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Geometrical product specifications (GPS) — Acceptance and reverification tests for coordinate measuring systems (CMS) —

Part 12: Articulated arm coordinate measurement machines (CMM)

Spécification géométrique des produits (GPS) — Essais de réception et de vérification périodique des systèmes de mesure tridimensionnels (SMT) —

Partie 12: Machines à mesurer tridimensionnelles à bras articulés (MMT)

Reference number
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Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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

The committee responsible for this document is 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 systems (CMS)*:

— *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 system*

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

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

— *Part 8: CMMs with optical distance sensors*

— *Part 9: CMMs with multiple probing systems*

— *Part 10: Laser trackers for measuring point-to-point distances*

— *Part 12: Articulated arm coordinate measuring machines (CMM)*

Introduction

This part of ISO 10360 is a general GPS standard (see ISO 14638). For more detailed information about the relation of this part of ISO 10360 to other standards and the GPS matrix model, see Annex I.

This part of ISO 10360 is included in the ISO/GPS Masterplan given in ISO 14638, which gives an overview of the ISO/GPS system. The fundamental rules of ISO/GPS given in ISO 8015 apply to this part of ISO 10360 and the default decision rules given in ISO 14253-1 apply to specifications made in accordance with this part of ISO 10360, unless otherwise indicated.

The objective of this part of ISO 10360 is to provide a well-defined testing procedure to

— enable manufacturers of articulated arm CMMs to provide specification MPEs, and

— enable users to test articulated arm CMMs to manufacturer specifications using calibrated traceable reference artefacts.

The benefits of these tests are that the measured result has a direct traceability to the unit length, the metre, and that they give information on how the articulated arm CMM will perform on similar length measurements.

Geometrical product specifications (GPS) — Acceptance and reverification tests for coordinate measuring systems (CMS) —

Part 12:
Articulated arm coordinate measurement machines (CMM)

1 Scope

This part of ISO 10360 specifies the acceptance tests for verifying the performance of an articulated arm CMM by measuring calibrated test lengths as stated by the manufacturer. It also specifies the reverification tests that enable the user to periodically reverify the performance of the articulated arm CMM. It applies to articulated arm CMMs using tactile probes and optionally optical distance sensors (also referred to as laser line scanners or laser line probes). Details on tests for scanner accessories are given in Annex E.

This part of ISO 10360 does not specify how often or when testing is performed, if at all, nor does it specify which party should bear the cost of testing.

This part of ISO 10360 specifies

— performance requirements that can be assigned by the manufacturer or the user of the articulated arm 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 documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 10360-8:2013, *Geometrical product specifications (GPS) — Acceptance and reverification tests for coordinate measuring systems (CMS) — Part 8: CMMs with optical distance sensors*

ISO 10360-9:2013, *Geometrical product specifications (GPS) — Acceptance and reverification tests for coordinate measuring systems (CMS) — Part 9: CMMs with multiple probing systems*

3 Terms and definitions

For the purposes of this document, the following terms and definitions given in ISO 10360-1 and the following apply.

NOTE The definitions in this section are intended to concisely state the meaning of terms. For metrological characteristics that have numerical values, the complete description of the procedure and derivation of test results in Clause 6 and Annex E are to be followed in determining values.

3.1
articulated arm coordinate measuring machine
system that measures spatial coordinates and comprises

— an open chain of fixed-length segments,

— joint assemblies interconnecting the segments and the probing system and attaching them to the stationary environment, and

— a probing system at the free end of the chain

Note 1 to entry: The probing system may comprise a rigid probe or a sensing system such as a scanner.

Note 2 to entry: Rotary joint assemblies connected to the fixed-length segments are equipped with angular encoders. Cartesian coordinates of each measuring point are calculated from the measured angles and segment lengths.

3.2
joint
connection between adjacent elements of an articulated arm CMM that allows a single rotational degree of freedom between these elements

Note 1 to entry: There are two types of joints: hinge joints, which cause a hinging movement between adjacent arm segments, and swivel joints, which cause a rotary movement around the axis of the connected arm segment.

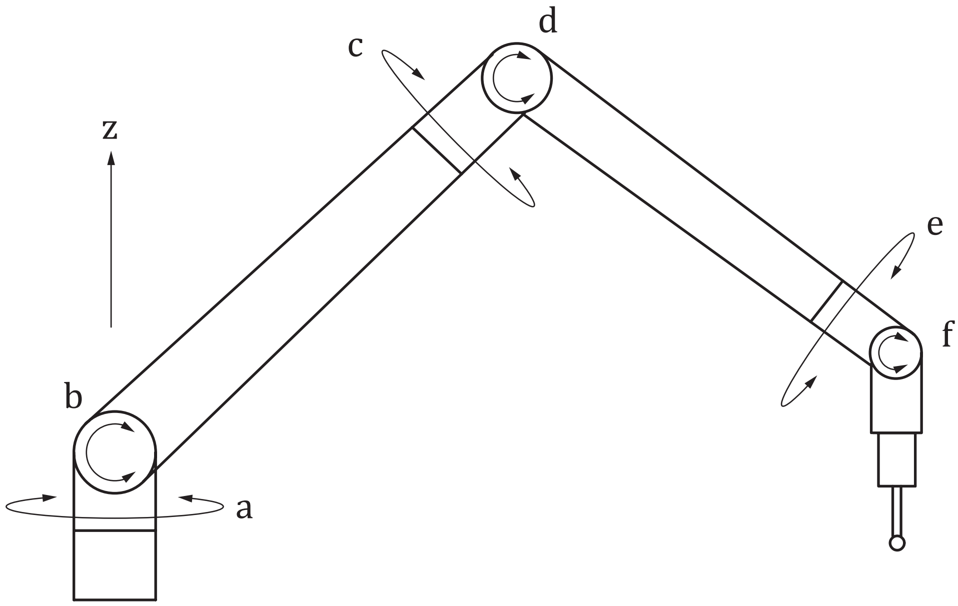
Note 2 to entry: Each joint ordinarily includes an angle measuring device (rotary encoder).

3.3
joint assembly
assembly of two or more joints between two adjacent elements of an articulated arm CMM

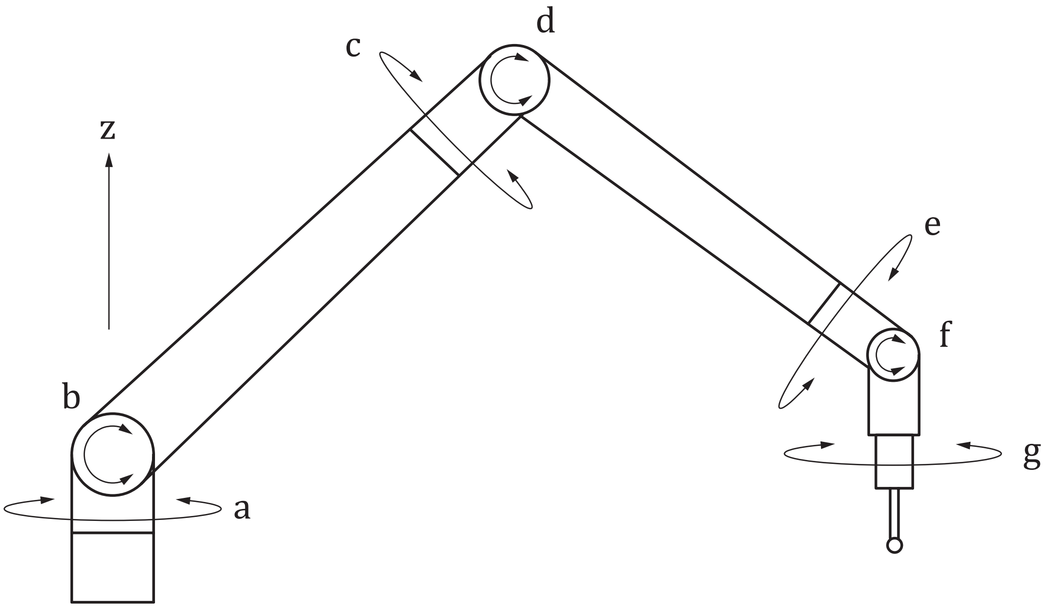
Note 1 to entry: Usually, a joint assembly includes at least a hinge joint and a swivel joint.

Note 2 to entry: In analogy to the human arm, the three main joint assemblies are designated the shoulder, elbow, and wrist.

Note 3 to entry: Current machines have 2 or 3 degrees of freedom each for shoulder (a, b), elbow (c, d), and wrist (e, f, g), as shown in Figure 1. Consequently, articulated arm CMMs are referred to as either six or seven axis machines.



a) With six rotary axes



b) With seven rotary axes

Figure 1 — Articulated arm CMM

3.4
measuring range
diameter of the spherical volume within which an articulated arm CMM is capable of measuring

Note 1 to entry: The measuring range is specified by the manufacturer.

Note 2 to entry: The measuring range is twice the reach of the articulated arm. However, some of the regions that can be reached by the articulated arm may not be within the measuring volume.

3.5
measuring volume
region in space over which the manufacturer specifies the performance of the articulated arm CMM

Note 1 to entry: The measuring volume is restricted by inaccessible zones specified by the manufacturer. For example, there may be an inaccessible zone close to the vertical main axis.

Note 2 to entry: Manufacturers may specify more than one measuring volume for a machine, each measuring volume having a separate performance specification.

Note 3 to entry: Because of the possibility of binding up a joint when adjacent arm segments are brought close together, the size of the measuring volume may depend on the direction of the probe stylus in relation to the outside of the measuring volume or inaccessible zones within the measuring volume. The manufacturer may specify one or more measuring volumes according to the direction of the probe stylus.

3.6
useful arm length
half the measuring range

3.7
coefficient of thermal expansion
CTE
α
linear thermal expansion coefficient of a material at 20 °C

Note 1 to entry: The above definition for CTE does not imply that a user is required to make measurements at 20 °C.

3.8
normal CTE material
material with a CTE between 8 × 10^{-6}/°C and 13 × 10^{-6}/°C

Note 1 to entry: Some documents may express CTE in units 1/K, which is equivalent to 1/°C.

[SOURCE: ISO 10360-2]

3.9
kinematic seat
mechanical seat (nest) that repeatably holds the centre of a spherical surface in a fixed position in space

Note 1 to entry: An example of a kinematic seat is a trihedral seat that includes three hardened spheres, each sphere placed on a circle and separated from the other spheres by nominally 120°. Each of the three spheres contacts the surface of a larger sphere (or spherical surface) so as to permit repeatable positioning of the centre of the larger sphere in space.

Note 2 to entry: As used in this part of ISO 10360, a kinematic seat provides constraint for 3 degrees of freedom rather than 6 degrees of freedom.

3.10
single-point articulation test
test in which articulated arm CMM probe is held within a kinematic seat while the elbow location is rotated by 180°

Note 1 to entry: The single-point articulation test is an interim test described in Annex D.

3.11
articulated location error, tactile
$L_{\mathrm{Dia.5x5:Art:Tact.AArm}}$
diameter of the minimum circumscribed sphere encompassing the points that are the centres of the five spheres obtained from performing the articulated location test when using a tactile probe

Note 1 to entry: In the context of this part of ISO 10360, the local abbreviation $L_{\mathrm{Dia.5x5:Art}}$ is used.

3.12
length measurement error, bidirectional
$E_{\mathrm{Bi:0:Tact.AArm}}$
error of indication when performing a bidirectional point-to-point distance measurement

Note 1 to entry: In the context of this part of ISO 10360, the local abbreviation E_{Bi} is used.

Note 2 to entry: The subscript 0 indicates that there is no tip offset. There may be an offset in some other parts of ISO 10360.

3.13
length measurement error, unidirectional
$E_{\mathrm{Uni:0:Tact.AArm}}$
error of indication when performing a unidirectional point-to-point distance measurement

Note 1 to entry: Annex B discusses unidirectional and bidirectional measurements.

Note 2 to entry: In the context of this part of ISO 10360, the local abbreviation E_{Uni} is used.

3.14
probing form error, tactile
$P_{\mathrm{Form.Sph.1x25::Tact.AArm}}$
error of indication within which the range of Gaussian radial distances can be determined by a Gaussian (least-squares) fit of 25 points measured by a tactile probe on a test sphere

Note 1 to entry: In the context of this part of ISO 10360, the local abbreviation $P_{\mathrm{Form.Sph.1x25}}$ is used.

3.15
probing size error, tactile
$P_{\text{Size.Sph.1x25::Tact.AArm}}$
error of indication of the diameter of a spherical material standard of size as determined by a Gaussian (least-squares) fit of 25 points measured by a tactile probe

Note 1 to entry: In the context of this part of ISO 10360, the local abbreviation $P_{\text{Size.Sph.1x25}}$ is used.

3.16
maximum permissible error of articulated location error, tactile
$L_{\text{Dia.5x5:Art:Tact.AArm,MPE}}$
extreme value of the articulated location error, tactile, $L_{\text{Dia.5x5:Art:Tact.AArm}}$, permitted by specifications

Note 1 to entry: In the context of this part of ISO 10360, the local abbreviation $L_{\text{Dia.5x5:Art,MPE}}$ is used.

3.17
maximum permissible error of bidirectional length measurement
$E_{\text{Bi:0:Tact.AArm,MPE}}$
extreme value of the bidirectional length measurement error, $E_{\text{Bi:0:Tact.AArm}}$, permitted by specifications

Note 1 to entry: In the context of this part of ISO 10360, the local abbreviation $E_{\text{Bi,MPE}}$ is used.

3.18
maximum permissible error of unidirectional length measurement
$E_{\text{Uni:0:Tact.AArm,MPE}}$
extreme value of the unidirectional length measurement error, $E_{\text{Uni:0:Tact.AArm}}$, permitted by specifications

Note 1 to entry: In the context of this part of ISO 10360, the local abbreviation $E_{\text{Uni,MPE}}$ is used.

3.19
maximum permissible error of probing form, tactile
$P_{\text{Form.Sph.1x25::Tact.AArm,MPE}}$
extreme value of the probing form error for tactile probe, $P_{\text{Form.Sph.1x25::Tact.AArm}}$, permitted by specifications

Note 1 to entry: In the context of this part of ISO 10360, the local abbreviation $P_{\text{Form.Sph.1x25,MPE}}$ is used.

3.20
maximum permissible error of probing size, tactile
$P_{\text{Size.Sph.1x25::Tact.AArm,MPE}}$
extreme value of the probing size error for a tactile probe, $P_{\text{Size.Sph.1x25::Tact.AArm}}$, permitted by specifications

Note 1 to entry: In the context of this part of ISO 10360, the local abbreviation $P_{\text{Size.Sph.1x25,MPE}}$ is used.

3.21
rated operating condition
operating condition that must be fulfilled during measurement in order that a measuring instrument or measuring system performs as designed

Note 1 to entry: Rated operating conditions generally specify intervals of values for a quantity being measured and for any influence quantity.

[SOURCE: ISO/IEC Guide 99:2007, 4.9]

Note 2 to entry: Within the ISO 10360 series, the term “as designed” means as specified by MPEs.

Note 3 to entry: If an MPE specification is thought of as a function (where different MPE values could be given for different conditions), then the rated operating conditions define the domain of that function.

4 Symbols

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

Table 1 — Symbols

Global symbols	Local abbreviations	Term
$L_{\text{Dia.5x5:Art:Tact.AArm}}$	$L_{\text{Dia.5x5:Art}}$	Articulated location error, tactile
$E_{\text{Uni:0:Tact.AArm}}$	E_{Uni}	Length measurement error, unidirectional
$E_{\text{Bi:0:Tact.AArm}}$	E_{Bi}	Length measurement error, bidirectional
$P_{\text{Form.Sph.1x25::Tact.AArm}}$	$P_{\text{Form.Sph.1x25}}$	Probing form error, tactile
$P_{\text{Size.Sph.1x25::Tact.AArm}}$	$P_{\text{Size.Sph.1x25}}$	Probing size error, tactile
$E_{\text{Uni:0:Tact.AArm,MPE}}$	$E_{\text{Uni,MPE}}$	Maximum permissible error of unidirectional length measurement
$E_{\text{Bi:0:Tact.AArm,MPE}}$	$E_{\text{Bi,MPE}}$	Maximum permissible error of bidirectional length measurement
$P_{\text{Form.Sph.1x25::Tact.AArm,MPE}}$	$P_{\text{Form.Sph.1x25,MPE}}$	Maximum permissible error for probing form, tactile
$P_{\text{Size.Sph.1x25::Tact.AArm,MPE}}$	$P_{\text{Size.Sph.1x25,MPE}}$	Maximum permissible error of probing size, tactile
$L_{\text{Dia.5x5:Art:Tact.AArm,MPE}}$	$L_{\text{Dia.5x5:Art,MPE}}$	Maximum permissible error of articulated location error, tactile
$P_{\text{Form.Sph.1x25::ODS.AArm}}$	$P_{\text{Form.Sph.1x25::ODS}}$	Probing form error, ODS (based on ISO 10360-8)[a]
$P_{\text{Form.Sph.D95\%::ODS.AArm}}$	$P_{\text{Form.Sph.D95\%::ODS}}$	Probing dispersion error (based on ISO 10360-8)[a]
$P_{\text{Size.Sph.1x25::ODS.AArm}}$	$P_{\text{Size.Sph.1x25::ODS}}$	Probing size error, ODS (based on ISO 10360-8)[a]
$P_{\text{Size.Sph.All::ODS.AArm}}$	$P_{\text{Size.Sph.All::ODS}}$	Probing size error All (based on ISO 10360-8)[a]
$P_{\text{Form.Sph.1x25::ODS.AArm,MPE}}$	$P_{\text{Form.Sph.1x25::ODS,MPE}}$	Maximum permissible error for probing form, ODS (based on ISO 10360-8)[a]
$P_{\text{Form.Sph.D95\%::ODS.AArm,MPE}}$	$P_{\text{Form.Sph.D95\%::ODS,MPE}}$	Maximum permissible error for probing dispersion (based on ISO 10360-8)[a]
$P_{\text{Size.Sph.1x25::ODS.AArm,MPE}}$	$P_{\text{Size.Sph.1x25::ODS,MPE}}$	Maximum permissible error for probing size, ODS (based on ISO 10360-8)[a]
$P_{\text{Size.Sph.All::ODS.AArm,MPE}}$	$P_{\text{Size.Sph.All::ODS,MPE}}$	Maximum permissible error for probing size All (based on ISO 10360-8)[a]
$P_{\text{Form.Pla.D95\%::ODS.AArm}}$	$P_{\text{Form.Pla.D95\%::ODS}}$	Probing flat form error (based on ISO 10360-8)[a]
$P_{\text{Form.Pla.D95\%::ODS.AArm,MPE}}$	$P_{\text{Form.Pla.D95\%::ODS,MPE}}$	Maximum permissible error for probing flat form error (based on ISO 10360-8)[a]
$P_{\text{Form.Sph.1x25::MPS.AArm}}$	$P_{\text{Form.Sph.1x25::MPS}}$	Multiple system probing form error (based on ISO 10360-9)[a]
$P_{\text{Size.Sph.1x25::MPS.AArm}}$	$P_{\text{Size.Sph.1x25::MPS}}$	Multiple system probing size error (based on ISO 10360-9)[a]
$L_{\text{Dia.1x25::MPS.AArm}}$	$L_{\text{Dia.1x25::MPS}}$	Multiple system probing location error (based on ISO 10360-9)[a]
$P_{\text{Form.Sph.1x25::MPS.AArm,MPE}}$	$P_{\text{Form.Sph.1x25::MPS,MPE}}$	Maximum permissible error for multiple system probing form error (based on ISO 10360-9)[a]

[a] The trailing qualifier, ".AArm", indicates that this metrological characteristic as defined in the relevant ISO 10360 part is tested with an articulating arm CMM.

[b] These symbols relate to metrological characteristics for which specification and testing are optional (not normative).

Table 1 *(continued)*

Global symbols	Local abbreviations	Term
$P_{\text{Size.Sph.1x25::MPS.AArm,MPE}}$	$P_{\text{Size.Sph.1x25::MPS,MPE}}$	Maximum permissible error for multiple system probing size error (based on ISO 10360-9)[a]
$L_{\text{Dia.1x25::MPS.AArm,MPE}}$	$L_{\text{Dia.1x25::MPS,MPE}}$	Maximum permissible error for multiple system probing location error (based on ISO 10360-9)[a]
$R_{\text{Uni.0::Tact.AArm}}$	$R_{\text{Uni.0::Tact}}$	Repeatability range of the bidirectional length measurement errors[a, b]
$R_{\text{Bi.0::Tact.AArm}}$	$R_{\text{Bi.0::Tact}}$	Repeatability range of the unidirectional length measurement errors[a, b]
$P_{\text{Size.5x5:Art:Tact.AArm}}$	$P_{\text{Size.5x5:Art:Tact}}$	Probing articulated size error[a, b]
$P_{\text{Form.5x5:Art:Tact.AArm}}$	$P_{\text{Form.5x5:Art:Tact}}$	Probing articulated form error[a, b]
$R_{\text{Uni.0::Tact.AArm,MPE}}$	$R_{\text{Uni.0::Tact,MPE}}$	Maximum permissible error for the repeatability range of unidirectional length measurement errors[a, b]
$R_{\text{Bi.0::Tact.AArm,MPE}}$	$R_{\text{Bi.0::Tact,MPE}}$	Maximum permissible error for the repeatability range of bidirectional length measurement errors[a, b]
$P_{\text{Size.5x5:Art:Tact.AArm,MPE}}$	$P_{\text{Size.5x5:Art:Tact,MPE}}$	Maximum permissible error for probing articulated size error[a, b]
$P_{\text{Form.5x5:Art:Tact.AArm,MPE}}$	$P_{\text{Form.5x5:Art:Tact,MPE}}$	Maximum permissible error for probing articulated form error[a, b]

[a] The trailing qualifier, ".AArm", indicates that this metrological characteristic as defined in the relevant ISO 10360 part is tested with an articulating arm CMM.

[b] These symbols relate to metrological characteristics for which specification and testing are optional (not normative).

Local abbreviations are used in this part of ISO 10360 for the sake of simplicity; however, local abbreviations used in different part(s) of ISO 10360 may not be the same, i.e. the same abbreviation may refer to different complete symbols. Use of abbreviated symbols is not recommended outside the exclusive context of this part of ISO 10360.

5 Rated operating conditions

5.1 Environmental conditions

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

— the manufacturer, in the case of acceptance tests, and

— the user, in the case of reverification tests.

In both cases, the user is free to choose the environmental conditions under which the testing will be performed within the stated limits. (Form 1 in Annex A shows an example method for stating these conditions.) The manufacturer shall provide at a single location in published literature MPE values and operating conditions under which the MPE values are valid.

If the user wishes to have testing performed under environmental conditions other than the ambient conditions of the test site (e.g. at an elevated or lowered temperature), agreement between parties regarding who bears the cost of environmental conditioning should be obtained.

5.2 Operating conditions

The articulated arm CMM shall be operated by an appropriately trained and skilled operator 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) machine compensation procedures,

c) location, type and number of environmental sensors,

d) location, type and number of thermal workpiece sensors, and

e) mounting constraints.

6 Acceptance tests and reverification tests

6.1 General

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

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

Each error obtained in an acceptance test of this part of ISO 10360 shall be compared to the MPE value or values stated by the manufacturer for the stylus configuration used in the test.

Optionally, a test report may include a plot of the measurement errors and the corresponding MPE values.

NOTE For an articulated arm CMM, it is often the case that a single MPE value is valid throughout the entire measuring volume.

6.2 Probing size and form errors

6.2.1 Principle

The principle of this test procedure is to measure the size and form of a test sphere by probing 25 points on the surface of the sphere. A Gaussian (least-squares) sphere fit of the 25 points is examined for the errors of indication for form and size. This analysis yields the form error, $P_{\text{Form.Sph.1x25}}$, and the size error, $P_{\text{Size.Sph.1x25}}$.

6.2.2 Measuring equipment

The material standard of size, i.e. the test sphere, shall have a diameter not less than 10 mm and not greater than 51 mm.

Note 1 The uncertainty in the calibrated size value of the test sphere and the form error of the test sphere contribute to the test value uncertainty.

Note 2 A test sphere smaller than 20 mm may be difficult to probe without encountering interference problems from a sphere support.

6.2.3 Procedure

Set up and qualify the probing system of the articulated arm CMM in accordance with the manufacturer's normal procedures. Choose two locations for the test sphere anywhere in the measuring volume taking into consideration the direction of the stylus during the test (see NOTE 3 of 3.5). By default, one location is near the vertical main axis of the articulated arm CMM, and the other location is near the outer surface of the measuring volume.

The test sphere and articulated arm CMM shall be mounted rigidly, both individually and with respect to one another, to minimize errors due to bending.

Measure and record 25 points without rotating the stylus or changing the direction of the stylus. The points shall be approximately evenly distributed over at least a hemisphere of the test sphere. Their positions shall be at the discretion of the user and, if not specified, the following probing pattern is recommended (see Figure 2):

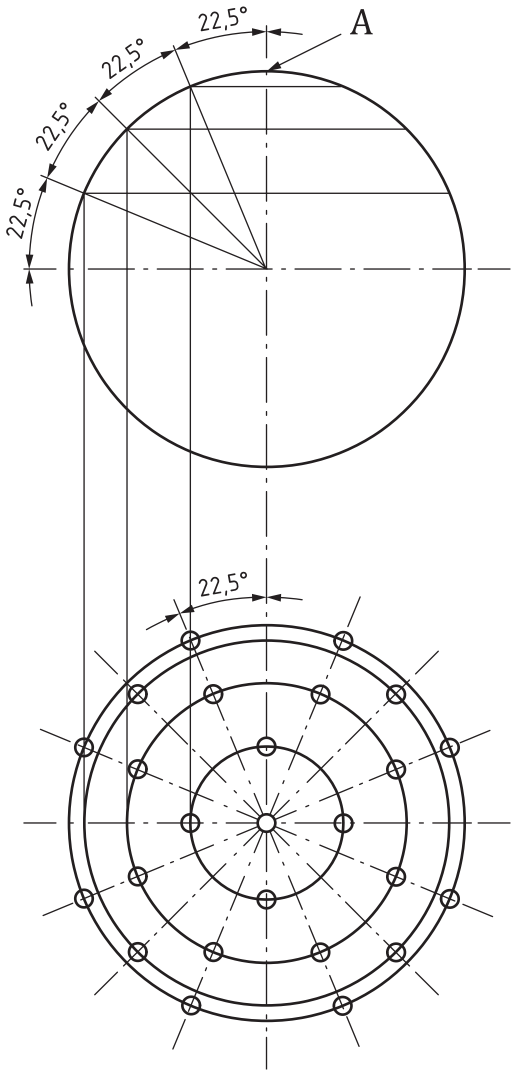
— one point on the pole (defined by the direction of the stylus shaft) of the test sphere;

— four points (equally spaced) 22,5° below the pole;

— eight points (equally spaced) 45° below the pole and rotated 22,5° relative to the previous group;

— four points (equally spaced) 67,5° below the pole and rotated 22,5° relative to the previous group;

— eight points (equally spaced) 90° below the pole (i.e. on the equator) and rotated 22,5° relative to the previous group.



Key

A pole

Figure 2 — Location of probing points

6.2.4 Derivation of test results

For each of the first and second locations, using all 25 measured points, compute the Gaussian (least-squares) associated sphere. Subtract the calibrated diameter, D_{Ref}, from the calculated diameter, D_{Meas}, of the Gaussian (least-squares) associated sphere to get $P_{Size.Sph.1x25} = D_{Meas} - D_{Ref}$. The absolute value of the probing size error at each location shall be compared to the MPE value or values specified by the manufacturer.

For each of the first and second locations, using all 25 measured points, compute the Gaussian (least-squares) associated sphere. For each of the 25 measured points, calculate R, the distance from the measured point to the Gaussian (least-squares) sphere centre (i.e. the Gaussian radial distance). Calculate the probing form error by taking the range of Gaussian radial distances: $P_{Form.Sph.1x25} = R_{max} - R_{min}$. The probing form error at each location shall be compared to the MPE value or values specified by the manufacturer.

NOTE The term Gaussian (least-squares) radial distance is defined in ISO 10360-1.

6.3 Articulated location errors

6.3.1 Principle

The principle of 6.3 and 6.4 is to include all of the articulation joints of the articulated arm CMM in a performance evaluation of this part of ISO 10360. The evaluation described in 6.4 includes all articulation joints except the wrist joint assembly, which includes the fifth swivel joint, the sixth hinge joint, and the seventh (if available) swivel joint; the evaluation in 6.3 focuses on the evaluation of this joint assembly. The test procedure is to probe the surface of a test sphere in a manner that extensively articulates the wrist by measuring with five orthogonal stylus orientations articulated at the wrist. For each of the five orientations, the test sphere is probed with five points and a Gaussian (least-squares) sphere centre location is calculated. The set of the five sphere centres, which ideally should have the same coordinates, is used to evaluate the articulated location error, $L_{Dia.5x5:Art}$.

If the articulated arm CMM is equipped with a swivel joint on a seventh axis, the stylus may be rotated by an arbitrary angle between each of the five sphere centre measurements.

If the articulated arm CMM is equipped with multiple styli, e.g. “cluster styli”, then the multiple styli test in ISO 10360-5 should also be performed.

6.3.2 Measuring equipment

The test sphere, calibrated for size and form, shall have a diameter not less than 10 mm and not greater than 51 mm.

NOTE 1 The uncertainty in the size of the test sphere and form error of the test sphere contribute to the test value uncertainty.

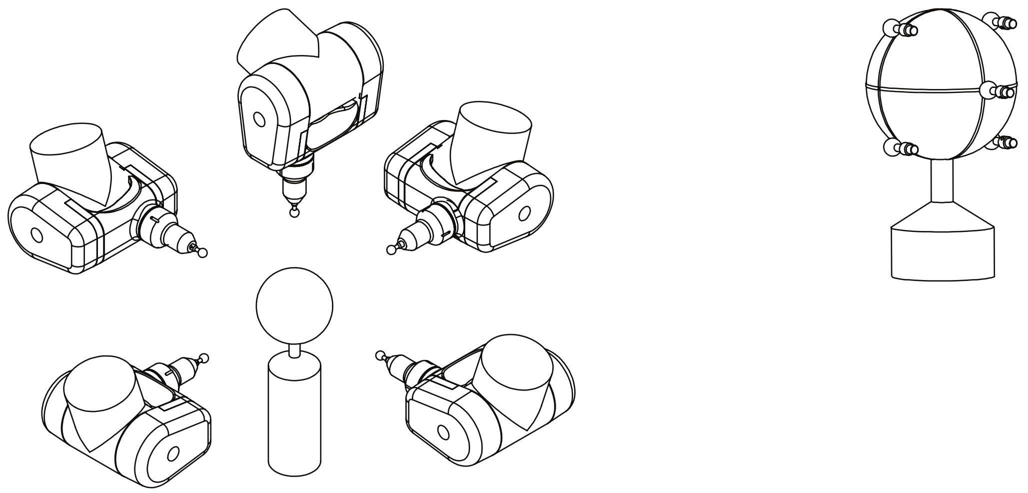
NOTE 2 A test sphere smaller than 20 mm may be difficult to probe without encountering interference problems from a sphere support.

6.3.3 Procedure

Set up and qualify the probing system on the articulated arm CMM in accordance with the manufacturer’s normal procedures. Choose two locations for the test sphere anywhere in the measuring volume taking into consideration the direction of the stylus during the test (see NOTE 3 of 3.5).

The test sphere and articulated arm CMM shall be mounted rigidly, both individually and with respect to one another, to minimize errors due to bending.

Measure on the test sphere each of the five pole points as shown in Figure 3 a). In this figure, four of the five pole points are placed on four quadrants of an equatorial plane of the test sphere, and the fifth pole is placed on the test sphere so as to be symmetrical with respect to the other four. For each pole point, measure on the sphere four additional points without changing the direction of the stylus or rotating the stylus, as shown in Figure 3 b). For a given stylus direction, the five measured points are spaced approximately evenly over a hemisphere of the test sphere. However, the full set of 25 points may not be evenly distributed over the sphere (i.e. points from different sets may be close to one another).



a) Five stylus directions   b) Five points with common stylus direction

Figure 3 — Pole points

6.3.4 Derivation of test results

For each of the first and second locations, compute a Gaussian (least-squares) associated sphere for each of the five sets of five points to find the five sphere centres. Calculate the articulated location error $L_{\mathrm{Dia.5x5:Art}}$ by finding the diameter of the minimum circumscribed sphere that encompasses the five sphere centres. The articulated location error at the first and second locations shall be compared to the MPE value or values specified by the manufacturer, $L_{\mathrm{Dia.5x5:Art,MPE}}$.

NOTE Two additional parameters may be of interest: the form and size errors of the resulting 5 × 5 point sphere. A user may wish to use these parameters as a reflection of point measurement capability when articulating to access different points. Annex G contains additional details regarding the calculation of these parameters.

6.4 Length measurement errors

6.4.1 Principle

The principle of the length error assessment is to use a calibrated test length, traceable to the metre, to establish whether the articulated arm CMM is capable of measuring within the stated maximum permissible error of length measurement provided by the manufacturer. The manufacturer may choose to provide specifications for the maximum permissible error of unidirectional length measurement, $E_{\mathrm{Uni,MPE}}$, the maximum permissible error of bidirectional length measurement, $E_{\mathrm{Bi,MPE}}$, or both. The length measurement error shall be compared to the MPE value or values specified by the manufacturer for the stylus configuration used in the test.

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 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_1B_1, A_2B_2, A_3B_3 or A_1B_1, B_2A_2, A_3B_3. Other sequences such as $A_1A_2A_3$, $B_1B_2B_3$ are not permitted.

For articulated arm CMMs without workpiece thermal expansion compensation, the uncorrected differential thermal expansion between the articulated arm 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 articulated arm CMMs with workpiece thermal expansion compensation, this thermally induced error is greatly reduced. For these articulated arm 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 within the manufacturer's specifications of the expanded uncertainty in the CTE of the test length.

For some articulated arm 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 articulated arm CMM software that performs the thermal compensation. Manual thermal compensation by the user is not permitted.

6.4.2 Measuring equipment

A traceable reference length may be realized in a number of ways, including nest bars, kinematic seats (nests) mounted on walls or freestanding structures, use of a rail-and-carriage system, gauge blocks, ball bars, step gauge bars, etc. Suitable artefacts are discussed further in Annex B.

A calibrated test length shall be a normal CTE material unless the manufacturer's specifications explicitly state otherwise. In either case, the allowable CTE range is part of the rated operating conditions. The manufacturer shall specify the maximum permitted expanded ($k = 2$) uncertainty of the CTE of the calibrated test length. The manufacturer may calibrate the CTE of a calibrated test length.

The manufacturer may state limits on the CTE of the calibrated test length. If the specification of the calibrated test length does not include a normal CTE material, then the corresponding $E_{\mathrm{Uni,MPE}}$ and/or $E_{\mathrm{Bi,MPE}}$ values are designated with an asterisk (*) and an explanatory note shall be provided describing the CTE of the calibrated test length.

Example: $E_{\mathrm{Uni,MPE}}$*

* The calibrated test length shall have a CTE no greater than $0{,}5 \times 10^{-6}/°C$ and a CTE expanded uncertainty ($k = 2$) no greater than $0{,}3 \times 10^{-6}/°C$

If the manufacturer's specification states that the calibrated test length will be a non-normal CTE material and the CTE is less than $2 \times 10^{-6}/°C$, then perform an additional measurement as described in 6.4.3.3.

6.4.3 Procedure

6.4.3.1 Measurement positions

Five calibrated test lengths are measured along each of seven measurement lines, as described below. The five calibrated test lengths may comprise a single artefact or multiple artefacts. The longest of the five test lengths shall be at least 66 % of the measuring range. The five test lengths shall be well distributed.

NOTE An example of five well distributed test lengths (for the case of five distinct lengths) over a one metre measurement line is: 100 mm, 200 mm, 400 mm, 600 mm, and 800 mm.

Annex B describes calibrated test lengths suitable for use in unidirectional and bidirectional testing.

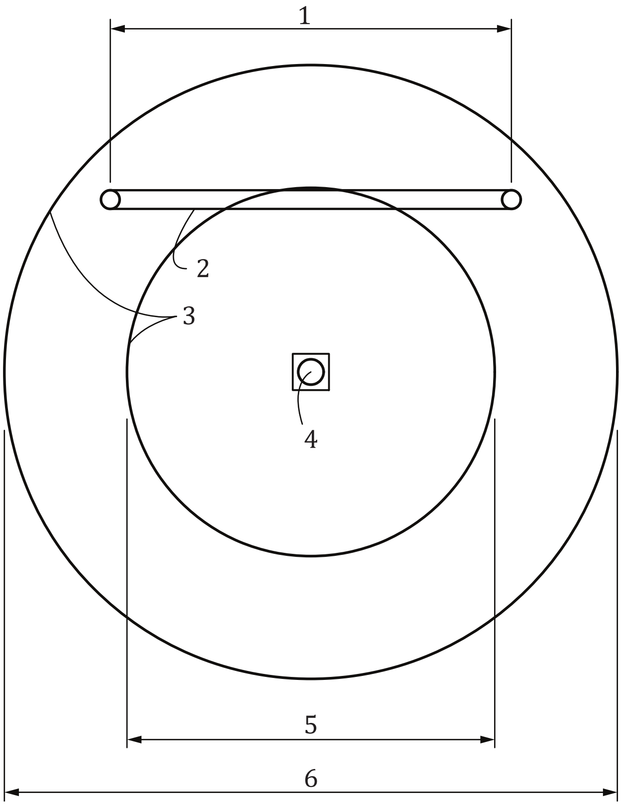
The articulated arm CMM has a standing axis “z” of the swivel joint “a” as shown in Figure 1. For the purpose of carrying out the test, the tester constructs a reference plane that includes the standing axis “z” and a point selected arbitrarily by the user on the base of the arm and a measurement plane that includes the standing axis and the centre of a calibrated test length. The azimuth angle for a particular measurement is defined as the angle between the reference plane and the measurement plane, with the angle measured along a plane perpendicular to the standing axis.

As shown in Table 2, the calibrated test length should be placed along seven measurement lines 1 to 7 in horizontal, 45°-diagonal, and vertical directions. The azimuth angle is by default 0° in the vertical direction and 0°, 120°, and 240° in the horizontal and 45°-diagonal directions.

Table 2 — Measurement positions

Measurement line	Direction	Azimuth angle (°)
1, 2, 3	Horizontal	0, 120, 240
4, 5, 6	Diagonal, 45°	0, 120, 240
7	Vertical	0

As shown in Figure 4, the end points of the largest calibrated test length shall lie within a spherical envelope covering 60 % to 100 % of the measuring range.



Key

1 66 % of measuring range
2 calibrated test length
3 spheres about centre
4 centre of articulated arm CMM
5 60 % of measuring range
6 100 % of measuring range

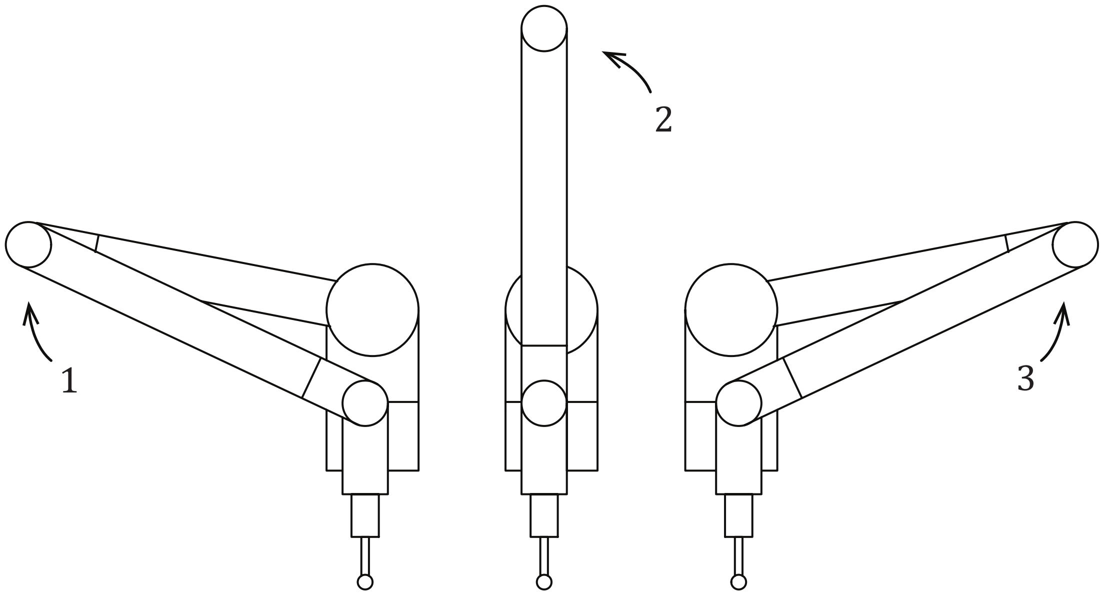
Figure 4 — Placement of calibrated test length for positions

6.4.3.2 Measurement procedure

Set up and qualify the probing system in accordance with the manufacturer's normal procedures (see 5.2).

For each of the five calibrated test lengths, obtain three measurement results. Repeat for all seven measurement lines to obtain 105 measurement results from the calibrated test lengths.

Each point may be measured with the elbow of the articulated arm CMM oriented elbow left (L), elbow overhead (O), or elbow right (R), as shown in Figure 5.



Key

1 elbow left (L)

2 elbow overhead (O)

3 elbow right (R)

Figure 5 — Elbow positions

Since each length measurement includes steps of measuring a first point (as L, O, or R) and a second point on a calibrated test length (as L, O, or R), there are nine possible combinations of elbow positions possible in measuring the two points of each calibrated test length. Using the abbreviations, the nine combinations are LL, LO, LR, OL, OO, OR, RL, RO, and RR.

EXAMPLE The example measurement procedure given in Table 3 is to measure the first 30 lengths (6 × 5 lengths) by cycling through the combinations, with the three repeated measurements performed using the identical combination as shown in Table 3. The last five lengths, which according to Table 2 are for the calibrated test length in the vertical orientation, are carried out with the elbow to one side of the other (LL or RR). Ordinarily the articulated arm CMM is placed to one side or the other of the vertical artefact so that the elbow can only be bent in one direction or the other. The user may choose to measure using different elbow orientations or in a different order.

Table 3 — Example of alternating elbow orientations for measurement of first and second points

Length number	Repeat 1	Repeat 2	Repeat 3
1	LL	LL	LL
2	LO	LO	LO
3	LR	LR	LR
4	OL	OL	OL
5	OO	OO	OO
6	OR	OR	OR
7	RL	RL	RL
8	RO	RO	RO

Table 3 *(continued)*

Length number	Repeat 1	Repeat 2	Repeat 3
9	RR	RR	RR
10	LL	LL	LL
11	LO	LO	LO
12	LR	LR	LR
13	OL	OL	OL
14	OO	OO	OO
15	OR	OR	OR
16	RL	RL	RL
17	RO	RO	RO
18	RR	RR	RR
19	LL	LL	LL
20	LO	LO	LO
21	LR	LR	LR
22	OL	OL	OL
23	OO	OO	OO
24	OR	OR	OR
25	RL	RL	RL
26	RO	RO	RO
27	RR	RR	RR
28	LL	LL	LL
29	LO	LO	LO
30	LR	LR	LR
31	LL or RR	LL or RR	LL or RR
32	LL or RR	LL or RR	LL or RR
33	LL or RR	LL or RR	LL or RR
34	LL or RR	LL or RR	LL or RR
35	LL or RR	LL or RR	LL or RR

6.4.3.3 Low CTE case

For the case in which the manufacturer's specification for $E_{\mathrm{Uni,MPE}}$ or $E_{\mathrm{Bi,MPE}}$ requires having a CTE less than 2 × 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 approximately 0,5 m for articulated arm CMMs having a measuring range greater than 0,75 m and greater than 50 % of the measuring range for smaller articulated arm CMMs. The measurement shall be performed once. The manufacturer may calibrate the CTE of the test length.

6.4.3.4 Derivation of test results

For the 105 measurements, and (if required) the additional length measurement according to 6.4.3.3, calculate the unidirectional length measurement error, E_{Uni}, or the bidirectional length measurement error, E_{Bi}, or both E_{Uni} and E_{Bi}, by taking the difference between the measured (indicated) value and the calibrated value of the test length. The articulated arm CMM may correct for thermally induced errors (including thermal expansion) in a calibrated test length if it has accessory devices for this purpose. Manual correction of test results to remove thermally induced errors shall not be allowed when the environmental conditions satisfy 5.1.

For each of the 105 length measurement errors (E_{Uni}, E_{Bi} value) and (if required) the additional length measurement error according to 6.4.3.3, determine the corresponding MPE value ($E_{Uni,MPE}$, $E_{Bi,MPE}$ value) based on the manufacturer's MPE specification.

NOTE 1 For an articulated arm CMM, it is often the case that a single MPE value is valid throughout the entire measuring volume.

NOTE 2 An additional parameter may be of interest: the repeatability range of the length measurement errors, which may be $R_{Uni.0::AArm.Tact}$ or $R_{Bi.0::AArm.Tact}$, or both. Annex H contains additional details regarding the calculation of this parameter.

7 Compliance with specification

7.1 Acceptance tests

7.1.1 Acceptance criteria

The probing performance of the articulated arm CMM with a tactile probe is verified if, for each measured value

— the probing form error, tactile, $P_{Form.Sph.1x25}$, is not greater than the relevant maximum permissible error for probing form, tactile, $P_{Size.Sph.1x25,MPE}$, as specified by the manufacturer and taking into account the test value uncertainty, and

— the absolute value of the probing size error, tactile, $P_{Size.Sph.1x25}$, is not greater than the relevant maximum permissible error for probing size, tactile, $P_{Size.Sph.1x25,MPE}$, as specified by the manufacturer and taking into account the test value uncertainty.

The articulation performance of the articulated arm CMM is verified if

— the articulated location error, tactile, $L_{Dia.5x5:Art}$, is not greater than the relevant maximum permissible error of articulated location error, tactile, $L_{Dia.5x5:Art,MPE}$, as specified by the manufacturer and taking into account the test value uncertainty of measurement.

The length measuring performance of the articulated arm CMM is verified if

— the manufacturer specifies at least one of a maximum permissible error for unidirectional $E_{Uni,MPE}$ and a maximum permissible error for bidirectional length, $E_{Bi,MPE}$,

— the absolute value of length measurement errors, unidirectional, E_{Uni}, are within the maximum permissible error for unidirectional length, $E_{Uni,MPE}$, if specified by the manufacturer, taking into account the test value uncertainty, and

— the absolute value of length measurement errors, bidirectional, E_{Bi}, are within the maximum permissible error for bidirectional length, $E_{Bi,MPE}$, if specified by the manufacturer, taking into account the test value uncertainty.

7.1.2 Data rejection and repeated measurements

7.1.2.1 Probing form error and probing size error

If the performance of probing form error or probing size error is not verified for both locations of the test, the probing equipment shall be checked for the faults that could be influencing the measurement result. Any faults shall be corrected and the relevant test (at both locations) repeated once only. The original measurement results shall be discarded.

No additional repeated measurement shall be performed.

7.1.2.2 Articulated location error

If the performance of articulated location error is not verified by the test, the probing equipment shall be checked for the faults that could be influencing the measurement result. Any faults shall be corrected and the relevant test repeated once only (at both sphere locations included in the test), and the original measurement results shall be discarded.

No additional repeated measurement shall be performed.

7.1.2.3 Length measurement error

A maximum of five of the 35 sets of three repeated measurements may have one (and no more than one) of the three values of the length measurement error fail the acceptance criteria.

Each such failed measurement shall be remeasured three times at the relevant position.

If all the values of the errors of indication of the calibrated test lengths from the three repeated measurements are within the manufacturer's specifications taking into account the test value uncertainty, then the performance of the articulated arm CMM is verified at that position.

No additional repeated measurement shall be performed.

7.2 Reverification tests

As in 7.1, but specifications are made by the user (following manufacturer procedures).

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, etc.

the acceptance test specified in this part of ISO 10360 may be used as a test for verifying the performance of the articulated arm CMM used for measuring linear dimensions in accordance with the specification for the stated maximum permissible errors, $P_{\text{Form.Sph.1x25,MPE}}$, $P_{\text{Size.Sph.1x25,MPE}}$, $L_{\text{Dia.5x5:Art,MPE}}$, $E_{\text{Uni,MPE}}$, and $E_{\text{Bi,MPE}}$, as agreed upon by the manufacturer and the user and, if agreed upon by the manufacturer and the user, optional specifications $R_{\text{Uni.0::AArm.Tact}}$, $R_{\text{Bi.0::AArm.Tact}}$, $P_{\text{Size.Sph.5x5:Art:Tact.AArm}}$ and $P_{\text{Form.Sph.5x5:Art:Tact.AArm}}$.

The manufacturer is permitted to specify detailed limitations applicable for $P_{\text{Form.Sph.1x25,MPE}}$, $P_{\text{Size.Sph.1x25,MPE}}$, $L_{\text{Dia.5x5:Art,MPE}}$, $E_{\text{Uni,MPE}}$, and $E_{\text{Bi,MPE}}$. If no such specification is given, $P_{\text{Form.Sph.1x25,MPE}}$, $P_{\text{Size.Sph.1x25,MPE}}$, $L_{\text{Dia.5x5:Art,MPE}}$, $E_{\text{Uni,MPE}}$, and $E_{\text{Bi,MPE}}$ apply for any location and orientation in the measuring volume of the articulated arm 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 articulated arm CMM used for measuring linear dimensions in accordance with the specification for the maximum permissible errors, $P_{\text{Form.Sph.1x25,MPE}}$, $P_{\text{Size.Sph.1x25,MPE}}$, $L_{\text{Dia.5x5:Art,MPE}}$, $E_{\text{Uni,MPE}}$, and $E_{\text{Bi,MPE}}$, as stated by the user. The user is permitted to state the values of, and to specify detailed limitations applicable to, $P_{Form.Sph.1x25,MPE}$, $P_{Size.Sph.1x25,MPE}$, $L_{Dia.5x5:Art,MPE}$, $E_{Uni,MPE}$, and $E_{Bi,MPE}$.

NOTE 1 The tester accounts for the test value uncertainty; accordingly a reverification test (where typically the tester is the user) may have a different conformance zone than in 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 articulated arm CMM conforms with specified requirements regarding the maximum permissible errors and maximum permissible limits, $P_{Form.Sph.1x25,MPE}$, $P_{Size.Sph.1x25,MPE}$, $L_{Dia.5x5:Art,MPE}$, $E_{Uni,MPE}$, and $E_{Bi,MPE}$. The extent of the performance verification as described in this part of ISO 10360 may be reduced by using fewer measurements and positions.

An effective interim test is the single point articulation test, described in greater detail in Annex D.

NOTE This part of ISO 10360 is primarily concerned with acceptance and reverification testing. Interim testing is often associated with quality assurance.

9 Indication in product documentation and data sheets

Table 4 — Symbols and corresponding indications in product documentation, drawings, data

Symbol used in this part of ISO 10360	Corresponding indication
$L_{\text{Dia.5x5:Art:Tact.AArm}}$	*L*Dia.5x5:Art:Tact.AArm
$E_{\text{Uni:0:Tact.AArm}}$	*E*Uni:0:Tact.AArm
$E_{\text{Bi:0:Tact.AArm}}$	*E*Bi:0:Tact.AArm
$P_{\text{Form.Sph.1x25::Tact.AArm}}$	*P*Form.Sph.1x25::Tact.AArm
$P_{\text{Size.Sph.1x25::Tact.AArm}}$	*P*Size.Sph.1x25::Tact.AArm
$E_{\text{Uni:0:Tact.AArm,MPE}}$	*E*Uni:0:Tact.AArm,MPE
$E_{\text{Bi:0:Tact.AArm,MPE}}$	*E*Bi:0:Tact.AArm,MPE
$P_{\text{Form.Sph.1x25::Tact.AArm,MPE}}$	*P*Form.Sph.1x25::Tact.AArm,MPE
$P_{\text{Size.Sph.1x25::Tact.AArm,MPE}}$	*P*Size.Sph.1x25::Tact.AArm,MPE
$L_{\text{Dia.5x5:Art:Tact.AArm,MPE}}$	*L*Dia.5x5:Art:Tact.AArmMPE
$P_{\text{Form.Sph.1x25::ODS.AArm}}$	*P*Form.Sph.1x25::ODS.AArm
$P_{\text{Form.Sph.D95\%::ODS.AArm}}$	*P*Form.Sph.D95%::ODS.AArm
$P_{\text{Size.Sph.1x25::ODS.AArm}}$	*P*Size.Sph.1x25::ODS.AArm
$P_{\text{Size.Sph.All::ODS.AArm}}$	*P*Size.Sph.All::ODS.AArm
$P_{\text{Form.Sph.1x25::ODS.AArm,MPE}}$	*P*Form.Sph.1x25::ODS.AArm,MPE
$P_{\text{Form.Sph.D95\%::ODS.AArm,MPE}}$	*P*Form.Sph.D95%::ODS.AArm,MPE
$P_{\text{Size.Sph.1x25::ODS.AArm,MPE}}$	*P*Size.Sph.1x25::ODS.AArm,MPE
$P_{\text{Size.Sph.All::ODS.AArm,MPE}}$	*P*Size.Sph.All::ODS.AArm,MPE
$P_{\text{Form.Pla.D95\%::ODS.AArm}}$	*P*Form.Pla.D95%::ODS.AArm
$P_{\text{Form.Pla.D95\%::ODS.AArm,MPE}}$	*P*Form.Pla.D95%::ODS.AArm,MPE
$P_{\text{Form.Sph.1x25::MPS.AArm}}$	*P*Form.Sph.1x25::MPS.AArm
$P_{\text{Size.Sph.1x25::MPS.AArm}}$	*P*Size.Sph.1x25::MPS.AArm
$L_{\text{Dia.1x25::MPS.AArm}}$	*L*Dia.1x25::MPS.AArm
$P_{\text{Form.Sph.1x25::MPS.AArm,MPE}}$	*P*Form.Sph.1x25::MPS.AArm,MPE
$P_{\text{Size.Sph.1x25::MPS.AArm,MPE}}$	*P*Size.Sph.1x25::MPS.AArm,MPE
$L_{\text{Dia.1x25::MPS.AArm,MPE}}$	*L*Dia.1x25::MPS.AArm,MPE
$R_{\text{Uni.0::Tact.AArm}}$	*R*Uni.0::Tact.AArm
$R_{\text{Bi.0::Tact.AArm}}$	*R*Bi.0::Tact.AArm
$P_{\text{Size.5x5:Art:Tact.AArm}}$	*P*Size.5x5:Art:Tact.AArm
$P_{\text{Form.5x5:Art:Tact.AArm}}$	*P*Form.5x5:Art:Tact.AArm
$R_{\text{Uni.0::Tact.AArm,MPE}}$	*R*Uni.0::Tact.AArm,MPE
$R_{\text{Bi.0::Tact.AArm,MPE}}$	*R*Bi.0::Tact.AArm,MPE
$P_{\text{Size.5x5:Art:Tact.AArm,MPE}}$	*P*Size.5x5:Art:Tact.AArm,MPE
$P_{\text{Form.5x5:Art:Tact.AArm,MPE}}$	*P*Form.5x5:Art:Tact.AArm,MPE

Annex A
(informative)

Forms

Form 1: Example of general specifications and rated operating conditions

RATED CONDITIONS					
a. *Measuring range*		________ m			
b. *Regions excluded from measuring volume*		________________________			
c. *Temperature range*					
Operating	min.	________ °C	max.	____ °C	
Thermal gradient limits	max.	________ °C	max.	____ °C/h	
d. *Electrical*	Voltage	________ V	Current	____ A	
	Frequency	________ Hz	Surge/sag	____ V	
	Transient max.	________ V	Transient duration	____ s	
e. *Allowable orientations (vertical, horizontal, etc.)*		________________________			
f. *Probe type (used during performance testing)*	Diameter	________ mm			
g. *Reference artefact*					
CTE	min. (optional)	________ 10^{-6}/°C	max.	____ 10^{-6}/°C	
CTE expanded uncertainty		________	max.	____ 10^{-6}/°C	
h. *Warm-up time*	min.	________ minutes			
LIMITING CONDITIONS					
i. *Temperature range*	min.	________ °C	max.	____ °C	
j. *Humidity*		________________	max.	____ %RH	

Form 2: Manufacturer's performance specifications and test results

Dimensions of all units in µm

	Symbol, MPE	Value, MPE	Symbol, measure	Value, measure	Pass/fail
Length measurement error, unidirectional	$E_{\text{Uni:0:Tact.AArm,MPE}}$		$E_{\text{Uni:0:Tact.AArm}}$		
Length measurement error, bidirectional	$E_{\text{Bi:0:Tact.AArm,MPE}}$		$E_{\text{Bi:0:Tact.AArm}}$		
Probing form error, tactile	$P_{\text{Form.Sph.1x25::Tact.AArm,MPE}}$		$P_{\text{Form.Sph.1x25::Tact.AArm}}$		
Probing size error, tactile	$P_{\text{Size.Sph.1x25::Tact.AArm,MPE}}$		$P_{\text{Size.Sph.1x25::Tact.AArm}}$		
Articulated location error	$L_{\text{Dia.5x5:Art:Tact.AArm,MPE}}$		$L_{\text{Dia.5x5:Art:Tact.AArm}}$		

Test performed by

Date

Serial number

Final test results (pass/fail)

Annex B
(normative)

Artefacts that represent a calibrated test length

B.1 General

For 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 an articulated arm 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 two categories of articulated arm CMM errors:

a) geometrical and thermal errors associated with the articulated arm CMM between the two end points of the calibrated test length, either in a bidirectional or in a unidirectional manner; and

b) if a bidirectional test is performed, size errors caused by an articulating function for the probe if applicable.

B.2 and B.3 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 articulated arm CMMs. In this case, both parties may agree to use other means to generate a calibrated test length. These might include calibrated length standards that are “stitched” together (i.e. overlapped end-to-end) to form a longer test length, or other types of laser-based calibrated test lengths, e.g. produced by multilateration. In the latter case, issues associated with the absence of contact probing shall be accounted for. 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 6.4.2 and 6.4.3.3. 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 interferometer is used to produce a calibrated test length for testing a temperature-compensated articulated arm CMM, then the workpiece CTE in the articulated arm CMM’s software shall be set to 0.

B.2 Bidirectional measurements for verifying bidirectional length measuring performance

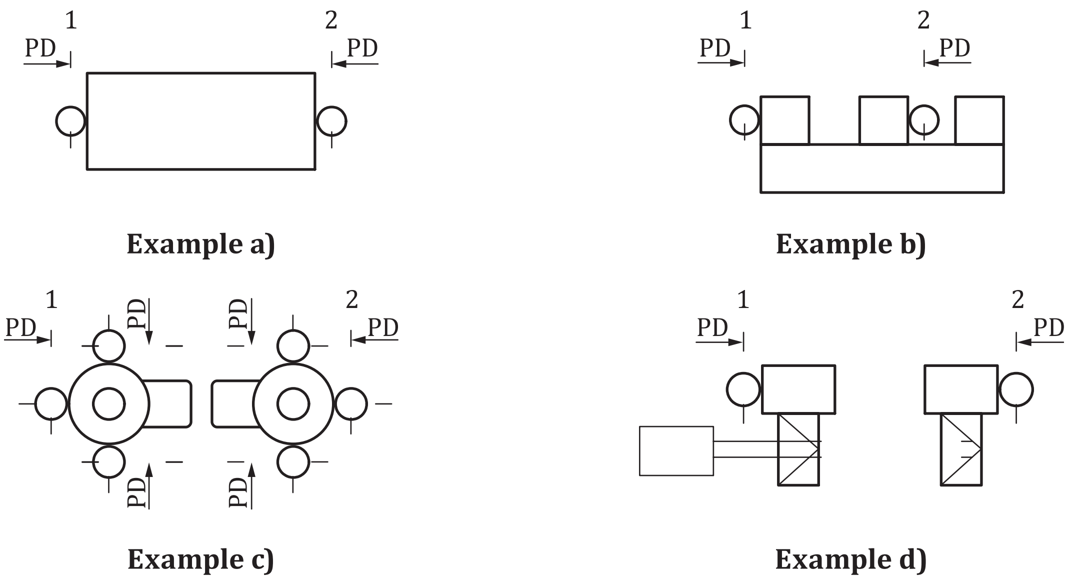
B.2.1 General

Bidirectional measurements of calibrated gauges represent a bidirectional calibrated test length. A bidirectional measurement involves probing a single point or a representative point (explained in ISO 10360-8, applicable to optical distance sensors) on each gauging point of the gauge, and sensing these probing points from diametrically opposite directions (see Figure B.1 as examples of external bidirectional measurements). Internal and external bidirectional measurements shall not be mixed on a measurement line. Several possible bidirectional measurement methods are described below.

Some optical distance sensors may obtain probing points without probing motion. However in case a sensor requiring probing motion is tested, it is recommended to follow the probing direction shown in Figure B.1.

For the case of an articulated arm CMM used to measure a calibrated test length in a bidirectional manner by measuring a single point on each end of the calibrated test length, it is recommended that a guide (or mark) be provided for the placement of the probe tip.

In a Cartesian CMM, the probe tip retains its orientation so that measurement of a single point on each of two sides of a calibrated test length reveals errors associated with errors of size and errors of form of the probing element. In the case of an articulated arm CMM, it is possible to rotate the probing element by 180°, thereby obscuring these errors. To avoid this possibility, the orientation of the probe tip of an articulated arm CMM should be retained during such a measurement. In practice, the errors associated with the size or form error of the probing tip is usually negligible compared to other error sources in the measurement.



Key

PD probing direction

1 position 1

2 position 2

Figure B.1 — Examples of bidirectional measurements, each probed with a single-point-to-single-point or equivalent

B.2.2 Step gauge measured in a bidirectional manner

A calibrated test length may be produced using a calibrated step gauge measured with a single-point-to-single-point bidirectional method [see Figure B.1 b)]. See Annex C for alignment procedures.

B.2.3 Gauge block measured in a bidirectional manner

A calibrated test length may be produced using one or more properly affixed (e.g. wrung) calibrated gauge blocks measured with a single-point-to-single-point method where the point is a single point. It is advised that each probing point be located at the calibrated gauging point for the block [see Figure B.1 a)]. See Annex C for alignment procedures.

B.2.4 Ball bars/ball plates measured in a bidirectional manner

A calibrated test length may be produced using a ball bar/ball plate at four specific points on each ball [see Figure B.1 c)]. This measurement is equivalent to a single-point-to-single-point measurement; the three points at each end control alignment and the one point at each end is approximately on the gauge axis containing the sphere centre. See Annex C for alignment procedures.

B.2.5 Laser interferometry measured in a bidirectional manner with optical probing

A calibrated test length can be produced using a laser interferometer and a material standard calibrated for the size, and measured by two probing points or two representative points. The calibrated test length is the sum of the calibrated length of the material standard of size and the displacement recorded by a calibrated laser interferometer system. The material standard of size is measured with a single point or a representative point at the initial position. Then the opposite face of the material standard of size is measured with a single point or a representative point at the second position [see Figure B.1 d)].

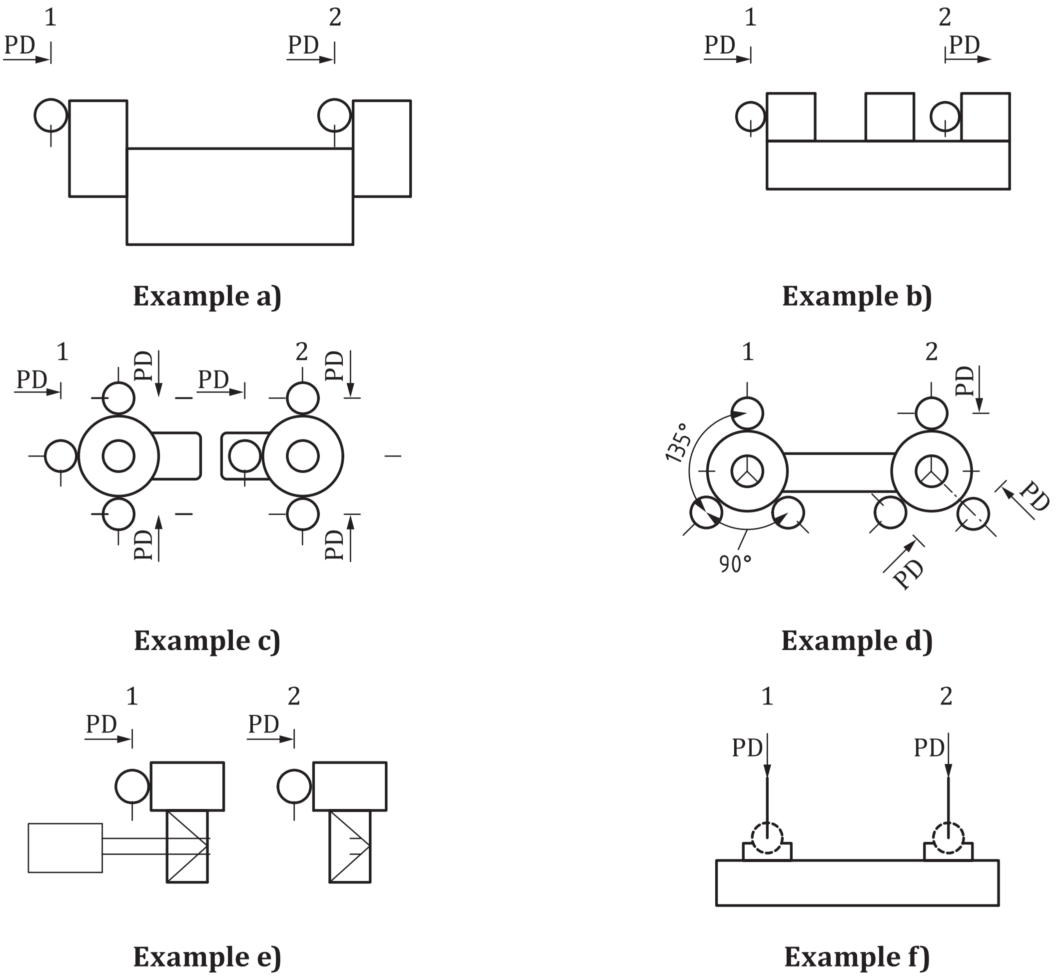
A measurement of a reference standard in a tactile probing mode must include contact of the probe with a calibrated test length. A measurement in which a retroreflector is attached to a stylus of an articulated arm CMM and a displacement of the retroreflector measured with an interferometer is not considered a valid measurement of length error according to 6.4.

B.3 Unidirectional measurements

B.3.1 General

Unidirectional measurements of calibrated gauges represent a unidirectional calibrated test length. A unidirectional measurement involves probing a probing point or a representative point on each gauging point of the gauge, and sensing these probing points from nominally the same directions (see Figure B.2). One-sided unidirectional measurements and the opposite sided unidirectional measurements shall not be mixed on a measurement line. Several possible unidirectional measurement methods are described below.

Some optical distance sensors may obtain probing points without probing motion. However in case a sensor requiring probing motion is tested, it is recommended to follow the probing direction shown in Figure B.2.



Key

PD probing direction

1 position 1

2 position 2

Figure B.2 — Examples of unidirectional measurements for verifying unidirectional length measuring performance

B.3.2 Gauge blocks

A calibrated test length may be produced using one or more properly affixed (e.g. wrung) calibrated gauge blocks measured with a single-point-to-single-point method where the point is a single point or a representative point. As the calibrated gauging points are inaccessible due to the stacking of the gauges, it is advised that each probing point be located as close as practical to the calibrated gauging point for the blocks [see Figure B.2 a)]. See Annex C for alignment procedures.

B.3.3 Step gauges measured in a unidirectional manner

A calibrated test length may be produced using a calibrated step gauge measured with a single-point-to-single-point unidirectional method where the point is a single point or a representative point [see Figure B.2 b)]. See Annex C for alignment procedures.

B.3.4 Ball bars/ball plates measured in a unidirectional manner

A calibrated unidirectional test length may be produced using a ball bar or ball plate. The calibrated test length that is needed will be different depending on the probing strategy used during testing.

With the test measuring strategy shown in Figure B.2 c), the calibrated test length is equal to the calibrated sphere centre-to-centre length, adding one half the calibrated diameter of the first ball, and subtracting one half the calibrated diameter of the second ball.

With the measuring strategy shown in Figure B.2 c), the first ball is on the left and the second ball is on the right.

NOTE Care must be used to relate the probing pattern correctly to the addition and subtraction of the calibrated half-diameters. The “first” ball has the measuring point on the far side of the ball from the line segment connecting the ball centres, and the “second” ball has the measuring point nominally on the line segment connecting the centres (i.e. between the two balls).

L_{Uni} (calibrated test length) = $L_{\text{calibrated c-c}} + D_{\text{first}} / 2 - D_{\text{second}} / 2$

The calculation of the measured length, L_{Uni} (measured), should follow the calculation of the calibrated test length, using the measured centre to centre distance and measured sphere diameters.

A calibrated test length may be produced using a ball bar/ball plate where the length is equal to the calibrated sphere centre-to-centre length. The test length is then measured with probing points as shown in Figure B.2 d).

The results produced using these point placements are equivalent to a single-point-to-single-point measurement. These point placements are carefully chosen (in particular the angular spacing in Figure B.2 d)) to give this equivalence; other point patterns or numbers of points (e.g. a 5-point strategy) may not be equivalent.

B.3.5 Laser interferometry measured in a unidirectional manner with optical probing

A calibrated test length can be produced using a laser interferometer and a material standard measured by two probing points or two representative points. The calibrated test length is the displacement recorded by a calibrated laser interferometer system. The material standard is measured with a single point or a representative point (explained in ISO 10360-8, applicable to optical distance sensors) at the initial position. Then nominally the same gauging point on the material standard is measured with a single point or a representative point at the second position [see Figure B.2 e)].

A measurement of a reference standard in a tactile probing mode must include contact of the probe with a calibrated test length. A measurement in which a retroreflector is attached to a stylus of an articulated arm CMM and a displacement of the retroreflector measured with an interferometer is not considered a valid measurement of length error according to 6.4.

B.3.6 Direct probing of calibrated nest bar

A calibrated test length may be produced as a centre-to-centre length between the two kinematic seats (nests) as in Figure B.2 f). The kinematic seats are measured directly with a ball probe of an articulated arm CMM. Each seat shall be a kinematic seat, which is to say that the centre of the ball probe may be repeatably positioned in the kinematic seat. A kinematic seat may be a trihedral seat or, in less demanding situations, a conical seat or a chamfered hole seat.

B.4 Upper limit for bidirectional length errors based on unidirectional length errors and probing size errors

In many cases, for a particular articulated arm CMM, the errors observed in a unidirectional length test will be seen to be approximately equal to the errors observed in a bidirectional length test. However, bidirectional length tests are much more time consuming to perform than unidirectional length tests. For this reason, this part of ISO 10360 allows that, for a given test length, the sum of the absolute values of the unidirectional length error, E_{Uni}, and the larger of the two probing size errors, $P_{Size.Sph.1x25}$, obtained at the two different locations in 6.2 can be taken as an upper bound for verifying the bidirectional specifications.

In this case, an articulated arm CMM meets a manufacturer's bidirectional length specification, E_{Bi}, without making a bidirectional length test. This is possible if the following inequality is true:

$$|E_{Uni}| + \max(|P_{Size.Sph.1x25}|_{Loc1}, |P_{Size.Sph.1x25|Loc2}) \leq E_{Bi,MPE}$$

Annex C
(informative)

Alignment of artefacts

C.1 General

To compare the length measured by a CMM to the calibrated value of the test length, it is necessary to align the calibrated test length properly. If the calibration certificate of the material standard 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 on the alignment procedure.

C.2 Parallel face artefacts

For parallel face artefacts, the following alignment procedure may be useful.

Probe many points on one gauge face and establish a (least-squares fit) reference plane. The direction perpendicular to the plane is the reference (gauge axis) direction. Measure a single point or a representative point on each gauging face, e.g. on each end of a gauge block, with each point taken as close as practical to the calibration point on the artefact. Construct the point-to-point length, then project this length onto the reference (gauge axis) direction. The projected length is then compared to the calibrated value of the artefact.

For some gauges that are very long relative to the size of the gauging faces (e.g. when the calibrated test length is greater than 10 times the size of the gauging face), the reference direction may be established using points on the non-gauging surfaces of the artefact. For example, measuring points on two of the long sides of a gauge block can be used to establish the reference (gauge axis) direction. This alignment technique should also be used for step gauges, if there is no alignment procedure in the calibration certificate. The single point or the representative point measured on each gauging surface is then used to construct a point-to-point length that is projected onto the reference direction. This projected length is then compared to the calibrated value of the artefact.

For unidirectional lengths using wrung gauge blocks, determination of the gauge axis may require the use of the non-gauging surfaces, and the calibration points may be inaccessible.

C.3 Ball bar/Ball plate

A method of aligning ball bars or ball plates when they are measured in a bidirectional manner is to measure each sphere using four points or four representative points, one point located on the sphere, intersecting the gauge axis (i.e. end point), and the other three points spaced 90° apart, located on the sphere and in a plane orthogonal to the gauge axis and containing the sphere centre (i.e. points on the equator). These three points serve to align the ball bar or ball plate. See Figure C.1.

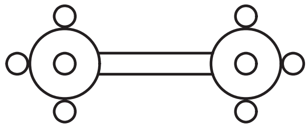


Figure C.1 — View showing a four-point probing pattern per sphere used for a bidirectional ball bar measurement

Annex D
(informative)

Interim testing

D.1 General

A quick and effective interim test of the articulated arm‘s correct operation and compensation is the single point articulation test. This test is described in greater detail below. Additional tests of known lengths (for example, measurements selected from the length error test) are also useful interim tests.

D.2 Single point articulation test

D.2.1 Principle

The principle of the single point articulation assessment is to measure the variation in position of an articulated arm CMM ball probe (tactile probe) in a kinematic seat as the elbow of the articulated arm CMM joints is rotated about the seat. During the rotation, 10 points are measured. The maximum distance between the measured and averaged coordinates of the 10 points yields the single point articulation (SPAT) error. The manufacturer provides a maximum recommended value for the test. The absolute value of the SPAT error is expected to be less than the corresponding maximum recommended value for a properly operating articulated arm CMM.

D.2.2 Measuring equipment

The kinematic seat may be a conical socket or trihedral socket. A magnet may be placed in the bottom of the seat to assist the operator in keeping the articulated arm CMM ball probe in contact with the seat during the test.

It is recommended that the position of a sphere placed in the kinematic seat be repeatable to less than or equal to 20 % of the maximum recommended value for the SPAT.

NOTE 1 The most common type of trihedral socket comprises three mounted spheres onto which the larger sphere is placed.

NOTE 2 The conical socket has a recommended cone angle of 60° to 120° and a recommended depth such that at least one-third of the sphere diameter lies inside the cone.

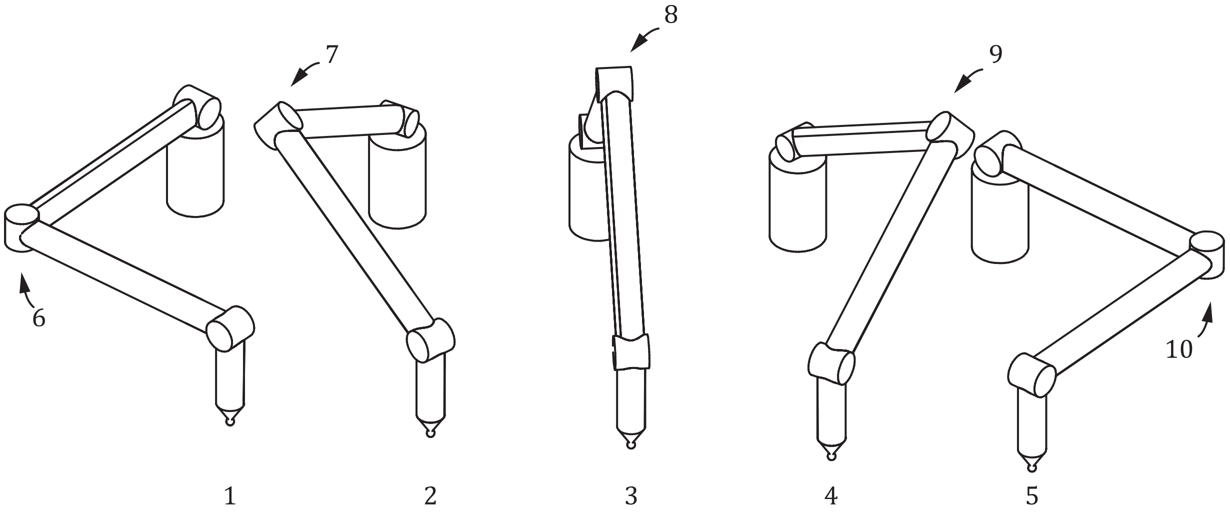
D.2.3 Procedure

The measurement may be performed at any location within the measuring volume of the articulated arm CMM.

As shown in Figure D.1, begin by placing the articulated arm CMM probe in the socket. Place the arm elbow to the left and down. Keeping the probe stylus vertical and the probe tip in contact with the socket, move the elbow through a 180° arc so that the elbow points upward midway through the arc and down to the right at the end. Record the coordinates of the probe at the end points (shown in Figure D.1, points 1, 5) and at three additional intermediate points (Figure D.1, points 2, 3, 4) approximately evenly spaced throughout the arc. A total of five points are collected in this first movement.

If the articulated arm CMM has the capability, rotate the last axis (usually the seventh axis) by 180°. Whether the last axis has been rotated or not, place the articulated arm CMM probe in the socket with the arm elbow to the right and down. Keeping the probe in contact with the socket, move the elbow through a 180° arc so that the elbow points upward midway through the arc and down to the left at the end. Record the coordinates of the probe at end points and at three additional points approximately evenly spaced throughout the arc. A total of 10 points will be collected in the first and second movements of the elbow in this test.

During this test, the stylus probing point is held at a fixed three-dimensional position within the socket.



Key

1-5 five elbow positions
6 elbow 90° left
7 elbow 45° left
8 elbow overhead
9 elbow 45° right
10 elbow 90° right

Figure D.1 — View showing five positions of an articulated arm CMM in performing a single point articulation test

D.2.4 Derivation of test results

Find the average Cartesian coordinate of the probe tip by averaging the 10 measured values. Calculate half the range in each of x, y, and z directions. The maximum of these three range values is the SPAT error. If the SPAT error exceeds the corresponding maximum recommended value provided by the manufacturer, there may be something wrong with the articulated arm or with the measurement setup or environment.

Annex E
(normative)

Testing a scanning probing system of an articulated arm CMM

E.1 Probing errors of form and size

There are two metrological results that are important in providing confidence in measurements taken with an articulated arm CMM integrated with a scanner (sometimes referred to as a laser scanner or laser line probe). The first of these is a test of the system when the scanner probing system is used, and the second is a test of the registration of this probing method to the default (tactile) probing system.

The methods described in this annex intentionally reflect other parts of the ISO 10360 series and intend to refine, not change, these existing methods.

Measurements are performed at the two locations indicated in 6.2.3. Measurements are performed according to ISO 10360-8:2013, 6.2. Quantities to be measured include probing form error, $P_{\text{Form.Sph.1x25::ODS.AArm}}$, probing dispersion error, $P_{\text{Form.Sph.D95\%::ODS.AArm}}$, probing size error, $P_{\text{Size.Sph.1x25::ODS.AArm}}$, and probing size error All, $P_{\text{Size.Sph.All::ODS.AArm}}$. The measured values are compared to specifications provided by the manufacturer, $P_{\text{Form.Sph.1x25::ODS.AArm,MPE}}$, $P_{\text{Form.Sph.D95\%::ODS.AArm,MPE}}$, $P_{\text{Size.Sph.1x25::ODS.AArm,MPE}}$, and $P_{\text{Size.Sph.All::ODS.AArm,MPE}}$, respectively, to determine compliance, as described in ISO 10360-8:2013, 7.1.

During performance of measurements in this annex, the operator shall move the scanning probing system smoothly rather than in a chaotic manner. Furthermore, the user shall follow the practices recommended by the manufacturer in an operating manual for the use of the scanner when measuring workpieces.

E.2 Flat form errors

The flat form measurement is performed in any one location of the measuring volume. Measurements are performed according to ISO 10360-8:2013, 6.4. If desired, position (2) of the artefact may be obtained by leaving the artefact in position (1) and changing the orientation of the scanner. The probing flat form error $P_{\text{Form.Pla.D95\%::ODS.AArm}}$ is measured and compared to the corresponding maximum permissible error $P_{\text{Form.Pla.D95\%::ODS.AArm,MPE}}$ provided by the manufacturer to determine compliance, as described in ISO 10360-8:2013, 7.1.

E.3 Registration errors

The registration of the scanner probing system to the tactile probing system of the articulated arm CMM is tested according to the method of ISO 10360-9. Three test spheres shall be placed at locations in the measuring volume. The centres of the three spheres are determined using the tactile probe and the scanning probe of the articulated arm CMM following the method of ISO 10360-9:2013, Clause 6. For the scanning probe, the 25 points are determined using the method of ISO 10360-8:2013, 6.2.4.1. Quantities to be measured include multiple probing system form error, $P_{\text{Form.Sph.1x25::MPS.AArm}}$, multiple probing system size error, $P_{\text{Size.Sph.1x25::MPS.AArm}}$, and multiple probing system location value, $L_{\text{Dia.1x25::MPS.AArm}}$. The measured values are compared to specifications provided by the manufacturer, $P_{\text{Form.Sph.1x25::MPS.AArm,MPE}}$, $P_{\text{Size.Sph.1x25::MPS.AArm,MPE}}$, and $L_{\text{Dia.1x25::MPS.AArm,MPE}}$, respectively, to determine compliance, as described in ISO 10360-9:2013, 7.1.

Annex F
(normative)

Length error measurement by concatenating test lengths

F.1 General

If a calibrated test length spanning 66 % of the measuring range is not available, the following method of concatenation of two calibrated test lengths measurement may be used by mutual agreement. This method shall not be used for calibrated test lengths spanning less than 66 % of the measuring range.

NOTE Once the concatenated length measurement is agreed upon, the resulting values are subject to all decision rules according to Clause 7.

F.2 Length error using concatenated test lengths

F.2.1 Principle

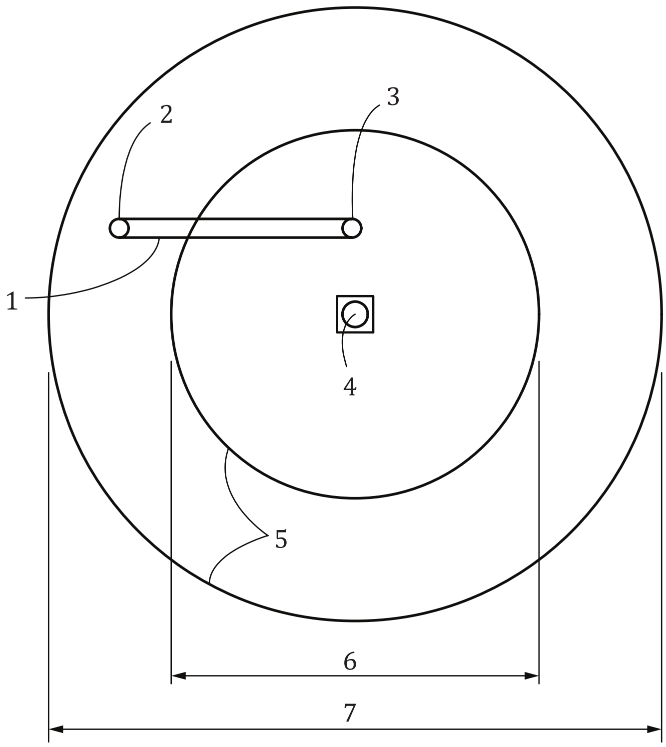
The principle of the length error assessment using concatenated lengths is to use two calibrated test lengths, traceable to the metre, to demonstrate compliance of the articulated arm CMM to the stated maximum permissible error of the combined length measurement provided by the manufacturer. The manufacturer may choose to provide specifications for the maximum permissible error of unidirectional length measurement, $E_{\mathrm{Uni,MPE}}$, the maximum permissible error of bidirectional length measurement, $E_{\mathrm{Bi,MPE}}$, or both.

F.2.2 Measuring equipment

The measuring equipment, which includes one or more calibrated test length, has the characteristics described in 6.4.2.

F.2.3 Procedure

As shown in Figure F.1, place a first calibrated test length so that the first end of the artefact lies within a spherical envelope covering 60 % to 100 % of the measuring range.



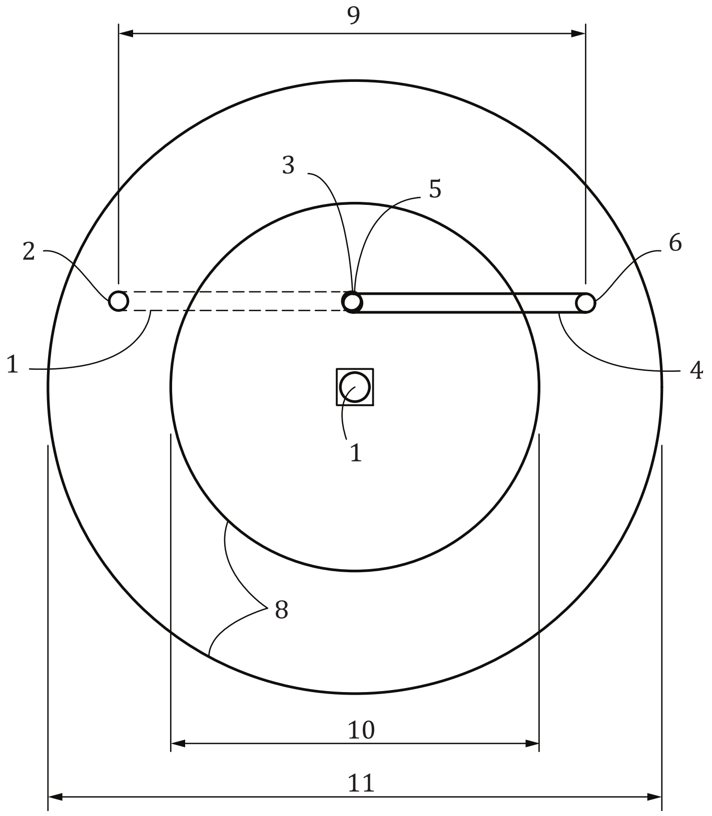
Key

1 first calibrated test length, E11, E12, E13
2 first end of first calibrated test length
3 second end of first calibrated test length
4 centre of articulated arm CMM
5 spheres about centre
6 60 % of measuring range
7 100 % of measuring range

Figure F.1 — View showing first calibrated test length

Measure the first calibrated test length three times using the elbow position indicated in Table 3. The same sequence of elbow positions is used for all three repeats.

As shown in Figure F.2, place a second calibrated test length so that the distance between the second end of the first calibrated test length and the first end of the second calibrated test length is not greater than 12 mm. Align the second test length to have the same nominal direction as the first test length. The distance between the first end of the first calibrated test length and the second end seat of the second calibrated test length shall be at least 66 % of the measuring range. The second end of the second calibrated test length shall lie within a spherical envelope covering 60 % to 100 % of the measuring range.



Key

1 first calibrated test length, E11, E12, E13
2 first end of first calibrated test length
3 second end of first calibrated test length
4 second calibrated test length, E11, E12, E13
5 first end of second calibrated test length
6 second end of second calibrated test length
7 centre of articulated arm CMM
8 spheres about centre
9 66 % of measuring range
10 60 % of measuring range
11 100 % of measuring range

Figure F.2 — View showing relative positions of first and second calibrated test lengths

Measure the second calibrated test length three times using the elbow position indicated in Table 3. The same sequence of elbow positions is used for all three repeats.

This procedure is required for each position indicated in Table 2 that requires concatenation.

F.2.4 Derivation of test results

Following the procedure of 6.4, the first test length is measured three times and the calibrated test length subtracted from each of the three measured values to obtain three signed length errors E_{11}, E_{12}, and E_{13}. In these expressions, the first subscript represents the number of the test length (first or second), and the second subscript indicates the number of the repetition (first, second, or third). The errors E_{11}, E_{12}, and E_{13} may represent E_{Uni}, E_{Bi}, or both, according to the manufacturer's specifications.

The second test length is likewise measured three times and the calibrated test length subtracted from each to obtain three signed length errors E_{21}, E_{22}, and E_{23}.

Three concatenated length errors are calculated using $E_{c1} = E_{11} + E_{21}$, $E_{c2} = E_{12} + E_{22}$, and $E_{c3} = E_{13} + E_{23}$. Each of the concatenated length errors may be a unidirectional length measurement error, E_{Uni}, a bidirectional length measurement error, E_{Bi}, or both E_{Uni} and E_{Bi} according to the manufacturer's specifications. Note that the three repetitions are matched. The first repetition of the first test length is added to the first repetition of the second test length, and so forth.

NOTE 1 The measurement errors for the first calibrated reference length and the second calibrated reference length are reported with the sign (+ or −) of the error. The sign is retained in subsequent additions to get the three concatenated length errors.

NOTE 2 The concatenation method of this annex typically overestimates the error that would have occurred with a single calibrated test length spanning 66 % of the measuring range. The intermediate nest position provides an additional source of error because of non-repeatability of the measurement system.

F.2.5 Test value uncertainty

For the three measurements of the first calibrated test length, calculate three corresponding signed length errors.

The evaluation of the test value uncertainties is to be carried out for each test position of the calibrated test length.

The test value uncertainty associated with the concatenation method depends on the calibrated test lengths used in the procedure. If a different calibrated test length artefact is used on stage 2 of the concatenation than on stage 1 then the test value uncertainty includes the RSS (root-sum-of-squares) of the two uncertainties. If the calibrated test length used is stage 2 of the concatenation method is the same artefact as stage 1 then the test value uncertainty includes the arithmetic sum of the uncertainties associated with each calibrated test length measurement. The uncertainty contribution from the action of staging itself, i.e. misalignment of the artefacts relative to the line between the start and end nests, is evaluated for each stage of the measurements:

$u(E)$ is the standard uncertainty of length measurement error;

$u_{S1}(E)$ is the standard uncertainty of length measurement error for the first test length;

$u_{S2}(E)$ is the standard uncertainty of length measurement error for the second test length.

The general measurement uncertainty contributors are:

$$u\left(E\right)=\sqrt{u^2\left(\varepsilon_{\text{cal}}\right)+u^2\left(\varepsilon_{\alpha}\right)+u^2\left(\varepsilon_{t}\right)+u^2\left(\varepsilon_{\text{align}}\right)+u^2\left(\varepsilon_{\text{fixt}}\right)+u^2\left(\varepsilon_{\text{drift}}\right)}$$

where

$u(\varepsilon_{cal})$ is the calibration standard uncertainty;

$u(\varepsilon_{\alpha})$ is the standard uncertainty due to CTE;

$u(\varepsilon_{t})$ is the standard uncertainty due to temperature during measurement;

$u(\varepsilon_{\text{align}})$ is the standard uncertainty due to alignment (in the concatenation method, the misalignment is that of the calibrated test length relative to the line between the starting nest and the ending nest of the measurement procedure);

$u(\varepsilon_{\text{fixt}})$ is the standard uncertainty due to fixturing;

$u(\varepsilon_{\text{drift}})$ is the standard uncertainty attributed to changes in the calibrated test lengths.

NOTE The standard uncertainty due to CTE, $u(\varepsilon_\alpha)$, and temperature, $u(\varepsilon_t)$, are zero for either of two cases: (1) no artefact temperature compensation is used or (2) artefact temperature compensation is provided as part of the articulated arm test system. The standard uncertainty due to CTE, $u(\varepsilon_\alpha)$, and temperature, $u(\varepsilon_t)$, are not zero when temperature compensation, which is not part of the articulated arm test system, is applied by the operator.

The expanded uncertainties ($k = 2$) for the two artefact stages are

$$U_{S1}\left(E\right) = 2\sqrt{u_1^2\left(\varepsilon_{\text{cal}}\right) + u_1^2\left(\varepsilon_\alpha\right) + u_1^2\left(\varepsilon_{\text{t}}\right) + u_1^2\left(\varepsilon_{\text{align}}\right) + u_1^2\left(\varepsilon_{\text{fixt}}\right) + u_1^2\left(\varepsilon_{\text{drift}}\right)}$$

$$U_{S2}\left(E\right) = 2\sqrt{u_2^2\left(\varepsilon_{\text{cal}}\right) + u_2^2\left(\varepsilon_\alpha\right) + u_2^2\left(\varepsilon_{\text{t}}\right) + u_2^2\left(\varepsilon_{\text{align}}\right) + u_2^2\left(\varepsilon_{\text{fixt}}\right) + u_2^2\left(\varepsilon_{\text{drift}}\right)}$$

The test value uncertainty associated with the concatenated test length is

$$U\left(E\right) = U_{S1}\left(E\right) + U_{S2}\left(E\right)$$ if the first calibrated test length is the same as the second calibrated test length, and

$$U\left(E\right) = \sqrt{U_{S1}^2\left(E\right) + U_{S2}^2\left(E\right)}$$ if the first calibrated test length is different than the second calibrated test length.

Annex G
(informative)

Optional probing articulated size and forms errors

G.1 General

A method for determining articulated location errors is described in 6.3. By mutual agreement, two additional errors may be calculated using the data collected in the test procedure of 6.3: probing articulated size error, $P_{\text{Size.Sph.5x5:Art:Tact.AArm}}$, and probing articulated form error, $P_{\text{Form.Sph.5x5:Art:Tact.AArm}}$.

G.2 Probing articulated size form errors

G.2.1 Principle

The principle of measurement is described in 6.3.

G.2.2 Measuring equipment

The measuring equipment is described in 6.3.

G.2.3 Procedure

The procedure is described in 6.3.

G.2.4 Derivation of test results

For each of the first and second locations, using all 25 measurements, compute the Gaussian (least-squares) associated sphere. Subtract the calculated diameter D_{Meas} of the Gaussian (least-squares) associated sphere from the calibrated diameter D_{Ref} to get $P_{\text{Size.Sph.5x5:Art:Tact.AArm}} = D_{\text{Meas}} - D_{\text{Ref}}$. The absolute value of the probing articulated size error at each location shall be compared to the MPE value or values specified by the manufacturer, $P_{\text{Size.Sph.5x5:Art:Tact.AArm,MPE}}$.

For each of the first and second locations, using all 25 measurements, compute the Gaussian (least-squares) associated sphere. For each of the 25 measurements, calculate a Gaussian radial distance R with respect to the Gaussian (least-squares) sphere centre. Calculate the probing form error by taking the range of Gaussian radial distances: $P_{\text{Form.Sph.5x5:Art:Tact.AArm}} = R_{\max} - R_{\min}$. The probing articulated form error at each location shall be compared to the MPE value or values specified by the manufacturer, $P_{\text{Form.Sph.5x5:Art:Tact.AArm,MPE}}$.

Annex H
(informative)

Optional repeatability range of the length measurement error

H.1 General

A method for determining length measurement error is described in 6.4. By mutual agreement, the data collected in the test procedure of 6.4 may be used to calculate a unidirectional repeatability range of the length measurement error, $R_{\text{Uni.0::Tact.AArm}}$, a bidirectional repeatability range of the length measurement error, $R_{\text{Bi.0::Tact.AArm}}$, or both.

H.2 Repeatability range of the length measurement error

H.2.1 Principle

The measuring equipment is described in 6.4

H.2.2 Measuring equipment

The measuring equipment is described in 6.4

H.2.3 Procedure

The measuring equipment is described in 6.4

H.2.4 Derivation of test results

H.2.4.1 For unidirectional length error measurements

If unidirectional length errors are obtained in 6.4, $R_{\text{Uni.0::Tact.AArm}}$ may be determined by carrying out two steps:

a) calculating a range for each of the 35 sets of three repeated unidirectional length error measurements;

b) taking the maximum of the 35 ranges.

The absolute value of the unidirectional range of length measurement error at each location shall be compared to the corresponding MPE value, $R_{\text{Uni.0::Tact.AArm,MPE}}$.

H.2.4.2 For bidirectional length error measurements

Follow H.2.4.1 but for the case of bidirectional measurements.

Annex I
(informative)

Relation to the GPS matrix model

I.1 General

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

I.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.

I.3 Position in the GPS matrix model

This part of ISO 10360 is a general GPS standard. The rules and principles given in this part of ISO 10360 apply to all segments of the ISO GPS matrix which are indicated with a filled dot (•), as graphically illustrated in Table I.1.

Table I.1 — Fundamental and general ISO GPS standards matrix

	Chain links						
	A	B	C	D	E	F	G
	Symbols and indications	Feature requirements	Feature properties	Conformance and non-conformance	Measurement	Measurement equipment	Calibration
Size						•	
Distance						•	
Form						•	
Orientation						•	
Location						•	
Run-out						•	
Profile surface texture							
Areal surface texture							
Surface imperfections							

I.4 Related standards

The related standards are those of the chains of standards indicated in Table I.1.

Bibliography

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

[2] ISO 8015, *Geometrical product specifications (GPS) — Fundamentals — Concepts, principles and rules*

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

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

[5] ISO 14253-1, *Geometrical product specifications (GPS) — Inspection by measurement of workpieces and measuring equipment — Part 1: Decision rules for proving conformity or nonconformity with specifications*

[6] ISO 14638, *Geometrical product specifications (GPS) — Matrix model*

[7] ISO 17450-1, *Geometrical product specifications (GPS) — General concepts — Part 1: Model for geometrical specification and verification*

[8] ISO/IEC Guide 99:2007, *International vocabulary of metrology — Basic and general concepts and associated terms (VIM)*

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