lengths are described in B.2.

B.4.3 Unidirectional test length

B.4.3.1 General

Any type of unidirectional test length is allowed, such as those shown in Figure B.2, however, the unidirectional test length is not measured as defined in B.3. When doing bidirectional equivalency measurements using both unidirectional and bidirectional test lengths, there is no requirement for the unidirectional test lengths to be measured using single probing points; instead, the unidirectional test lengths shall be measured as described below.

B.4.3.2 Step gauges or linescales

A unidirectional measurement of a calibrated step gauge or linescale may be produced by measuring each gauging surface with three discrete probing points (at the same target point) and the coordinates averaged. The length is determined using the averaged coordinates.

B.4.3.3 Circle plates

A unidirectional measurement of an artefact with circular features, such as a circle plate artefact, consists of each circle measured with four probing points 90 degrees apart and the (least squares fit) centre-to-centre length determined.

B.4.3.4 Stair step gauge

A unidirectional measurement of a calibrated stair step gauge may be produced by measuring each gauging surface with three probing points (at the same target point) and the coordinates averaged. The length is determined using the averaged coordinates.

NOTE The stair step gauge can be useful for testing E_{UZ}.

B.4.3.5 Multiple gauge blocks

A calibrated unidirectional test length may be produced by stacking (or wringing) two or more calibrated gauge blocks and measuring the accessible face of each block with three probing points (at the same target point) and the coordinates averaged. The length is determined using the averaged coordinates.

NOTE Multiple gauge blocks can be useful for testing E_{UZ}.

B.4.3.6 Laser interferometry without contact probing measured in a unidirectional manner

In some cases (particularly large CMMs), it may be convenient to replace the probing system with a retroreflector and to measure the displacement of the CMM using laser interferometry. Each laser displacement measurement is considered a unidirectional measurement.

For some CMMs tested with laser interferometry used without probing, the interferometric measurements might not appropriately implement the CMM compensation for geometrical errors. Consequently, this will yield an error of indication much larger than would be the case with probing. In such cases, a calibrated test length involving probing should be employed and an external trigger activating the error compensation may alleviate the problem.

B.4.4 Measurement procedure

For each measurement line under testing, measure a short bidirectional test length in the manner described in B.4.2. The short bidirectional test length shall be oriented along the measurement line. The location of the short bidirectional test length shall be as close as possible to the measurement line under testing; however, for ease of fixturing, the short bidirectional test length may be located near the CMM table surface.

For example, if a body diagonal of the CMM is the measurement line under testing, then the short bidirectional test length shall be oriented along the direction of the body diagonal, but may be located “beneath” the diagonal and fixtured near the table surface.

The short bidirectional test length shall be measured a total of three times and the errors of indication recorded in their chronological order.

For each of the five lengths (per measurement line), measure a calibrated unidirectional test length three times and record the errors of indication in chronological order; details for specific types of unidirectional test lengths are described in B.4.3.

NOTE The test results are affected by the position of the short bidirectional test length, e.g. locating the short bidirectional test length near the CMM table may alter the test performance due to the CMM behaviour when the ram is fully extended. The intended representation of the CMM performance is approximated by locating the short bidirectional test length in the middle of the measuring line. However, this may cause fixturing problems. It is up to the tester to choose the best compromise.

B.4.5 Derivation of test results

To each of the three unidirectional errors of indication, add (in the usual arithmetical manner) the chronologically corresponding bidirectional errors of indication to create the errors of indication of the equivalent bidirectional test lengths. Repeat for all five lengths per measurement line; this involves a total of 15 unidirectional measurements and three short bidirectional test length measurements per measurement line.

Annex C
(informative)

Alternative method for checking the squareness error

C.1 General

The test method for the squareness error, $E_{SQ,\ MPE}$, normally involves the use of a calibrated square and an external indicator, as described in 6.3. This procedure is not always practical or suitable. This annex presents an alternative method that may be desirable for the manufacturer or user to consider. It may be used in place of the test for $E_{SQ,\ MPE}$ with mutual agreement between the two parties.

C.2 Measuring equipment

A calibrated test length is used in accordance with 6.2.

C.3 Measuring positions

The test length is rigidly mounted on a fixture that supports the test length at a defined angle relative to the worktable of the CMM. See Figure C.1.

NOTE The worktable is often a glass plate and is approximately parallel to the imaging probe focal plane (XY plane).

The length of the test length and the angle of inclination relative to the worktable shall be such that the test length covers at least 66 % of the entire measurable range parallel to the optical axis, the Z-axis. See Figure C.1.

C.4 Measuring procedure

An alignment shall be created such that all measurements of the test length are projected into a plane that is nominally parallel to the XY plane; see Figure C.1. The alignment is carried out according to the manufacturer's recommended procedure.

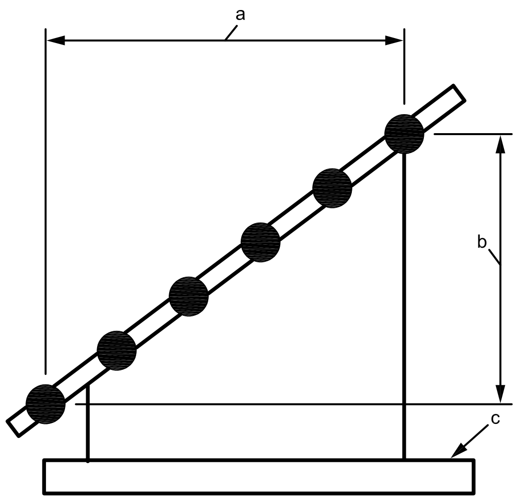
The alignment procedure may involve measuring a reference plane on the fixture that holds the test length and either mechanically, or in software, establishing this plane for alignment purposes. The angle between this reference plane and the test length should not change when the fixture and test length is moved to different measuring positions.

Five lengths are measured three times each on the test length. These lengths are measured as projections into the alignment plane.

This measurement procedure is carried out in four positions of the test length, with the test length and support being rotated approximately 90° in the plane of the worktable. In each position, the same five projected lengths shall be measured.

C.5 Derivation of test results

For each of the five test lengths, the squareness error, E_{SQ}, is calculated by taking one-half of the difference between the maximum and minimum of the four measured projected lengths. Plot all the squareness errors (values of E_{SQ}) on a diagram, as indicated on the figure (Figure 12, Figure 13 or Figure 14 of ISO 10360-1:2000) that matches the expressed form of $E_{SQ, MPE}$.



[a] Projected test length.

[b] Minimum 66 % of Z-axis travel.

[c] Reference plane.

Figure C.1 — Example of a test length mounted at a defined angle relative to the worktable of the CMM using an alignment such that all measurements of the test length are projected into a plane that is nominally parallel to the XY plane

Annex D
(normative)

Mathematical adjustments to low CTE artefacts

D.1 General

In some situations, a mathematical adjustment to account for thermal expansion facilitates CMM testing.

Consider a large CMM that is made of steel, used to measure steel parts, and does not have any method to account for workpiece thermal expansion. Such a large CMM requires a long calibrated test length and, hence, thermal equilibrium of the test length is important for normal CTE artefacts. To reduce the effect of non-equilibrium thermal conditions, a low CTE test length may be used.

However, a low CTE test length will have a large uncorrected thermal expansion difference between the test length and the (normal CTE) CMM. Hence, large length measurement errors, e.g. the E_0 values, will be observed that are not characteristic of errors when measuring steel workpieces. Consequently, it may be advantageous to perform a mathematical adjustment to the calibrated length of the low CTE artefact, making it appear to the CMM as if it were steel.

Implementing such an adjustment requires the low CTE test length to have its temperature measured once at the beginning of each test using a calibrated thermometer. This temperature is used to calculate a “synthetic length” equivalent to a steel gauge with an exactly known CTE, $\alpha = 11{,}5 \times 10^{-6}$/°C. The effect of this adjustment is to change the calibration of the low CTE test length such that it corresponds to a synthetic length, with a CTE of $11{,}5 \times 10^{-6}$/°C, at the measured temperature. In the example given above, the advantage of this procedure is that the steel CMM will be measuring a “synthetic steel” test length and hence not suffer the uncorrected thermal expansion error.

NOTE The mathematical adjustment to the low CTE artefact is performed by the tester according to the requirements of D.2. This adjustment is equivalent to a recalibration of the artefact and does not violate the prohibition of manual corrections of CMM measurement results described in 6.2.3.4, 6.2.4.3, 6.2.5.4, 6.2.6.3, and 6.3.5.

D.2 Requirements

When implementing the mathematical adjustment procedure for acceptance or reverification testing, several issues shall be observed:

- the mathematical adjustment is only permitted on CMMs that do not have the capability for workpiece thermal expansion compensation;
- the mathematical adjustment is only permitted on artefacts with a CTE of 2×10^{-6}/°C or less;
- the actual CTE of the artefact shall be stated on its calibration certificate prior to any measurements performed on the CMM;
- the mathematical adjustment will be to a CTE of $11{,}5 \times 10^{-6}$/°C exactly, and no other synthetic CTE may be used;
- the mathematical adjustment may be performed only once for each length measurement test, e.g. E_B. In each case, the temperature measurement shall occur before the beginning of each test;
- the low CTE test length shall be measured with a calibrated thermometer and not using any temperature measuring system supplied with the CMM;

- this adjustment is subject to the requirements of a low CTE artefact as described in 6.2.3.3 or 6.2.5.3 and the additional test length described in 6.2.3.3 or 6.2.5.3 shall be implemented;
- the temperature measurement used in the adjustment shall be taken on the steel gauge block described in 6.2.3.3 or 6.2.5.3 that has reached equilibrium with its environment, or on a thermally equivalent piece of steel;
- when employing the mathematical adjustment procedure, both the CTE of the test length and its synthetic CTE shall be stated on the test result page, e.g. "CTE of test length is $0,5 \times 10^{-6}$/°C mathematically adjusted to $11,5 \times 10^{-6}$/°C".

NOTE The effects of thermal gradients in the calibrated test length are greatly suppressed when using a low CTE artefact, but these effects may appear as length measurement errors when using a normal (e.g. steel) artefact.

Annex E
(informative)

Relation to the GPS matrix model

E.1 General

For full details about the GPS matrix model, see ISO/TR 14638.

E.2 Information about this part of ISO 10360 and its use

This part of ISO 10360 specifies the acceptance tests for verifying the performance of an imaging probe CMM as stated by the manufacturer. It also specifies the reverification tests that enable the user to periodically reverify the performance of an imaging probe CMM.

E.3 Position in the GPS matrix model

This part of ISO 10360 is a general GPS standard, which influences chain link 5 of the chains of standards on size, distance, radius, angle, form, orientation, location, run-out and datums in the general GPS matrix, as graphically illustrated in Figure E.1.

Fundamental GPS standards

Global GPS standards

General GPS standards						
Chain link number	**1**	**2**	**3**	**4**	**5**	**6**
Size					X	
Distance					X	
Radius					X	
Angle					X	
Form of line independent of datum					X	
Form of line dependent on datum					X	
Form of surface independent of datum					X	
Form of surface dependent on datum					X	
Orientation					X	
Location					X	
Circular run-out					X	
Total run-out					X	
Datums					X	
Roughness profile						
Waviness profile						
Primary profile						
Surface imperfections						
Edges						

Figure E.1 — Position in the GPS matrix model

E.4 Related standards

The related standards are those of the chains of standards indicated in Figure E.1.

Bibliography

[1] ISO 3650, *Geometrical Product Specifications (GPS) — Length standards — Gauge blocks*

[2] ISO/TR 14638, *Geometrical product specification (GPS) — Masterplan*

[3] ISO/TS 15530 (all parts), *Geometrical Product Specifications (GPS) — Coordinate measuring machines (CMM): Technique for determining the uncertainty of measurement*

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