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

Part 8:
CMMs with optical distance sensors

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

Partie 8: MMT avec détecteurs optiques sans contact

Reference number
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Foreword

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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. www.iso.org/directives

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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 WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

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 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*

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

— *Part 8: CMMs with optical distance sensors*

— *Part 9: CMMs with multiple probing systems*

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

The following parts are under preparation:

— *Part 12: Articulated-arm CMMs*

Computed tomography is to form the subject of a future part 11.

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 link 5 of the chains of standards on size, distance, radius, angle, form, orientation, location, run-out and datums. For more detailed information of the relation of this part of ISO 10360 to other standards and the GPS matrix model, see Annex E.

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

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 optical distance sensor and

b) to test the errors of the optical distance sensor.

Optical distance sensors treated in this standard are classified into two types,

— point measuring sensors, and

— area measuring sensors (e.g. laser point scan, laser line scan, fringe projection)

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

This part of ISO 10360 parallels that of ISO 10360-2 and ISO 10360-5, which is for CMMs equipped with contact probing systems. The testing methodology between these three parts of ISO 10360 is designed to be intentionally similar. The differences that exist may be eliminated in future revisions of this part or in ISO 10360-2.

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

Part 8: CMMs with optical distance sensors

1 Scope

This part of ISO 10360 specifies the acceptance tests for verifying the performance of a CMM (coordinate measuring machine) when measuring lengths 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 with optical distance sensors. This standard does not explicitly apply to non-Cartesian CMMs, however, the parties may apply this part of 10360 to non-Cartesian CMMs by mutual agreement.

NOTE This part of ISO 10360 is not intended to apply for CMMs whose measuring volume is significantly smaller than the size of the test sphere, however, the principle, artefacts, and procedure of the test described in this part of ISO 10360 are useful for the acceptance and reverification tests of those CMMs either as it is or with modifying the parameters such as the size of the test artefacts and the number of the measurements.

This part of ISO 10360 specifies:

— performance requirements that can be assigned by the manufacturer or the user of the CMM,

— the manner of execution of the acceptance and reverification tests to demonstrate the stated requirements,

— rules for verifying 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 10360-1:2000, *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 10360-5:2010, *Geometrical product specifications (GPS) — Acceptance and reverification tests for coordinate measuring machines (CMM) — Part 5: CMMs using single and multiple stylus contacting probing systems*

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*

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 part of ISO 10360, the terms and definitions given in ISO 10360-1, ISO 14253-1 and ISO/IEC Guide 99 and the following apply.

3.1
optical distance sensor
non-contacting probing system which determines a corrected measured point by means of optical distance measurement principle

Note 1 to entry: Typical measurement principles are triangulation and coaxial distance measurement. The former includes structured line projection, Moiré, slit light projection, point scanning, etc., and the latter includes interferometry and confocal systems.

3.2
local test flat
flat form standard used for evaluating the probing form error when testing the probing performance

Note 1 to entry: A local test flat is used in addition to the test sphere which is used for evaluating both the probing form and probing size errors.

Note 2 to entry: A local test flat is useful for testing probing performance when a calibrated test sphere with larger size suitable for an optical distance sensor with larger sensor area is practically difficult to obtain. Figure 5 shows a flow chart for material standard selection.

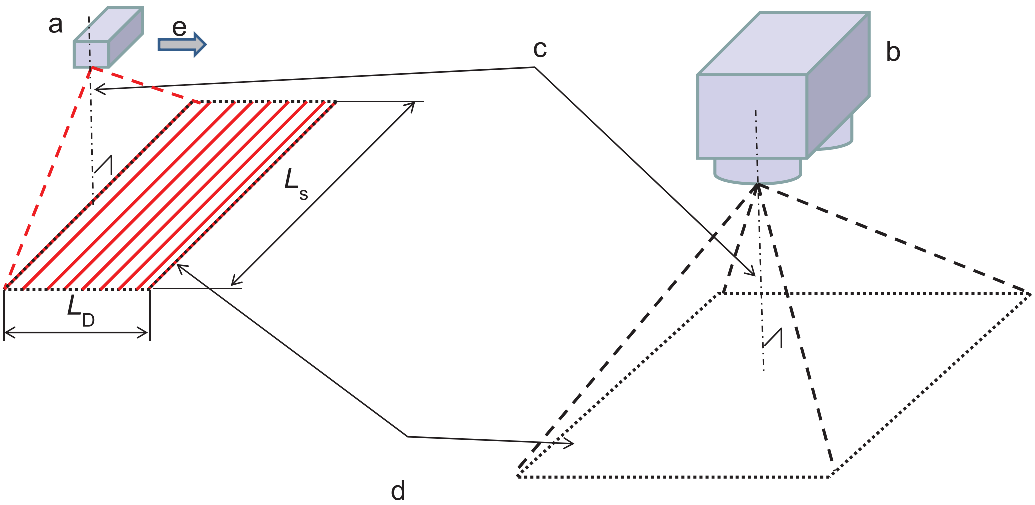
3.3
global test flat
flat form standard used when testing the flat form measurement error

Note 1 to entry: Global test flat is intended and encouraged to test form measuring performance of a CMM equipped with an optical distance sensor when the system is used for measuring a larger area than the sensor area.

3.4
sensor area
area illuminated by the optical distance sensor when a two-dimensional image-projection-type sensor is used

Note 1 to entry: The sensor area is determined not only by the length of the projection line of the sensor but also by the length of the sensor movement realized by the CMM when line scan or point scan sensors are used.

See Figure 1.



a) Example of line scan or point scan sensor **b) Example of two dimensional image projection sensor**

Key

L_S length of the projection line

L_D length of the sensor movement

a line scan or point scan sensor

b two dimensional image projection sensor

c sensor axis

d sensor area

e sensor motion

Figure 1 — Definition of the sensor area

3.5

probing form error

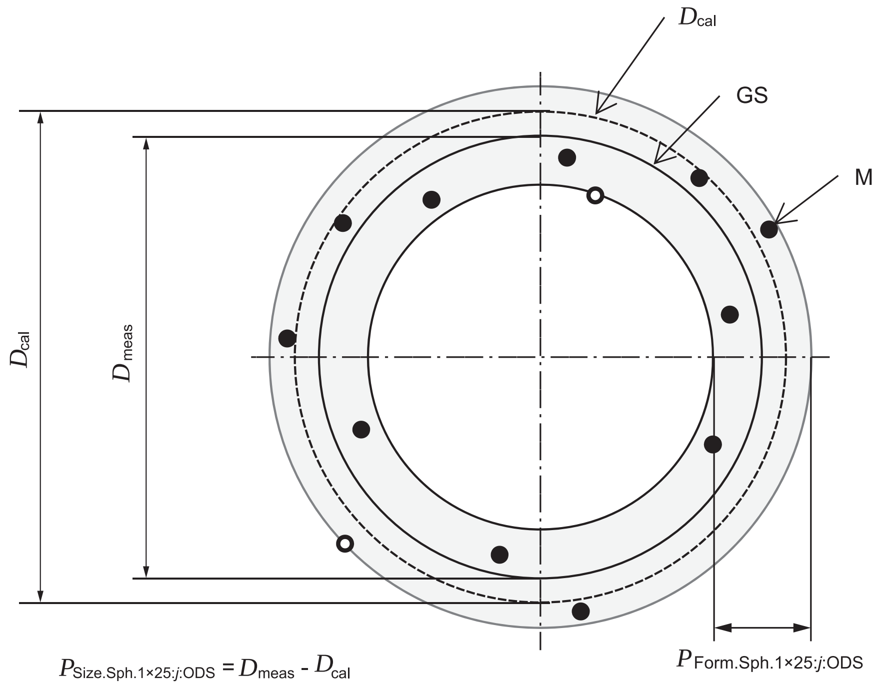
$P_{\text{Form.Sph.1×25:}j\text{:ODS}}$

error of indication within which the range of either the radial distances that can be determined by a least-squares fit (Gaussian associated feature) of points measured on a spherical material standard of size or those supplemented with the normal distances that can be determined by a least-squares fit of points measured on a local test flat

Note 1 to entry: The symbol “*P*” in $P_{\text{Form.Sph.1×25:}j\text{:ODS}}$ indicates that the error is associated with the probing system performance, the qualifier “Form.Sph” indicates that it is associated with the probing form error and the qualifier “ODS” indicates that it is associated with the optical distance sensor. The qualifier “*j*” identifies the measuring conditions of the CMM. $P_{\text{Form.Sph.1×25:Tr:ODS}}$ is the optical probing form error translatory, which is given when the sensor is moved by the CMM and measurements are taken at several positions. $P_{\text{Form.Sph.1×25:Art:ODS}}$ is the optical probing form error articulating, which is given when the alignment of the sensor is additionally modified by means of an *articulating* system. $P_{\text{Form.Sph.1×25:St:ODS}}$ is the optical probing form error *stationary*, which is given when the sensor is not moved by the CMM during measurements (see Figure 3).

Note 2 to entry: The probing form error is determined by the errors of the sensors (such as noise, digitizing errors, image distortion, optical interaction with the surface of the material standard, calibration errors of the sensor, faulty algorithms in measured data processing) and those of the CMM.

See Figure 2.



Key

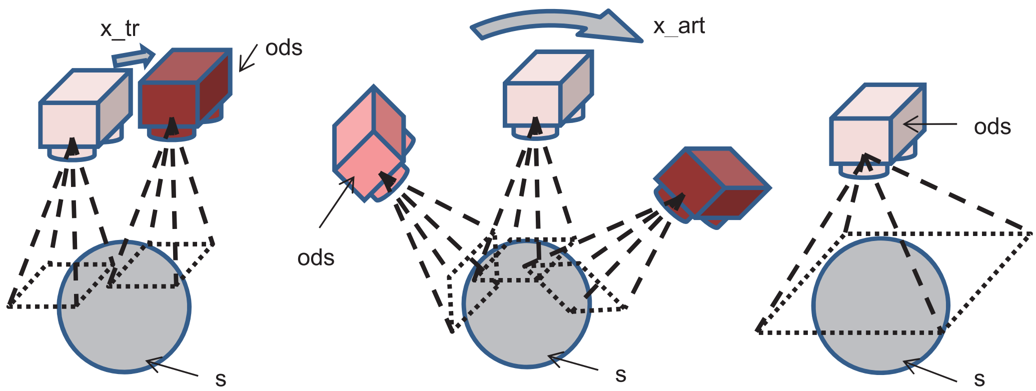
D_{cal} calibrated diameter of test sphere

D_{meas} measured diameter of test sphere

GS Gaussian associated sphere

MP measured point

Figure 2 — Illustration of $P_{Form.Sph.1×25:j:ODS}$ and $P_{Size.Sph.1×25:j:ODS}$



a) Translatory **b) Articulating** **c) Stationary**

Key

ods optical distance sensor

s test sphere

x_art articulation

x_tr translation

Figure 3 — Illustration of Tr, Art and St

3.6
probing dispersion value
$P_{\text{Form.Sph.D95\%:}j\text{:ODS}}$
smallest width of a spherical shell or smallest separation of two parallel planes that encompasses 95 % of all the data points

Note 1 to entry: The symbol "*P*" in $P_{\text{Form.Sph.D95\%:}j\text{:ODS}}$ indicates that the error is associated with the probing system performance, the qualifier "Form.Sph" indicates that it is associated with the probing form error, the qualifier "D95%" indicates that it is associated with the dispersion of the probing points with 95 % population and the qualifier "ODS" indicates that it is associated with the optical distance sensor. The qualifier "*j*" identifies the measuring conditions of the CMM. $P_{\text{Form.Sph.D95\%:Tr:ODS}}$ is the probing dispersion value translatory, which is given when the sensor is moved by the CMM and measurements are taken at several positions. $P_{\text{Form.Sph.D95\%:Art:ODS}}$ is the probing dispersion value articulating, which is given when the alignment of the sensor is additionally modified by means of an *articulating* system. $P_{\text{Form.Sph.D95\%:St:ODS}}$ is the probing dispersion value *stationary*, which is given when the sensor is not moved by the CMM during measurements (see Figure 3).

Note 2 to entry: The dispersion of the probing system is also called the range or thickness of the probing (point) cloud.

Note 3 to entry: 5 % of the measured points are eliminated to determine $P_{\text{Form.Sph.D95\%:}j\text{:ODS}}$. Outlier data points that might be present in the measurement data may also be eliminated by this operation.

Note 4 to entry: For this particular definition, the plane is thought of as a sphere of infinite radius.

3.7
probing size error
$P_{\text{Size.Sph.1×25:}j\text{:ODS}}$
error of indication of the difference between the diameter of a least-squares fit of 25 representative points on a test sphere and its calibrated diameter

Note 1 to entry: The symbol "*P*" in $P_{\text{Size.Sph.1×25:}j\text{:ODS}}$ indicates that the error is associated with the probing system performance, the qualifier "Size.Sph" indicates that it is associated with the probing size error and the qualifier "ODS" indicates that it is associated with the optical distance sensor. The qualifier "*j*" identifies the measuring conditions of the CMM. $P_{\text{Size.Sph.1×25:Tr:ODS}}$ is the optical probing size error *translatory*, which is given when the sensor is moved by the CMM and measurements are taken at several positions. $P_{\text{Size.Sph.1×25:Art:ODS}}$ is the optical probing size error *articulating*, which is given when the alignment of the sensor is additionally modified by means of an articulating system. $P_{\text{Size.Sph.1×25:St:ODS}}$ is the optical probing size error *stationary*, which is given when the sensor is not moved by the CMM during measurements (see Figure 3).

Note 2 to entry: Probing size error is determined by the errors of the sensors (such as noise, digitizing errors, image distortion, optical interaction with the surface of the material standard, calibration errors of the sensor, faulty algorithms in measured data processing) and those of the CMM.

See Figure 2.

3.8
probing size error All
$P_{\text{Size.Sph.All:}j\text{:ODS}}$
error of indication of the difference between the diameter of a least-squares fit of all points measured on a test sphere and its calibrated diameter

Note 1 to entry: The symbol "*P*" in $P_{\text{Size.Sph.All:}j\text{:ODS}}$ indicates that the error is associated with the probing system performance, the qualifier "Size.Sph" indicates that it is associated with the probing size error, the qualifier "All" indicates that all measuring points are used for the calculation and the qualifier "ODS" indicates that it is associated with the optical distance sensor. The qualifier "*j*" identifies the measuring conditions of the CMM. $P_{\text{Size.Sph.All:Tr:ODS}}$ is the optical probing size error *translatory*, which is given when the sensor is moved by the CMM and measurements are taken at several positions. $P_{\text{Size.Sph.All:Art:ODS}}$ is the optical probing size error *articulating*, which is given when the alignment of the sensor is additionally modified by means of an articulating system. $P_{\text{Size.Sph.All:St:ODS}}$ is the optical probing size error *stationary*, which is given when the sensor is not moved by the CMM during measurements (see Figure 3).

Note 2 to entry: Probing size error All is determined by the errors of the sensors (such as noise, digitizing errors, image distortion, optical interaction with the surface of the material standard, calibration errors of the sensor, faulty algorithms in measured data processing) and those of the CMM.

3.9
length measurement error
$E_{\text{Bi}:j:\text{ODS}}$
$E_{\text{Uni}:j:\text{ODS}}$
error of indication when measuring a calibrated test length

Note 1 to entry: The symbol "E" in $E_{\text{Bi}:j:\text{ODS}}$ or $E_{\text{Uni}:j:\text{ODS}}$ indicates that the error is associated with the measurement error, the qualifier "Bi" or "Uni" indicates that it is associated with the bidirectional or unidirectional length measurement error and the qualifier "ODS" indicates that it is associated with the optical distance sensor. The qualifier "j" identifies the measuring conditions of the CMM. $E_{\text{Bi:Tr:ODS}}$ or $E_{\text{Uni:Tr:ODS}}$ is the length measurement error using optical probe translatory, which is given when the sensor is moved by the CMM and measurements are taken at several positions. $E_{\text{Bi:Art:ODS}}$ or $E_{\text{Uni:Art:ODS}}$ is the length measurement error using optical probe articulating, which is given when the alignment of the sensor is additionally modified by means of an articulating system. $E_{\text{Bi:St:ODS}}$ or $E_{\text{Uni:St:ODS}}$ is the length measurement error using optical probe stationary, which is given when the sensor is not moved by the CMM during measurements.

Note 2 to entry: A calibrated test length may be either bidirectionally calibrated or unidirectionally calibrated. See Annex B for detail.

3.10
flat form measurement error
$E_{\text{Form.Pla.D95\%}:j:\text{ODS}}$
smallest distance between two parallel planes that envelope 95 % of the points measured on a global test flat

Note 1 to entry: The symbol "E" in $E_{\text{Form.Pla.D95\%}:j:\text{ODS}}$ indicates that the error is associated with the measurement error, the qualifier "Form.Pla" indicates that it is associated with the flat form measurement error, the qualifier "D95%" indicates that it is associated with the dispersion of the measuring points with 95 % population and the qualifier "ODS" indicates that it is associated with the optical distance sensor. The qualifier "j" identifies the measuring conditions of the CMM. $E_{\text{Form.Pla.D95\%:Tr:ODS}}$ is the optical probing flat form measurement error *translatory*, which is given when the sensor is moved by the CMM and measurements are taken at several positions. $E_{\text{Form.Pla.D95\%:Art:ODS}}$ is the optical probing flat form measurement error *articulating*, which is given when the alignment of the sensor is additionally modified by means of an articulating system.

3.11
maximum permissible probing form error
$P_{\text{Form.Sph.1×25}:j:\text{ODS,MPE}}$
extreme value of $P_{\text{Form.Sph.1×25}:j:\text{ODS}}$ permitted by specifications as maximum permissible error

Note 1 to entry: The maximum permissible error of the probing form error $P_{\text{Form.Sph.1×25}:j:\text{ODS,MPE}}$ may be expressed in one of three forms:

a) $P_{\text{Form.Sph.1×25}:j:\text{ODS,MPE}}$ = minimum of $(A+L_P/K)$ and B, or

b) $P_{\text{Form.Sph.1×25}:j:\text{ODS,MPE}} = (A+L_P/K)$, or

c) $P_{\text{Form.Sph.1×25}:j:\text{ODS,MPE}} = B$

where

A is a positive constant, expressed in micrometres and supplied by the manufacturer;

K is a dimensionless positive constant supplied by the manufacturer;

L_P is the distance in 3D between the centres of the reference sphere and the test sphere (or flat), in millimetres;

B is the maximum permissible error $P_{\text{Form.Sph.1×25}:j:\text{ODS,MPE}}$, in micrometres, as stated by the manufacturer.

3.12
maximum permissible limit of probing dispersion
$P_{\text{Form.Sph.D95\%:}j\text{:ODS,MPL}}$
extreme value of $P_{\text{Form.Sph.D95\%:}j\text{:ODS}}$ permitted by specifications as maximum permissible limit

Note 1 to entry: The maximum permissible limit of the probing dispersion value $P_{\text{Form, 95\%, X, MPL}}$ may be expressed in one of three forms:

a) $P_{\text{Form.Sph.D95\%:}j\text{:ODS,MPL}}$ = minimum of $(A+L_P/K)$ and B, or

b) $P_{\text{Form.Sph.D95\%:}j\text{:ODS,MPL}} = (A+L_P/K)$, or

c) $P_{\text{Form.Sph.D95\%:}j\text{:ODS,MPL}} = B$

where

A is a positive constant, expressed in micrometres and supplied by the manufacturer;

K is a dimensionless positive constant supplied by the manufacturer;

L_P is the distance in 3D between the centres of the reference sphere and the test sphere (or flat), in millimetres;

B is the maximum permissible limit $P_{\text{Form.Sph.D95\%:}j\text{:ODS,MPL}}$, in micrometres, as stated by the manufacturer.

3.13
maximum permissible probing size error
$P_{\text{Size.Sph.1×25:}j\text{:ODS,MPE}}$
extreme value of $P_{\text{Size.Sph.1×25:}j\text{:ODS}}$ permitted by specifications as maximum permissible error

Note 1 to entry: The maximum permissible probing size error $P_{\text{Size.Sph.1×25:}j\text{:ODS,MPE}}$ may be expressed in one of three forms:

a) $P_{\text{Size.Sph.1×25:}j\text{:ODS,MPE}}$ = minimum of $(A+L_P/K)$ and B, or

b) $P_{\text{Size.Sph.1×25:}j\text{:ODS,MPE}} = (A+L_P/K)$, or

c) $P_{\text{Size.Sph.1×25:}j\text{:ODS,MPE}} = B$

where

A is a positive constant, expressed in micrometres and supplied by the manufacturer;

K is a dimensionless positive constant supplied by the manufacturer;

L_P is the distance in 3D between the centres of the reference sphere and the test sphere (or flat), in millimetres;

B is the maximum permissible error $P_{\text{Size.Sph.1×25:}j\text{:ODS,MPE}}$, in micrometres, as stated by the manufacturer.

3.14
maximum permissible probing size error All
$P_{\text{Size.Sph.All:}j\text{:ODS,MPE}}$
extreme value of $P_{\text{Size.Sph.All:}j\text{:ODS}}$ permitted by specifications as maximum permissible error

Note 1 to entry: The maximum permissible probing size error All $P_{\text{Size.Sph.All:}j\text{:ODS,MPE}}$ may be expressed in one of three forms:

a) $P_{\text{Size.Sph.All:}j\text{:ODS,MPE}}$ = minimum of $(A+L_P/K)$ and B, or

b) $P_{\text{Size.Sph.All:}j\text{:ODS,MPE}} = (A+L_P/K)$, or

c) $P_{\text{Size.Sph.All:}j\text{:ODS,MPE}} = B$

where

A is a positive constant, expressed in micrometres and supplied by the manufacturer;

K is a dimensionless positive constant supplied by the manufacturer;

L_P is the distance in 3D between the centres of the reference sphere and the test sphere (or flat), in millimetres;

B is the maximum permissible error $P_{\text{Size.Sph.All:}j\text{:ODS,MPE}}$, in micrometres, as stated by the manufacturer.

3.15
maximum permissible length measurement error
$E_{\text{Bi:}j\text{:ODS,MPE}}$
$E_{\text{Uni:}j\text{:ODS,MPE}}$
extreme value of $E_{\text{Bi:}j\text{:ODS}}$ or $E_{\text{Uni:}j\text{:ODS}}$ permitted by specifications as maximum permissible error

3.16
maximum permissible flat form measurement error
$E_{\text{Form.Pla.D95\%:}j\text{:ODS,MPE}}$
extreme value of $E_{\text{Form.Pla.D95\%:}j\text{:ODS}}$ permitted by specifications as maximum permissible error

Note 1 to entry: The maximum permissible flat form measurement error $E_{\text{Form.Pla.D95\%:}j\text{:ODS,MPE}}$ may be expressed in one of three forms:

a) $E_{\text{Form.Pla.D95\%:}j\text{:ODS,MPE}}$ = minimum of $(A+L_F/K)$ and B, or

b) $E_{\text{Form.Pla.D95\%:}j\text{:ODS,MPE}} = (A+L_F/K)$, or

c) $E_{\text{Form.Pla.D95\%:}j\text{:ODS,MPE}} = B$

where

A is a positive constant, expressed in micrometres and supplied by the manufacturer;

K is a dimensionless positive constant supplied by the manufacturer;

L_P is the largest side length of the evaluated plane in millimetres;

B is the maximum permissible error $E_{\text{Form.Pla.D95\%:}j\text{:ODS,MPE}}$, in micrometres, as stated by the manufacturer.

3.17
articulated location value
$L_{\text{Dia.5×25:Art:ODS}}$
diameter of the minimum circumscribed sphere of the centres of all five spheres

Note 1 to entry: Where the location of a test sphere can be determined by a least-squares fit of points, the measurements being taken with five different articulating angles on the one test sphere located anywhere in the measuring volume.

Note 2 to entry: The symbol "*L*" in $L_{\text{Dia.5} \times 25\text{:Art:ODS}}$ indicates that it is a location value, the qualifier "Art" identifies the measuring conditions of the CMM and the qualifier "ODS" indicates that it is associated with the optical distance sensor.

Note 3 to entry: All the symbols used in this annex are listed in Table D.1.

Note 4 to entry: All values are absolute.

3.18
maximum permissible limit of the articulated location value

$L_{\text{Dia.5×25:Art:ODS,MPL}}$

extreme value of the *articulated location value* (3.17), $L_{\text{Dia.5×25:Art:ODS}}$, permitted by specifications, regulations, etc. for the CMM

Note 1 to entry: The maximum permissible limit of the articulated location value, $L_{\text{Dia.5} \times 25\text{:Art:ODS,MPL}}$, can be expressed in one of three forms:

a) $L_{\text{Dia.5} \times 25\text{:Art:ODS,MPL}}$ = minimum of $(A + L_P/K)$ and B; or

b) $L_{\text{Dia.5} \times 25\text{:Art:ODS,MPL}} = (A + L_P/K)$; or

c) $L_{\text{Dia.5} \times 25\text{:Art:ODS,MPL}} = B$

where

A is a positive constant, expressed in micrometres and supplied by the manufacturer;

K is a dimensionless positive constant supplied by the manufacturer;

L_P is the distance in 3D between the centres of the reference sphere and the test sphere, in millimetres;

B is the maximum permissible limit $L_{\text{Dia.5} \times 25\text{:Art:ODS,MPL}}$, in micrometres, as stated by the manufacturer.

Note 2 to entry: A maximum permissible limit (MPL) as opposed to a maximum permissible error (MPE) specification is used when the test measurements are not errors; hence, testing an MPL specification does not require the use of artefacts with a relevant calibration.

4 Symbols

For the purpose of this International Standard, the symbols of Table 1 apply.

Table 1 — Symbols

Symbol	Meaning
$P_{\text{Form.Sph.1×25:}j\text{:ODS}}$	probing form error
$P_{\text{Form.Sph.D95\%:}j\text{:ODS}}$	probing dispersion value
$P_{\text{Size.Sph.1×25:}j\text{:ODS}}$	probing size error
$P_{\text{Size.Sph.All:}j\text{:ODS}}$	probing size error All
$E_{\text{Bi:}j\text{:ODS}}$	bidirectional length measurement error
$E_{\text{Uni:}j\text{:ODS}}$	unidirectional length measurement error
$E_{\text{Form.Pla.D95\%:}j\text{:ODS}}$	flat form measurement error
$P_{\text{Form.Sph.1×25:}j\text{:ODS,MPE}}$	maximum permissible probing form error
$P_{\text{Form.Sph.D95\%:}j\text{:ODS,MPL}}$	maximum permissible limit of probing dispersion value

Table 1 *(continued)*

Symbol	Meaning
$P_{\mathrm{Size.Sph.1\times25}:j:\mathrm{ODS,MPE}}$	maximum permissible probing size error
$P_{\mathrm{Size.Sph.All}:j:\mathrm{ODS,MPE}}$	maximum permissible probing size error All
$E_{\mathrm{Bi}:j:\mathrm{ODS,MPE}}$	maximum permissible bidirectional length measurement error
$E_{\mathrm{Uni}:j:\mathrm{ODS,MPE}}$	maximum permissible unidirectional length measurement error
$E_{\mathrm{Form.Pla.D95\%}:j:\mathrm{ODS,MPE}}$	maximum permissible flat form measurement error
$L_{\mathrm{Dia.5\times25:Art:ODS}}$	articulated location value
$L_{\mathrm{Dia.5\times25:Art:ODS,MPL}}$	maximum permissible limit of the articulated location value
The following qualifiers are used in place of *j* in the definitions above.	
Tr	translatory; when the sensor is moved by the CMM and measurements are taken at several positions
Art	articulating; when the alignment of the sensor is additionally modified by means of an articulating system
St	stationary; when the sensor is not moved by the CMM during measurements

5 Requirements for metrological characteristics

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 influences 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 testing will be performed within the manufacturer's specified limits given in the CMM data sheet.

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 the maximum permissible errors cannot be required to be verified.

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 include

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

b) probing system qualification,

c) thermal stability of the probing system before calibration,

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

e) software filter.

NOTE Probing system qualification can include a probe coordinate system setting, a light intensity setting, a filter configuration setting, and so on.

5.3 Probing form error

The probing form error, $P_{Form.Sph.1\times25:j:ODS}$, shall not exceed the maximum permissible probing form error, $P_{Form.Sph.1\times25:j:ODS,MPE}$, as stated by:

— the manufacturer, in the case of acceptance tests;

— the user, in the case of reverification tests.

The probing form error, $P_{Form.Sph.1\times25:j:ODS}$, and the maximum permissible probing form error, $P_{Form.Sph.1\times25:j:ODS,MPE}$, are expressed in micrometres.

Manufacturers may, at their discretion, specify optionally additional specifications of $P_{Form.Sph.1\times25:j:ODS,MPE}$ for special operating conditions.

5.4 Probing dispersion value

The probing dispersion value, $P_{Form.Sph.D95\%:j:ODS}$, shall not exceed the maximum permissible limit of probing dispersion value,

$P_{Form.Sph.D95\%:j:ODS,MPL}$, as stated by:

— the manufacturer, in the case of acceptance tests;

— the user, in the case of reverification tests.

Probing dispersion value, $P_{Form.Sph.D95\%:j:ODS}$, and the maximum permissible limit of probing dispersion value, $P_{Form.Sph.D95\%:j:ODS,MPL}$, are expressed in micrometres.

Manufacturers may, at their discretion, specify optionally additional specifications of $P_{Form.Sph.D95\%:j:ODS,MPL}$ for special operating conditions.

5.5 Probing size error

The probing size error, $P_{Size.Sph.1\times25:j:ODS}$, shall not exceed the maximum permissible probing size error, $P_{Size.Sph.1\times25:j:ODS,MPE}$, as stated by:

— the manufacturer, in the case of acceptance tests;

— the user, in the case of reverification tests.

Probing size error, $P_{Size.Sph.1\times25:j:ODS}$, and the maximum permissible probing size error, $P_{Size.Sph.1\times25:j:ODS,MPE}$, are expressed in micrometres.

Manufacturers may, at their discretion, specify optionally additional specifications of $P_{Size.Sph.1\times25:j:ODS,MPE}$ for special operating conditions.

5.6 Probing size error All

Probing size error, $P_{Size.Sph.All:j:ODS}$, shall not exceed the maximum permissible probing size error, $P_{Size.Sph.All:j:ODS,MPE}$, as stated by:

— the manufacturer, in the case of acceptance tests;

— the user, in the case of reverification tests.

Probing size error, $P_{Size.Sph.All:j:ODS}$, and the maximum permissible probing size error, $P_{Size.Sph.All:j:ODS,MPE}$, are expressed in micrometres.

Manufacturers may, at their discretion, specify optionally additional specifications of $P_{Size.Sph.All:j:ODS,MPE}$ for special operating conditions.

5.7 Length measurement error

Length measurement error, $E_{\mathrm{Bi}:j:\mathrm{ODS}}$ or $E_{\mathrm{Uni}:j:\mathrm{ODS}}$, shall not exceed the maximum permissible length measurement error,

$E_{\mathrm{Bi}:j:\mathrm{ODS,MPE}}$ or $E_{\mathrm{Uni}:j:\mathrm{ODS,MPE}}$, as stated by:

— the manufacturer, in the case of acceptance tests;

— the user, in the case of reverification tests.

Length measurement error, $E_{\mathrm{Bi}:j:\mathrm{ODS}}$ or $E_{\mathrm{Uni}:j:\mathrm{ODS}}$, and the maximum permissible length measurement error, $E_{\mathrm{Bi}:j:\mathrm{ODS,MPE}}$ or $E_{\mathrm{Uni}:j:\mathrm{ODS,MPE}}$, are expressed in micrometres.

Manufacturers may, at their discretion, specify optionally additional specifications of $E_{\mathrm{Bi}:j:\mathrm{ODS,MPE}}$ or $E_{\mathrm{Uni}:j:\mathrm{ODS,MPE}}$ for special operating conditions.

5.8 Flat form measurement error

Flat form measurement error, $E_{\mathrm{Form.Pla.D95\%}:j:\mathrm{ODS}}$, shall not exceed the maximum permissible flat form measurement error,

$E_{\mathrm{Form.Pla.D95\%}:j:\mathrm{ODS,MPE}}$, as stated by:

— the manufacturer, in the case of acceptance tests;

— the user, in the case of reverification tests.

Flat form measurement error, $E_{\mathrm{Form.Pla.D95\%}:j:\mathrm{ODS}}$, and the maximum permissible flat form measurement error, $E_{\mathrm{Form.Pla.D95\%}:j:\mathrm{ODS,MPE}}$, are expressed in micrometres.

Manufacturers may, at their discretion, specify optionally additional specifications of $E_{\mathrm{Form.Pla.D95\%}:j:\mathrm{ODS,MPE}}$ for special operating conditions.

5.9 Workpiece loading effects

The length measurement error, $E_{\mathrm{Bi}:j:\mathrm{ODS}}$ or $E_{\mathrm{Uni}:j:\mathrm{ODS}}$, shall not exceed the maximum permissible error, $E_{\mathrm{Bi}:j:\mathrm{ODS,MPE}}$ or $E_{\mathrm{Uni}:j:\mathrm{ODS,MPE}}$, 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 error, $E_{\mathrm{Bi}:j:\mathrm{ODS}}$ or $E_{\mathrm{Uni}:j:\mathrm{ODS}}$, 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 and/or on individual point loads (kg/cm^2); 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

In the following:

— 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.

6.2 Probing characteristics

6.2.1 Principle

The principle of the assessment method for the probing errors and limit is to establish whether the CMM with optical distance sensors is capable of measuring within the stated maximum permissible probing errors and limit. The four characteristics, i.e. $P_{\text{Form.Sph.1×25:}j\text{:ODS}}$, $P_{\text{Form.Sph.D95\%:}j\text{:ODS}}$, $P_{\text{Size.Sph.1×25:}j\text{:ODS}}$, and $P_{\text{Size.Sph.All:}j\text{:ODS}}$ are evaluated, but $P_{\text{Form.Sph.D95\%:}j\text{:ODS}}$ and $P_{\text{Size.Sph.All:}j\text{:ODS}}$ do not apply for CMMs with point measuring optical distance sensors.

If the CMM under test is equipped with an articulating probing system, the test defined in Annex D shall be performed additionally.

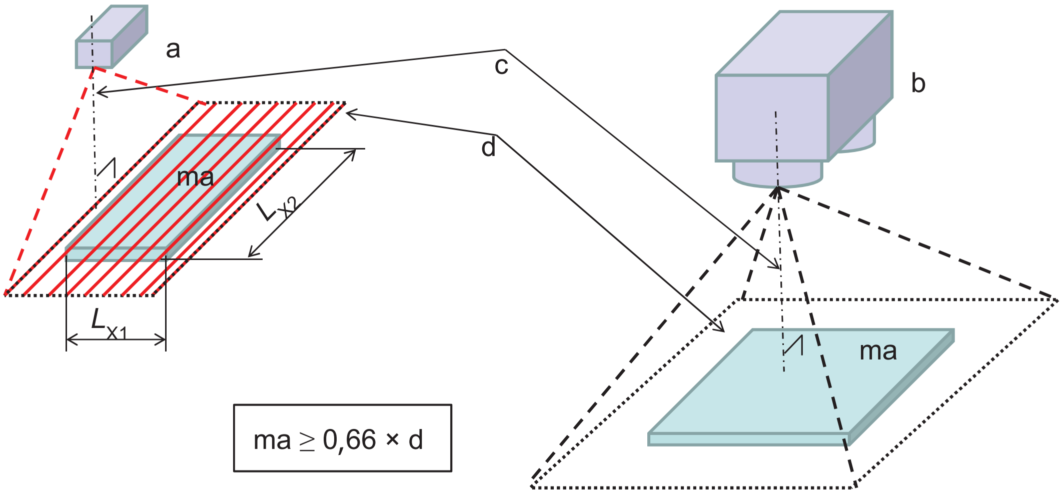
6.2.2 Measuring equipment

Material standards of ceramics or steel are used to determine the probing error and value. Other appropriate materials are permitted. The material used shall be stated as different materials have different optical characteristics such as reflectivity, optical penetration depth (volume scattering), colour, scattering characteristics, etc., which means that values of the probing errors and values to be verified may vary. The roughness of the material standards to be probed should be negligibly small with respect to the corresponding MPEs or MPL. Where the manufacturer fails to specify the material and surface of the material standard, these can be chosen arbitrarily by the user.

The size of the test sphere shall be 10 mm to 51 mm in diameter (which is called "Sphere Normal Diameter" hereafter in this part of ISO 10360) as a default. If the size of the test sphere is considerably smaller than to the sensor area (see Figure 4), the number of the captured points may not be sufficient and the distortion of the sensor may not be evaluated. When the measuring area on the test sphere is smaller than 66 % of the sensor area, a local test flat shall be measured as well. A sphere having a diameter of larger than 51 mm (which is called "Sphere Large Diameter") may be used instead of the local test flat if the manufacturer and the user agree with usage of the large sphere. The measuring area on the local test flat or the larger test sphere shall be at least 66 % of the sensor area.

The test sphere of 10 mm to 51 mm in diameter is used for evaluating the probing form error, the probing dispersion value, the probing size error and the probing size error All. The local test flat and the larger test sphere are used for evaluating the probing form error and the probing dispersion value.

If line scan or point scan sensors are tested, the shorter side length of the local test flat shall be at least the diameter of the Sphere Normal Diameter which is actually used for the probing test.



a) Example of line scan or point scan sensor **b) Example of two dimensional image projection sensor**

Key

L_{X1} shorter length of the test flat in the case of a line scan or point scan sensor

L_{X2} longer length of the test flat in the case of a line scan or point scan sensor

ma measuring area at least 66 % of the sensor area

a line scan or point scan sensor

b two dimensional image projection sensor

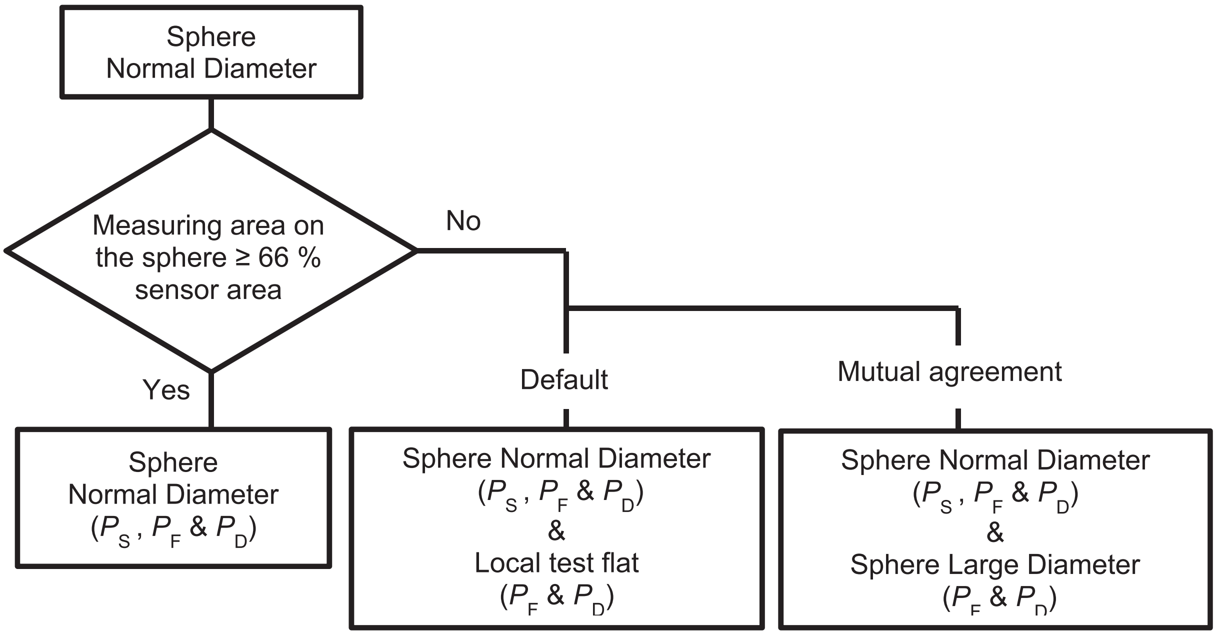
c sensor axis

d sensor area

Figure 4 — Relation between the measuring area and the sensor area

NOTE When the measuring area is 66 % of the sensor area, the diameter of the projected measuring circle on the test sphere is 92 % of the length of the sensor area which is derived from 0,66 approximately $(0,92/2)^2 \times \pi$.

To facilitate the understating of the selection of the material standards, a flowchart is illustrated in Figure 5.



Key

P_S $P_{Size.Sph.1\times25:j:ODS}$ and $P_{Size.Sph.All:j:ODS}$

P_F $P_{Form.Sph.1\times25:j:ODS}$

P_D $P_{Form.Sph.D95\%:j:ODS}$

NOTE 1 Sphere normal diameter: A test sphere of 10 mm to 51 mm in diameter.

NOTE 2 Sphere large diameter: A test sphere having larger diameter than that of sphere normal diameter

Figure 5 — Material standards selection flowchart for probing tests

The material standard such as the reference sphere supplied with the CMM with optical distance sensors for the probing system qualification purposes shall not be used for this test.

The diameter and form of the test sphere and the form of the local test flat shall be calibrated and it is recommended that the form error does not exceed 20 % of the corresponding MPEs or MPL of the instrument under test. The form deviation and the roughness of the test sphere and the local test flat influence the test result. It shall be taken into account using ISO 14253-1 when performing acceptance or reverification tests.

6.2.3 Procedure

6.2.3.1 General

All tested systems shall be qualified in accordance with the CMM manufacturer's normal operating procedures.

The user is free to choose the positions of the test sphere or the test flat within the limits specified by the manufacturer except the location where the reference sphere has been used for the probing system qualification. The test sphere or the test flat should be mounted rigidly to minimize the errors due to vibration.

The influence of the filter can be observed by the resolution tests described in Annex A. If the resolution test is performed, the same operating condition of the CMM shall be used.

When $P_{X:Tr:ODS}$ is evaluated, the points are measured while the sensor is moved by the CMM and measurements are taken at several positions. When $P_{X:Art:ODS}$ is evaluated, the points are measured while the alignment of the sensor is additionally modified by means of an articulating system. When $P_{X:St:ODS}$ is evaluated, the sensor is not moved by the CMM during measurements.

6.2.3.2 Test procedure using sphere

Measure the surface of the test sphere. The measured area on the test sphere should cover the widest cone angle of the sphere specified by the manufacturer (see Figure 6). The cone angle of the region of the sphere on which the points are selected shall be stated in the datasheet.

6.2.3.3 Test procedure using flat

Measure the surface of the test flat. The measured area on the test flat should be the widest within the sensor area as specified by the manufacturer. The measured area of the flat on which the points are selected shall be stated in the datasheet.

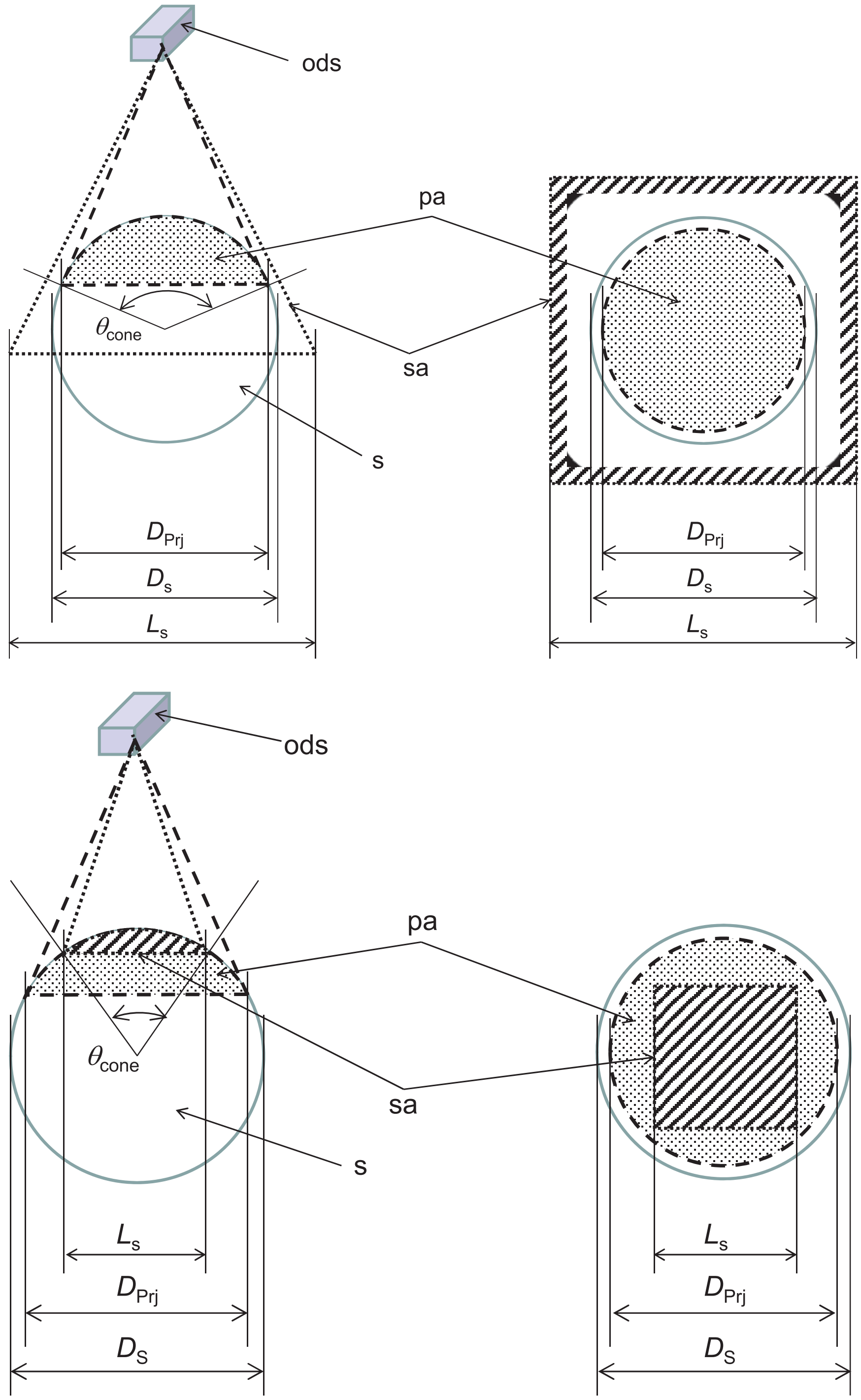
6.2.4 Derivation of test results

6.2.4.1 General

For CMMs equipped with optical distance sensors, the difference in the number of data points actually evaluated may significantly influence the test result. This part of ISO 10360 requires the disclosure of minimum density or minimum number of points necessary to perform the test.

If the software has an automated function to remove points belonging to another surface, this function may be used. If the manual selection of points evaluated is a part of the normal operating procedure, e.g. removing points that belong to another surface, this data selection shall be specified in the data sheet and performed also during the test. All measurement data except those eliminated by this automated or manual selection shall be used. The automated or manual data selection shall not be misused for the elimination of noise or outliers.

NOTE For the data elimination, the user is encouraged to have enough knowledge, e.g. characteristics of the optical distance sensor, the optical properties of the surface of the test sphere, ambient illumination and algorithm of the filter.



Key

L_s	length of the projection line
D_{prj}	diameter of the projected measuring area on the test sphere
θ_{cone}	cone angle
ods	optical distance sensor
s	test sphere
sa	sensor area
pa	projected measuring area on the test sphere

Figure 6 — Measuring area on the test sphere and cone angle to be reported

6.2.4.2 Probing characteristics by representative points

6.2.4.2.1 General

Select 25 areas from the measuring area on the test sphere or the local test flat and reduce to a representative point for each area. The areas shall be approximately evenly distributed to cover all measurement points.

For comparability reasons with those stated in the other part of ISO 10360, a single point shall be taken when probing form error stated in 6.2.4.2.2 or probing size error stated in 6.2.4.2.4 is tested. If a CMM equipped with area measuring sensors (e.g. point scan, line scan, fringe projection) is tested, a point reduced from the measured points in no larger than 5 mm^2 area shall be used as the representative point. The area shall be bounded by either a circular or a square circumference which encompasses all the data points used for deriving a representative point in the area. If the area of no larger than 5 mm^2 is recognized as being impractical due to technical reasons, a larger area may be applied by mutual agreement and the size of the area shall be stated in the datasheet.

The manufacturer shall provide the software tools to reduce the data to a representative point. These software tools have to be usable under the normal operating conditions of the CMM. Use and condition of the filtering, which is given in the manufacturer's operating manual, may be applied as a part of this tool by mutual agreement. The applied procedure of the filtering shall be recorded and reported to the user. When reducing the data to a representative point, a priori information (such as the diameter and the centre coordinate of the test sphere) except the fact that the area is a part of a sphere or a flat shall not be provided to the reducing software.

The 25 positions written in ISO 10360-5:2010, 6.2.2.4 are recommended as the centre positions of the 25 areas on the test sphere when the test is performed on the test sphere. If a CMM equipped with a sensor which measures individual discrete points is used, 25 points shall be measured following the procedure of ISO 10360-5. If the sensor is not capable of measuring the whole hemisphere, measurable cone angle may be specified by the manufacturer. The cone angle of the region of the sphere on which the points are distributed shall be stated in the data sheet.

The manufacturer may, at their discretion, specify additional MPEs for special operation conditions, e.g. filters. Filters requiring information of the test material standard may not be used when specifying or testing MPEs.

6.2.4.2.2 Probing form error tested using sphere

Using all 25 representative points, compute the unconstrained Gaussian (i.e. least-squares) associated sphere. For each of the 25 representative points, calculate the Gaussian radial distance, r. Record the range of Gaussian radial distances of the 25 representative points with respect to the least-squares sphere centre, i.e. the apparent sphere form, $r_{max} - r_{min}$. The absolute value of this difference is the probing form error, $P_{Form.Sph.1 \times 25:j:ODS}$.

$$P_{Form.Sph.1 \times 25:j:ODS} = r_{max} - r_{min}$$

NOTE Multiple methods can be considered to reduce the measured points to a representative point for each area. A simple method is to select a single point within each of the 25 areas or to calculate a simple arithmetic mean of 3D coordinates. A more sophisticated method is to fit the measured points in each area to a sphere and to determine a representative point on the sphere. Calculation result of probing form errors by these methods will be almost the same as each other, while the probing size error in 6.2.4.2.4 will be different since the representative points of the former methods may be located inside the Gaussian associated sphere of the latter method. Although the probing form error may be insensitive to the reducing method, the latter method is versatile since the same representative points are required to use both for the probing form error and the probing size error.

6.2.4.2.3 Probing form error tested using flat

Using all 25 representative points, compute the unconstrained Gaussian (i.e. least-squares) associated plane. For each of the 25 representative points, calculate the Gaussian normal distance, d. Record the range of Gaussian normal distances of the 25 representative points with respect to the least-squares plane, i.e. the apparent plane form, $d_{max} - d_{min}$. The absolute value of this difference is the probing form error, $P_{Form.Sph.1\times25:j:ODS}$.

$$P_{Form.Sph.1\times25:j:ODS} = d_{max} - d_{min}$$

NOTE Multiple methods can be considered to reduce the measured points to a representative point for each area. A simple method is to select a single point within each of the 25 areas or to calculate a simple arithmetic mean of 3D coordinates. A more sophisticated method may be to fit the measured points in each area to a plane and determine a representative point on the plane.

6.2.4.2.4 Probing size error

The same 25 representative points which has been used for the probing form error shall be applied.

It is recommended to fit the measured points in each area be fitted into a Gaussian associated sphere to determine a representative point on the sphere as described in 6.2.4.2.2.

Using all 25 representative points, the Gaussian associated sphere is determined according to the least squares method with the radius being unrestricted. The probing size error, $P_{Size.Sph.1\times25:j:ODS}$, is obtained from the difference between the measured diameter of the sphere, D_{meas}, and the calibrated diameter, D_{cal}, as follows:

$$P_{Size.Sph.1\times25:j:ODS} = D_{meas} - D_{cal}$$

6.2.4.3 Probing characteristics by point cloud

6.2.4.3.1 General

If a CMM equipped with a sensor which measures individual discrete points is used, the maximum permissible error and the limit by point cloud are not required to be specified and the tests are not required to be performed.

The test shall be carried out without user selectable software filtering no matter if the filtering is part of the normal operation conditions specified by the manufacturer. The manufacturer may optionally provide additional specifications for the probing characteristics by point cloud for cases in which specified type of filtering are applied.

6.2.4.3.2 Probing dispersion value

Determine the width of the spherical shell that encompasses 95 % of all measured points. This range is defined as a probing dispersion value. When using the local test flat, calculate the range of normal distances from the Gaussian associated plane in which 95 % of all measured points are included.

6.2.4.3.3 Probing size error All

All measured points for the test sphere are associated with the Gaussian sphere with the radius being unrestricted. The probing size error All, $P_{Size.Sph.All:j:ODS}$, is obtained from the difference between the measured diameter of the sphere, D_{meas}, and the calibrated diameter, D_{cal}, as follows:

$$P_{Size.Sph.All:j:ODS} = D_{meas} - D_{cal}$$

6.3 Length measurement error

6.3.1 Principle

The principle of the assessment method for length measurement error is to establish whether the CMM with optical distance sensors is capable of measuring within the stated maximum permissible length measurement error, $E_{\text{Bi:}j\text{:ODS,MPE}}$ or $E_{\text{Uni:}j\text{:ODS,MPE}}$, by comparing the calibrated values with the indicated values of five different test lengths.

For some types of CMM, it may be impractical to obtain bidirectional measurement results. In such cases, unidirectional length measurement specifications may be allowed. The procedure of measuring unidirectional length shall follow B.3.

If the CMM equipped with optical distance sensors also has another type of probing systems (such as a tactile probing system and an image probing system), the length measurement test shall be performed using one of the probing systems specified by the manufacturer. If only optical sensors are available, then the length measurement error test defined in this part of ISO 10360 shall be performed.

6.3.2 Measuring equipment

Material standards of ceramics or steel are used to determine the length measurement error. Other appropriate materials are permitted. The material used shall be stated at any rate as different materials have different optical characteristics such as reflection factor, optical penetration depth (volume scattering), colour, scattering characteristics, etc., which means that values of the length measurement errors and values to be verified may vary. The roughness of the features to be probed must be negligibly small with respect to the maximum permissible error of the length test. Where the manufacturer fails to specify the material and surface of the material standard, these can be chosen arbitrarily. Unless the user supplies the calibrated test length, the manufacturer may choose the material standard representing the calibrated test length those described in Annex B.

The length of each material standard shall be calibrated and the calibration uncertainty shall be taken into account by ISO 14253-1 when performing acceptance or reverification tests.

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.

6.3.3 Procedure

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 and Figure 7. The user may specify the remaining three positions; the default positions are parallel to each of the CMM axes, as shown in Table 2.

Arrangements differing from that of Table 2 and Figure 7 can be adopted by mutual agreement. In this case the arrangement shall be recorded in the data sheet.

NOTE 1 The choice of locations and orientations may significantly affect the test result.

The set up and the qualification of the probing system shall be done in accordance with the manufacturer's normal procedures.

If the software has an automated function to remove points belonging to another surface, this function may be used. If the manual selection of points evaluated is a part of the normal operating procedure, e.g. points that belong to another surface, this data selection shall be specified in the data sheet and performed also during the test. The automated or manual data selection shall not be misused for the elimination of noise or outliers.

NOTE 2 For the data elimination, the user is encouraged to have enough knowledge, e.g. characteristics of the optical distance sensor, the optical properties of the surface of the material standards, ambient illumination and the filter algorithm.

The influence of the filter can be observed by the resolution tests described in Annex A. If the resolution test is performed, the same operating conditions of the CMM shall be used.

The manufacturers may, at their discretion, specify additional MPEs for special operation condition, e.g. filters.

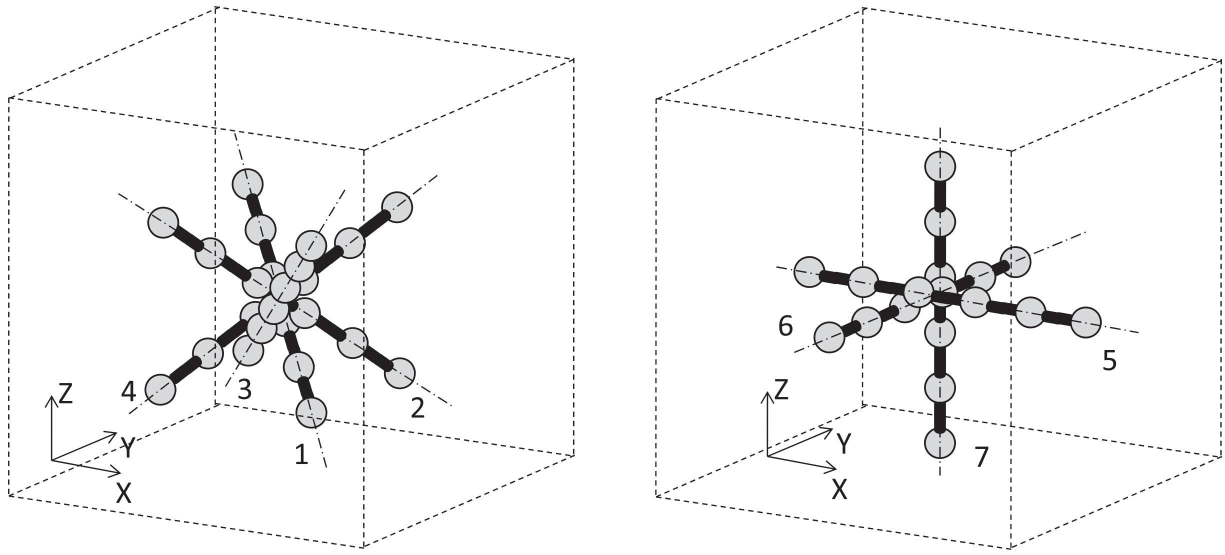


Figure 7 — Positions of material standards in the assessment: required four diagonal positions and default three positions along the axes of the coordinate system

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).		

6.3.4 Low CTE case

If the calibrated test length is not made of the 'normal CTE material' defined in ISO 10360-2:2009, then the corresponding $E_{\mathrm{Bi}:j:\mathrm{ODS,MPE}}$ or $E_{\mathrm{Uni}:j:\mathrm{ODS,MPE}}$ values are designated with an asterisk (*) and an explanatory note shall be provided describing the CTE of the calibrated test length.

EXAMPLE $E_{\mathrm{Bi}:j:\mathrm{ODS,MPE}}$ * or $E_{\mathrm{Uni}:j:\mathrm{ODS,MPE}}$ *

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

For the case where the manufacturer's specification for $E_{\mathrm{Bi}:j:\mathrm{ODS,MPE}}$ or $E_{\mathrm{Uni}:j:\mathrm{ODS,MPE}}$ requires α < 2 × 10^{-6} / K (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.

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 of ISO 10360-2:2009; however, this calibrated test length is still considered to have a low CTE and is subject to the requirement of this clause.

6.3.5 Derivation of test results

6.3.5.1 General

For all 105 measurements, a length measurement error, $E_{\mathrm{Bi}:j:\mathrm{ODS}}$ or $E_{\mathrm{Uni}:j:\mathrm{ODS}}$ is obtained.

For comparability reasons of length measurement error, $E_{\mathrm{Bi}:j:\mathrm{ODS}}$ or $E_{\mathrm{Uni}:j:\mathrm{ODS}}$, with those stated in Annex B, a single point shall be taken. If a CMM equipped with area measuring sensors (e.g. line scan, point scan, fringe projection) is tested, a point reduced from the measured points with no larger than 5 mm^2 area shall be applied as the representative point.

If the area of no larger than 5 mm^2 is recognized as being impractical due to technical reasons, a larger area may be applied by mutual agreement and the size of the area shall be stated in the datasheet.

When material standards are used and measured bidirectionally as stated in B.2, each $E_{\mathrm{Bi}:j:\mathrm{ODS}}$ is calculated from the difference between the measured and calibrated values of each material standard, $L_{\mathrm{Bi.meas}}$ and $L_{\mathrm{Bi.cal}}$, as follows:

$$E_{\mathrm{Bi}:j:\mathrm{ODS}} = L_{\mathrm{Bi.meas}} - L_{\mathrm{Bi.cal}}$$

When material standards are used and measured unidirectionally as stated in B.3, each $E_{\mathrm{Uni}:j:\mathrm{ODS}}$ is calculated from the difference between the measured and calibrated values of each material standard, $L_{\mathrm{Uni.meas}}$ and $L_{\mathrm{Uni.cal}}$, as follows:

$$E_{\mathrm{Uni}:j:\mathrm{ODS}} = L_{\mathrm{Uni.meas}} - L_{\mathrm{Uni.cal}}$$

When five lengths per measurement line are measured unidirectionally, either of the following two methods, method A or method B, may be used for the calculation of $E_{\mathrm{Bi}:j:\mathrm{ODS}}$.

NOTE 1 Method B needs no additional measurement but may result in larger error value than that of method A.

NOTE 2 Combination method of unidirectional measurements and bidirectional contributions is explicitly and differently specified in B.4.3.5 when point cloud sampling is adopted for unidirectional measurements.

6.3.5.2 Method A

Both unidirectional measurements and bidirectional measurements performed in a single-point-to-single-point manner where the point is a single point or a representative point as stated in B.4 shall be performed to derive bidirectional errors. Each $E_{\mathrm{Bi}:j:\mathrm{ODS}}$ is calculated from the difference between the measured and calibrated values of each unidirectional calibrated test length, $L_{\mathrm{Uni.meas}}$ and $L_{\mathrm{Uni.cal}}$, and the measured and calibrated values of each short bidirectional calibrated test length, $L_{\mathrm{Bi\text{-}Short.meas}}$ and $L_{\mathrm{Bi\text{-}Short.cal}}$ as follows:

$$E_{\mathrm{Bi}:j:\mathrm{ODS}} = L_{\mathrm{Uni.meas}} - L_{\mathrm{Uni.cal}} + L_{\mathrm{Bi\text{-}Short.meas}} - L_{\mathrm{Bi\text{-}short.cal}}$$

6.3.5.3 Method B

$E_{Bi:j:ODS}$ is calculated from the measured and the calibrated values of unidirectional measurements in accordance with B.4, $L_{Uni.meas}$ and $L_{Uni.cal}$, supplemented with both probing form error $P_{Form.Sph.1\times25:j:ODS}$, and probing size error $P_{Size.Sph.1\times25:j:ODS}$ described in 6.2, as follows:

In the case:

$$L_{Uni.meas} - L_{Uni.cal} + P_{Size.sph.1\times25;j;ODS} > 0$$

$E_{Bi:j:ODS}$ has an upper limit which can be used for verifying conformance:

$$E_{Bi:j:ODS} < L_{Uni.meas} - L_{Uni.cal} + P_{Size.sph.1\times25;j;ODS} + P_{Form.Sph.1\times25:j:ODS}$$

In the case:

$$L_{Uni.meas} - L_{Uni.cal} + P_{Size.sph.1\times25;j;ODS} = 0$$

$E_{Bi:j:ODS}$ has upper and lower limits which can be used for verifying conformance:

$$E_{Bi:j:ODS} < P_{Form.Sph.1\times25:j:ODS} \text{ and } E_{Bi:j:ODS} > -P_{Form.Sph.1\times25:j:ODS}$$

In the case:

$$L_{Uni.meas} - L_{Uni.cal} + P_{Size.sph.1\times25;j;ODS} < 0$$

$E_{Bi:j:ODS}$ has a lower limit which can be used for verifying conformance:

$$E_{Bi:j:ODS} > L_{Uni.meas} - L_{Uni.cal} + P_{Size.sph.1\times25;j;ODS} - P_{Form.Sph.1\times25:j:ODS}$$

Due to comparability reason, $P_{Form.Sph.1\times25:j:ODS}$ and $P_{Size.Sph.1\times25:j:ODS}$ are sampled and calculated once for 105 lengths to be tested when point cloud sampling is adopted as unidirectional errors.

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, including third party software, 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 condition specified by the manufacturer.

Plot all the errors (values of $E_{Bi:j:ODS}$ or $E_{Uni:j:ODS}$) on a diagram, as indicated on Figure 12, 13 or 14 of ISO 10360-1:2000, which matched the expressed form of $E_{Bi:j:ODS,MPE}$ or $E_{Uni:j:ODS,MPE}$.

6.4 Flat form measurement error

6.4.1 Principle

Area measuring sensors are likely to suffer from inherent errors, such as distortion of the optical system of the sensor and stitching errors.

These types of errors are not easy to detect by the probing form test. CMMs with area measuring sensors are often used to measure and evaluate surface forms. Since these types of errors give large influence on surface form measurements, for CMMs with area measuring sensors, the flat form test shall be specified and the test shall be performed.

Data merging operation known as 'stitching' is applied to obtain a unified image when measuring a workpiece with larger geometry than the sensor area. The stitching may be realized in several different ways. This part of ISO 10360 limits the stitching to those based on simple data merging by referring three dimensional coordinates obtained by Cartesian CMMs. Any other stitching based on e.g. numerical fitting by referring overlapped area or usage of a reference marker is out of the scope of this standard.

Additionally the straightness measurement error originated from imperfect mechanical structure of the CMM is difficult to detect by the probing form test. It is strongly recommended to perform the flat form test if CMMs are used for the applications in which the influence of straightness error is significant, e.g. semiconductor applications, LCD panel, and seal surfaces, no matter which type of the sensor is used.

The principle of the assessment method for the flat form measurement error is to establish whether the CMM with optical distance sensors is capable of measuring within the stated maximum permissible flat form measurement error, $E_{\text{Form.Pla.D95\%:}j\text{:ODS,MPE}}$, by determining:

— the range of distances of the measured points from the associated plane.

6.4.2 Measuring equipment

Test planes of ceramics or steel are used to determine the flat form measurement error. Other appropriate materials are permitted. The material used shall be stated at any rate as different materials have different optical characteristics such as reflection factor, optical penetration depth (volume scattering), colour, scattering characteristics, etc., which means that values of the flat form measurement errors and values to be verified may vary. The roughness of the features to be probed must be negligibly small with respect to the maximum permissible error of the flat test. Where the manufacturer fails to specify the material and surface of the artefact, these can be chosen arbitrarily. The form of the test plane shall be calibrated, since the form deviation influences the test results, and shall be taken into account when verifying conformance or non-conformance with the specification.

The dimensions of the test plane shall be as follows:

— the longer side length of the plane is at least twice as long as either the length of the projection line for line scan or point scan sensor, or the width of the measuring area for area measuring sensor, and

— the shorter side length of the plane if the line scan or point scan sensor is at least as long as the diameter of the Sphere Normal Diameter actually used for the probing test, and

— the shorter side length of the plane if the area measuring sensor is at least as long as the lesser of the Sphere Normal Diameter actually used for the probing test or the width of the measuring area.

The straightness measurement error can be seen more clearly when a longer flat is used.

The reference plane supplied with the CMM with optical distance sensors for the probing system qualification purposes shall not be used for this test.

If the test plane which covers the recommended size is not available, a travelling flat, a small test plane mounted on a travelling stage, or similar equipment can be used alternatively.

6.4.3 Procedure

The test plane shall be placed in two positions: on the CMM support (i.e. table) and as close as possible along a diagonal in space of the CMM's machine coordinate. The arrangement shown in Figure 8 and Table 3 is recommended. Arrangements differing from Figure 8 shall be documented. The use of available accessories' functions shall be at the discretion of the user.

The set up and the qualification of the probing system have to be done in accordance with the manufacturer's normal procedures.

Measure and record the number of measured points. The number of measured points shall be at least 25. The points shall be approximately evenly distributed over the test plane.

The test results may be significantly affected by the orientation of the optical distance sensor when the probing system is equipped with an articulating function. It is recommended to set the optical distance sensors at multiple orientations during the test to reveal the characteristics of the CMM.

If the software has an automated function to remove points belonging to another surface, this function may be used. If the manual selection of points evaluated is a part of the normal operating procedure, e.g. points that belong to another surface, this data selection shall be specified in the data sheet and performed also during the test. The automated or manual data selection shall not be misused for the elimination of noise or outliers. Global filters may not be used when MPEs are tested.

For the data elimination, the user is encouraged to have enough knowledge, e.g. characteristics of the optical distance sensor, the optical properties of the surface of the test plane, ambient illumination and algorithm of the filter.

The influence of the filter can be observed by the resolution tests described in Annex A. If the resolution test is performed, the same operating condition of the CMM shall be used.

The manufacturer may, at their discretion, specify additional MPEs for special operation condition, e.g. filters.

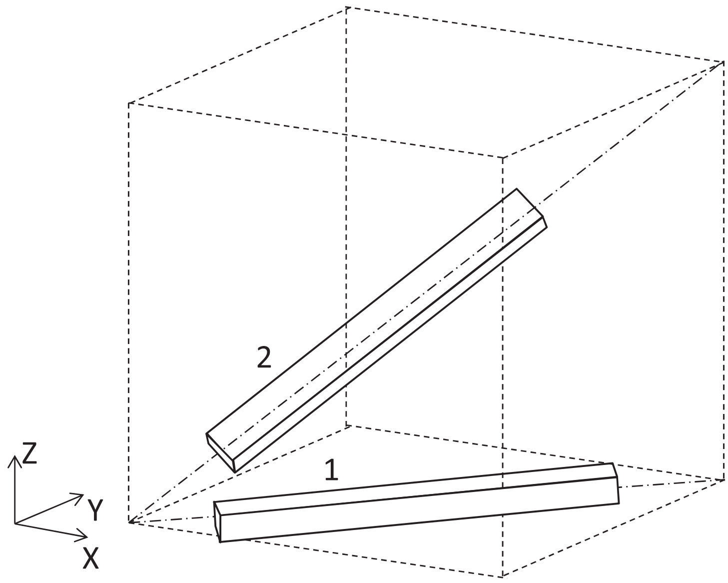


Figure 8 — Recommended positions of test planes in the assessment: one position along the diagonal line on the x-y **plane and one diagonal position**

Table 3 — Orientation in the measuring volume

Position number	Orientation in the measuring volume
1	Along the diagonal in x-y plane from point (0, 0, 0) to (1, 1, 0)
2	Along the diagonal in space from point (0, 0, 0) to (1, 1, 1)
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).	

6.4.4 Derivation of test results

Calculate the range of normal distances from the associated plane in which 95 % of all measured points are included. The flat form measurement error, $E_{\mathrm{Form.Pla.D95\%:}j\mathrm{:ODS}}$, as the range of the measured points' normal distances is defined as follows:

$$E_{\mathrm{Form.Pla.D95\%:}j\mathrm{:ODS}} = d_{\max} - d_{\min}$$

7 Compliance with specifications

7.1 Acceptance test

7.1.1 Acceptance criteria

The performance of the CMM with optical distance sensors is considered to have been verified if

— probing form error, $P_{\text{Form.Sph.1×25:}j\text{:ODS}}$, is not greater than the maximum permissible probing form error, $P_{\text{Form.Sph.1×25:}j\text{:ODS,MPE}}$, as specified by the manufacturer and taking into account the uncertainty of measurement according to ISO 14253-1,

— probing size error, $P_{\text{Size.Sph.1×25:}j\text{:ODS}}$, is not greater than the maximum permissible probing size error, $P_{\text{Size.Sph.1×25:}j\text{:ODS,MPE}}$, as specified by the manufacturer and taking into account the uncertainty of measurement according to ISO 14253-1,

and

— length measurement error, $E_{\text{Bi:}j\text{:ODS}}$ or $E_{\text{Uni:}j\text{:ODS}}$, is not greater than the maximum permissible length measurement error, $E_{\text{Bi:}j\text{:ODS,MPE}}$ or $E_{\text{Uni:}j\text{:ODS,MPE}}$, as specified by the manufacturer and taking into account the uncertainty of measurement according to ISO 14253-1 and ISO/TS 23165. If the CMM equipped with optical distance sensors also has another type of probing systems (such as a tactile probing system and an image probing system), the length measurement test shall be performed using one of the probing systems specified by the manufacturer,

and, for CMMs equipped with area measuring sensors,

— in the case in which an additional local test flat or large sphere is measured, the probing form error, $P_{\text{Form.Sph.1×25:}j\text{:ODS}}$, is also not greater than the maximum permissible probing form error, $P_{\text{Form.Sph.1×25:}j\text{:ODS,MPE}}$, as specified by the manufacturer and taking into account the uncertainty of measurement according to ISO 14253-1,

— probing dispersion value, $P_{\text{Form.Sph.D95\%:}j\text{:ODS}}$, is not greater than the maximum permissible limit of probing dispersion value, $P_{\text{Form.Sph.D95\%:}j\text{:ODS,MPL}}$, as specified by the manufacturer and taking into account the uncertainty of measurement according to ISO 14253-1,

— in the case in which an additional local test flat or large sphere is measured, the probing dispersion value, $P_{\text{Form.Sph.D95\%:}j\text{:ODS}}$, is also not greater than the maximum permissible limit of probing dispersion value, $P_{\text{Form.Sph.D95\%:}j\text{:ODS,MPL}}$, as specified by the manufacturer and taking into account the uncertainty of measurement according to ISO 14253-1,

— probing size error All, $P_{\text{Size.Sph.All:}j\text{:ODS}}$, is not greater than the maximum permissible probing size error All, $P_{\text{Size.Sph.All:}j\text{:ODS,MPE}}$, as specified by the manufacturer and taking into account the uncertainty of measurement according to ISO 14253-1,

— flat form measurement error, $E_{\text{Form.Pla.D95\%:}j\text{:ODS}}$, is not greater than the maximum permissible flat form measurement error, $E_{\text{Form.Pla.D95\%:}j\text{:ODS,MPE}}$, as specified by the manufacturer and taking into account the uncertainty of measurement according to ISO 14253-1.

7.1.2 Data rejection and repeated measurements

7.1.2.1 Probing form error

If the probing form error performance 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, and the original measurement results shall be discarded.

No additional repeated measurement shall be performed.

7.1.2.2 Probing size error

If the probing size error performance 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, and the original measurement results shall be discarded.

No additional repeated measurement shall be performed.

7.1.2.3 Probing dispersion value

If the probing dispersion value performance 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, and the original measurement results shall be discarded.

No additional repeated measurement shall be performed.

7.1.2.4 Probing size error All

If the probing size error All performance 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, and the original measurement results shall be discarded.

No additional repeated measurement shall be performed.

7.1.2.5 Length measurement error

A maximum of five of 35 sets of three repeated measurements in accordance with 6.3 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 remeasured three times at the relevant position.

If all the values of the length measurement errors 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.

7.1.2.6 Flat form measurement error

If the performance of flat form measurement 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, and the original measurement results shall be discarded.

No additional repeated measurement shall be performed.

7.2 Reverification test

The performance of the CMM with optical distance sensors is considered to have been verified if $P_{\text{Form.Sph.1×25}:j:\text{ODS}}$, $P_{\text{Size.Sph.1×25}:j:\text{ODS}}$, $P_{\text{Form.Sph.D95\%}:j:\text{ODS}}$, $P_{\text{Size.Sph.All}:j:\text{ODS}}$, $E_{\text{Bi}:j:\text{ODS}}$ and $E_{\text{Uni}:j:\text{ODS}}$ described in 6.2 and 6.3 are not greater than the maximum permissible errors and limit $P_{\text{Form.Sph.1×25}:j:\text{ODS,MPE}}$, $P_{\text{Size.Sph.1×25}:j:\text{ODS,MPE}}$, $P_{\text{Form.Sph.D95\%}:j:\text{ODS,MPL}}$, $P_{\text{Size.Sph.All}:j:\text{ODS,MPE}}$, $E_{\text{Bi}:j:\text{ODS,MPE}}$ and $E_{\text{Uni}:j:\text{ODS,MPE}}$ as determined in 7.1.

Where relevant, the performance of the CMM with optical distance sensors is considered to have been verified if additionally $E_{\text{Form.Pla.D95\%}:j:\text{ODS}}$ described in 6.4 is not greater than the maximum permissible error $E_{\text{Form.Pla.D95\%}:j:\text{ODS,MPE}}$ 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, maintenance, repair, renovation or upgrade contract, the acceptance tests described in this part of ISO 10360 may be used to verify the performances of the probing and the length measurement of a CMM with optical distance sensors, in accordance with the specified maximum permissible errors agreed on by the manufacturer and the user.

8.2 Reverification test

The reverification tests given in this part can be used in an organization's internal quality assurance system for verification of the performances of the probing and the length measurement of a CMM with optical distance sensors, in accordance with the specified appropriate maximum permissible errors as stated by the user with all possible and detailed limitations applied.

8.3 Interim check

In an organization's internal quality assurance system, reduced reverification tests can be used periodically to demonstrate the probability that the CMM conforms to the requirements for maximum permissible errors. The extent of the interim checks for optical distance sensors specified in this part may be reduced in respect of the number of actual measuring points being assessed.

It is recommended that the probing system be checked regularly, and after any incident which could have significantly affected the probing performance.

9 Indication in product documentation and data sheets

The symbols given in Clause 4 are not well suitable for use in product documentation, drawings, data sheets etc. Table 4 gives the corresponding indications also allowed.

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

Symbol used in this document	Corresponding indication
$P_{\text{Form.Sph.1×25:}j\text{:ODS}}$	P[Form.Sph.1×25:j:ODS]
$P_{\text{Form.Sph.D95\%:}j\text{:ODS}}$	P[Form.Sph.D95%:j:ODS]
$P_{\text{Size.Sph.1×25:}j\text{:ODS}}$	P[Size.Sph.1×25:j:ODS]
$P_{\text{Size.Sph.All:}j\text{:ODS}}$	P[Size.Sph.All:j:ODS]
$E_{\text{Bi:}j\text{:ODS}}$	E[Bi:j:ODS]
$E_{\text{Uni:}j\text{:ODS}}$	E[Uni:j:ODS]
$E_{\text{Form.Pla.D95\%:}j\text{:ODS}}$	E[Form.Pla.D95%:j:ODS]
$P_{\text{Form.Sph.1×25:}j\text{:ODS,MPE}}$	MPE(P[Form.Sph.1×25:j:ODS])
$P_{\text{Form.Sph.D95\%:}j\text{:ODS,MPL}}$	MPL(P[Form.Sph.D95%:j:ODS])
$P_{\text{Size.Sph.1×25:}j\text{:ODS,MPE}}$	MPE(P[Size.Sph.1×25:j:ODS])
$P_{\text{Size.Sph.All:}j\text{:ODS,MPE}}$	MPE(P[Size.Sph.All:j:ODS])
$E_{\text{Bi:}j\text{:ODS,MPE}}$	MPE(E[Bi:j:ODS])
$E_{\text{Uni:}j\text{:ODS,MPE}}$	MPE(E[Uni:j:ODS])
$E_{\text{Form.Pla.D95\%:}j\text{:ODS,MPE}}$	MPE(E[Form.Pla.D95%:j:ODS])

Annex A
(informative)

Structural resolution test

A.1 Introduction

Structural resolution R_S should be clearly distinguished from the (metrological) resolution, i.e. the minimum increment of the output data, of the instrument. Structural resolution characterizes the size of the smallest structures separately measurable.

Quantities influencing structural resolution are:

— quantisation of A/D converters;

— noise;

— pixel grid of image sensor;

— modulation Transfer Function or resolution of the optical system in use;

— filtering, averaging;

— spot size of laser/beam diameter, or probing spot;

— smallest structural dimension when applying the line projection principle;

— size of image-processing window (autofocus sensor).

The multitude of influencing quantities shows that the common formula, “pixel grid = resolution”, does not hold true. The practical structural resolution is considerably lower. It is therefore important that this characteristic be specified and tested.

A.2 Test method

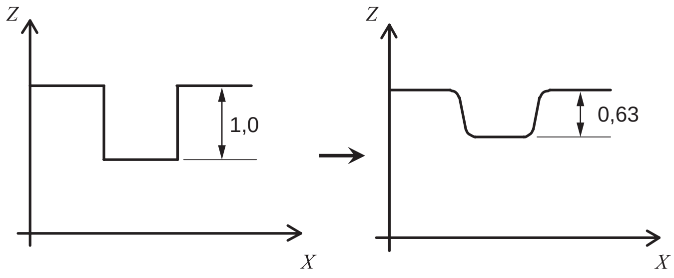
A.2.1 General

Take into account that additional movements at the relevant positions are required to allow for a three-dimensional functionality of one- and two-dimensional sensors. The speed at which these movements are performed affects the structural resolution and shall be adjusted, in accordance with the instruction manual, to a value also used in practical measurements. The same holds for adjustable sensor parameters such as the sampling frequency. Resolution may be directional, and may be specified differently for different directions. When using triangulation sensors, consider directionality when sampling edges. Methods described in the following clauses are proposed for verifying spatial resolution.

A.2.2 Structure standard

The manufacturer specifies the smallest structure that can be resolved (pit, gap, spike, ball, or similar). A material standard having this structure is produced and used to verify lateral resolution. If a rotation-symmetrical structure is used, information on any direction in the plane can be obtained. By way of example, consider Figure A.1, where a pit with a calibrated depth and diameter is measured. The diameter of this pit equals the specified resolution. The depth shall be chosen by the manufacturer in any convenient way ensuring reliable functioning of the sensor.

The depth measured using the sensor is compared to the calibrated depth. The ratio of measured depth over calibrated depth shall exceed 0,63 ($= 1 - e^{-1}$) for structural resolution to be less than or equal to the pit diameter. If the ratio is less than 0,63, the specified resolution has not been obtained.



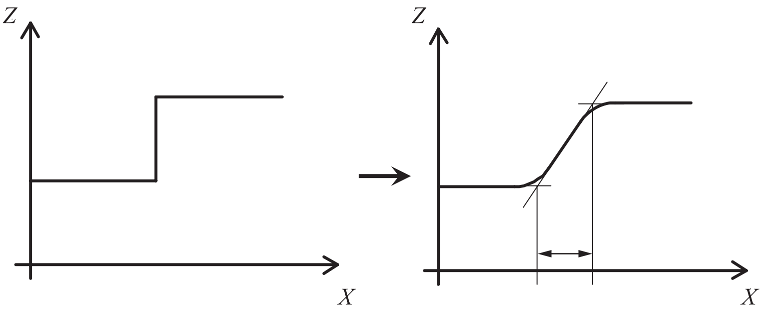
a) Gap or pit having a depth of 1,0 unit and width equalling cut-off wavelength

b) Structure is shown with only 63 % of its calibrated depth

Figure A.1 — Determination of structural resolution using a structure standard

A.2.3 Edge structure

As the feature to be tested, use a right-angled edge structure of a material standard (edge of a pit, spike, gap, or similar). The dimensions (such as pit diameter and depth) of the material standard shall be considerably greater than the resolution to be verified. If a rotation-symmetrical structure is used, information on any direction in the plane can be obtained. The quality of the edge (rounding of edge, orthogonality) must be significantly better than the resolution to be verified. As shown in Figure A.2, the edge profile is measured using a sensor, and the result is used to determine the structural resolution. The value thus obtained is compared to the specified value.



a) Actual profile

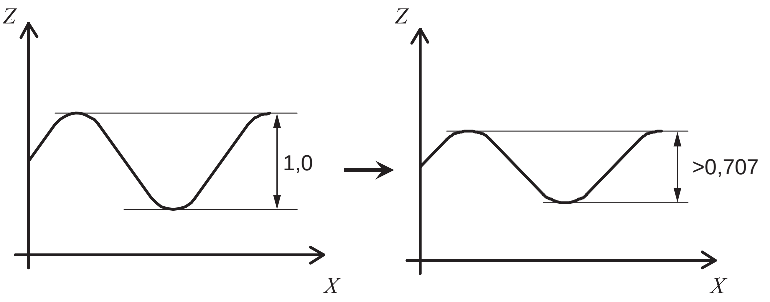
b) Measured profile

Figure A.2 — Determination of structural resolution by measuring an edge structure

A.2.4 Wave standard

As a material standard, use a standard embodying one or several sinusoidal waves. The cut-off wavelength to be verified, corresponding to the sought-for resolution, must exist on the material standard. Amplitude and wavelength shall be calibrated. If a rotation-symmetrical structure is used, information on any direction in the plane can be obtained.

The surface of the wave standard is measured using the sensor, and the result is used to determine that wavelength of the standard which can still be resolved, as shown in Figure A.3. This wavelength is characterized by a ratio of measured amplitude over calibrated amplitude greater than 0,7. This wavelength is compared to the specified resolution.



a) Calibrated height **b) Height measured if structural resolution is sufficient**

Figure A.3 — Determination of structural resolution by measuring a wave standard

A.3 Fundamentals

The theory of systems shows that resolution limits can be defined in the temporal (here: in the spatial) domain as well as in the frequency (here: spatial frequency, i.e. periods per millimetre) domain. Both views contain the same information and conversion from one to the other (and vice versa) is possible by means of a Fourier transform. As a model for resolution limits, a first-order low pass (known as a proportional element with first order delay in control engineering) is used.

First, consider the spatial domain (see Figure A.4). Characteristic structures (joint, step, slope) will give rise to the corresponding responses after filtering. A step is the most significant feature from the metrological point of view; it is realized in the form of an ideally shaped step.

The constant X_1, which is a filter characteristic, is the intersection between the tangent through zero and the height of the step at a sufficiently long distance from the tangent. This constant can be converted to a spatial cut-off frequency as follows:

For the step response in the spatial domain:

$$y = 1 - e^{-\frac{x}{X_1}}$$

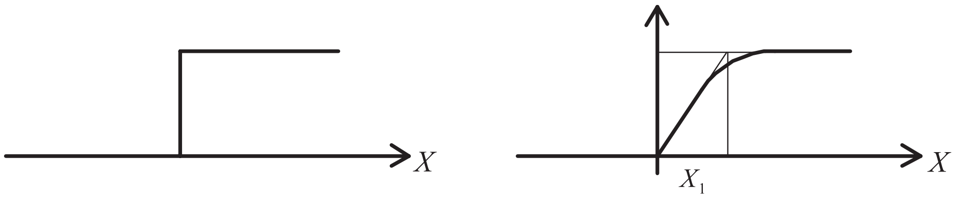
The spatial cut-off frequency, ν_g (unit: lines per millimetre) is the frequency at which the absolute value of the transfer factor has fallen to $1/\sqrt{2}$ (−3 dB limit):

$$G(j\omega) = \frac{1}{1 + j\omega X_1}$$

$$\left|G(j\omega)\right| = \frac{1}{\sqrt{1+\omega^2 X_1^2}} = \frac{1}{\sqrt{2}} (\Rightarrow) \omega_g \times X_1 = 1$$

$$X_1 = \frac{1}{2\pi \times \upsilon_g} = \frac{\lambda_g}{2\pi}$$

with λ_g cut-off wavelength



a) Calibrated height

$$\frac{1}{p} \times \left(\frac{1}{1 + pX_1} \right)$$

b) Height measured if structural resolution is sufficient

Figure A.4 — Step at the input of a system and response of the system, serving to determine the limit of structural resolution

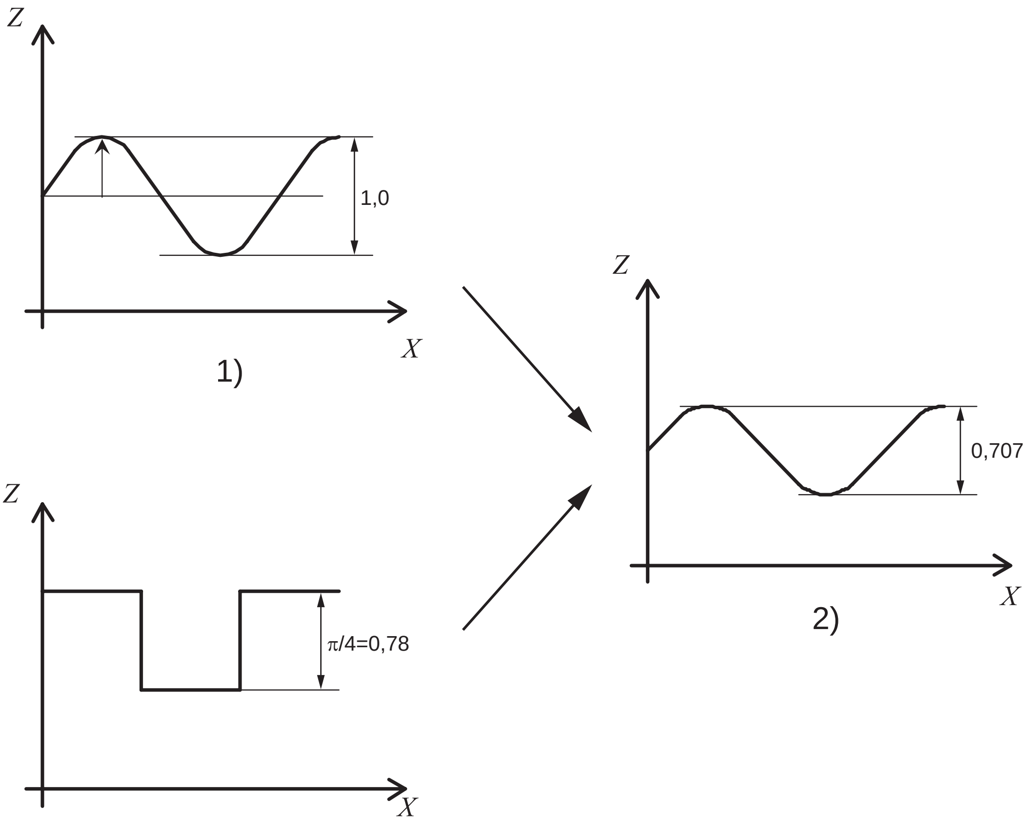
The step response (measurement of an ideally shaped step), therefore, allows to calculate the cut-off wavelength at which 70 % of height of a sine profile are still transferred.

$$\lambda_g = 2\pi \times X_1$$

Figure A.5 illustrates this relation.

Strictly speaking, this consideration is only true for sine profiles (wave standards). However, rectangular profiles can be used to a good approximation (this corresponds to the periodic extension of a positive and a negative step having the width of a half-period). This rectangular profile is made up of a sum of super-imposed sine waves (Fourier series). Considering only the fundamental (sinusoidal) wave is sufficient, as higher harmonics will largely disappear due to low-pass filtering. Use a wave standard having the resolution cut-off wavelength and check whether the transfer-factor is at least 70 % (sine) or 90 % (rectangular).

Producing or procuring multi-wave standards is demanding and expensive. It is therefore practical to obtain the same information on the step (see Figure A.4) or on two successive, opposite steps (gap).



Key

1 corresponding to rectangle with a height of 0,78 units

2 height decreases to 70 % of sine amplitude or 90 % of rectangle height

Figure A.5 — Sine and rectangular waves having the period of the specified cut-off wavelength, and response signal in the case of a successful test

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 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 end points of the test length, either in a bidirectional manner or in a unidirectional manner;

b) if a bidirectional test is performed, size errors caused by an optical probing system, a CMM, and an articulating function for the probe if applicable;

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

Clauses 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. In the latter case, issues associated with the absence of probing shall be accounted for (see B.3). 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 6.3.4. 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, 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.

In typical cases for testing CMMs equipped with optical distance sensors, the orientation of the sensor may have to be rotated and adjusted appropriately for CMMs to be able to access target measuring points or areas, e.g. a pair of points or areas facing diametrically opposite each other, on gauge block, sphere, and so on.

An area with no larger than 5 mm^2 from the measuring area on the calibrated test length should be selected and reduced to a representative point, except a case of point cloud measurement as described in B.4.3.5.

Manufacturers should provide the software tools to reduce the data to a representative point. These software tools should be usable under the normal operating conditions of the CMM. Use and condition of the filtering, which is given in the manufacturer's operating manual, may be applied as a part of this tool by mutual agreement. The applied procedure of the filtering should be recorded and reported to the user. When reducing the data to a representative point, *a priori* information (such as the diameter and the centre coordinate of the test sphere) should not be provided to the reducing software. The fact that the area is a part of a sphere or a flat should be provided.

If the software has an automated function to remove points belonging to another surface, this function may be used. If the manual selection of points evaluated is a part of the normal operating procedure, e.g. removing points that belong to another surface, this data selection should be specified in the data sheet and performed also during the test. The automated or manual data selection should not be misused for the elimination of noise or outliers.

NOTE For the data elimination, the user is encouraged to have enough knowledge, e.g. characteristics of the optical distance sensor, the optical properties of the surface of the test sphere, ambient illumination and algorithm of the filter.

Multiple methods can be considered to reduce the measured points to a representative point for each area. The easiest method is to either select a single point within each of the areas or to calculate a simple arithmetic mean of 3D coordinates. An alternative method is to fit the measured points in each area to a sphere or a flat and determine a representative point on the sphere or a flat. The latter method is recommended for the test if spheres are used.

If a CMM equipped with a sensor which measures individual discrete point is used, a point should be measured and evaluated.

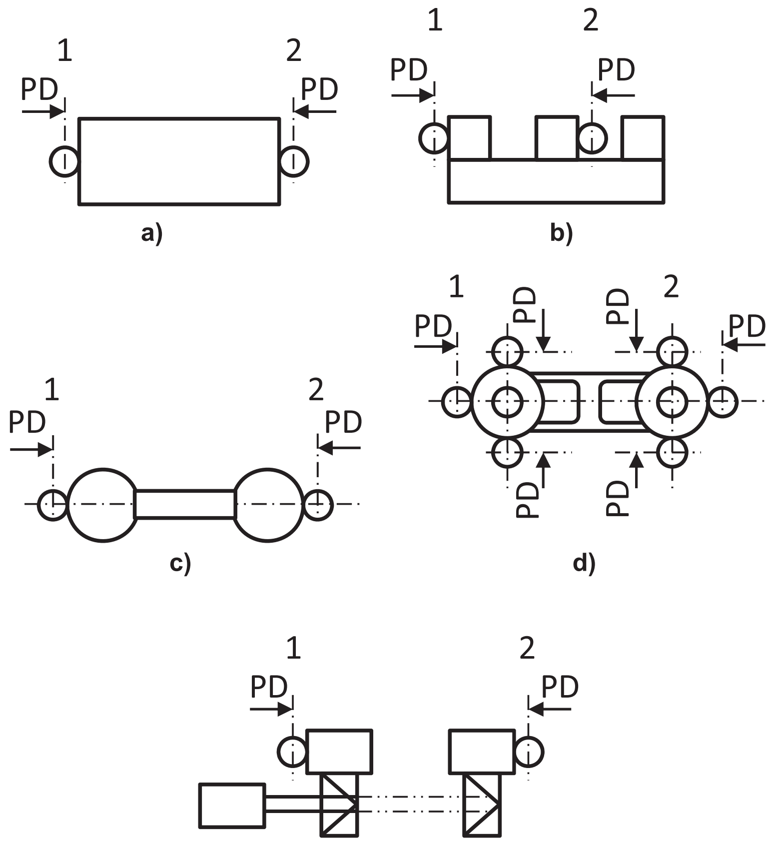
B.2 Bidirectional measurements for verifying bidirectional length measuring performance

B.2.1 General

A bidirectional measurement of a calibrated gauge yields a bidirectional calibrated test length. A bidirectional measurement involves probing a single point or a representative point 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.

NOTE Bidirectionality and unidirectionality is defined by probing errors not by probing direction.

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



Key

a gauge block
b step gauge
c ball bar (end-point-to-end-point measurement)
d ball bar (four-point measurement)
e laser interferometer

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 Gauge blocks

A calibrated test length may be produced using a calibrated gauge block measured with a single-point-to-single-point method where the point is a single point or a representative point. It is advised that each probing point be located at the calibrated gauging point for the block. See Annex C for alignment procedures.

B.2.3 Step gauges 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 where the point is a single point or a representative point (see Figure B.1). 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 where the length is equal to the calibrated sphere centre-to-centre length plus a summation of one half of the calibrated diameter of a sphere and that of the other sphere. The gauge is measured in a single-point-to-single-point bidirectional manner where the point is a single point or a representative point (identical to bidirectional size measurement on a gauge block). 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).

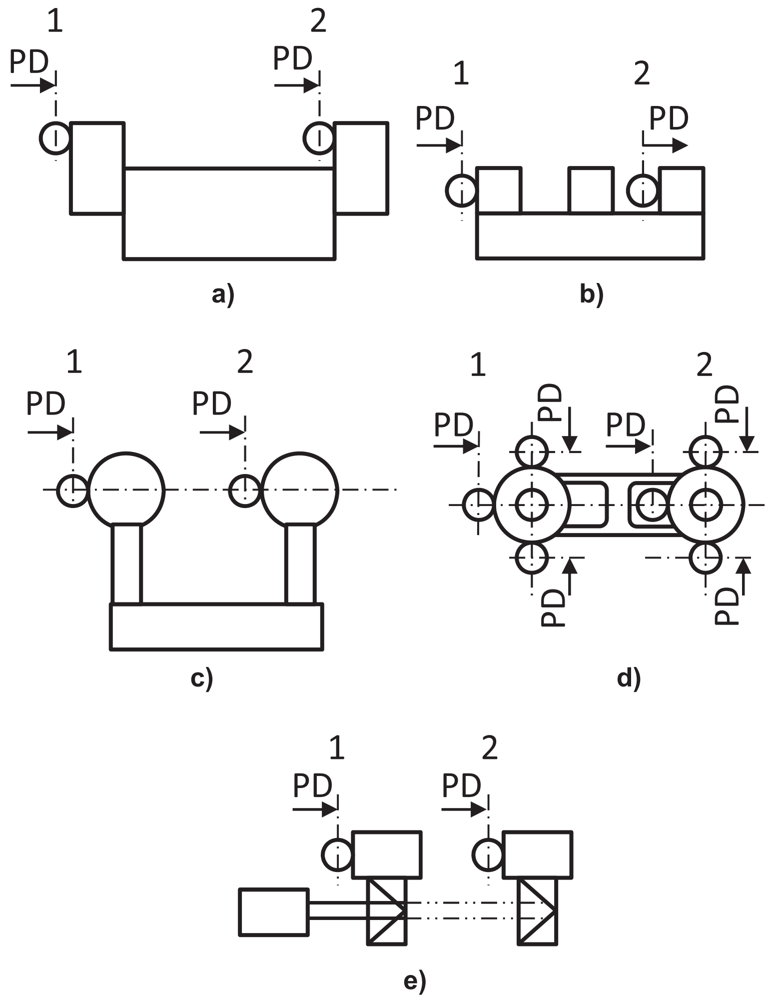
B.3 Unidirectional measurements for verifying unidirectional length measuring performance

B.3.1 General

A unidirectional measurement of a calibrated gauge yields 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 the same nominal direction (see Figure B.2). One sided unidirectional measurements from different directions shall not be mixed on a measurement line. Several possible unidirectional measurement methods are described below.

NOTE Bidirectionality and unidirectionality is defined by probing errors not by probing direction.

Some optical distance sensors may obtain probing points without probing motion. However, if a sensor requiring probing motion is tested, it is recommended that the probing direction shown in Figure B.2 be followed.



Key

a	gauge block	PD	probing direction
b	step gauge	1	position 1
c	ball bar (end-point-to-end-point measurement)	2	position 2
d	ball bar (four-point measurement)		
e	laser interferometer		

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

B.3.2 Gauge blocks

A calibrated test length may be produced using wrung calibrated gauge blocks measured with a single-point-to-single-point method where the point is a single point or a representative point. It is recommended that each probing point be located at the calibrated gauging point for the block. 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). See Annex C for alignment procedures.

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

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 with probing points measured as in Figure B.2 d). The gauge is measured in a single-point-to-single-point manner where the point is a single point or a representative point. See Annex C for alignment procedures.

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 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).

B.4 Unidirectional measurements to be supplemented with bidirectional measurements

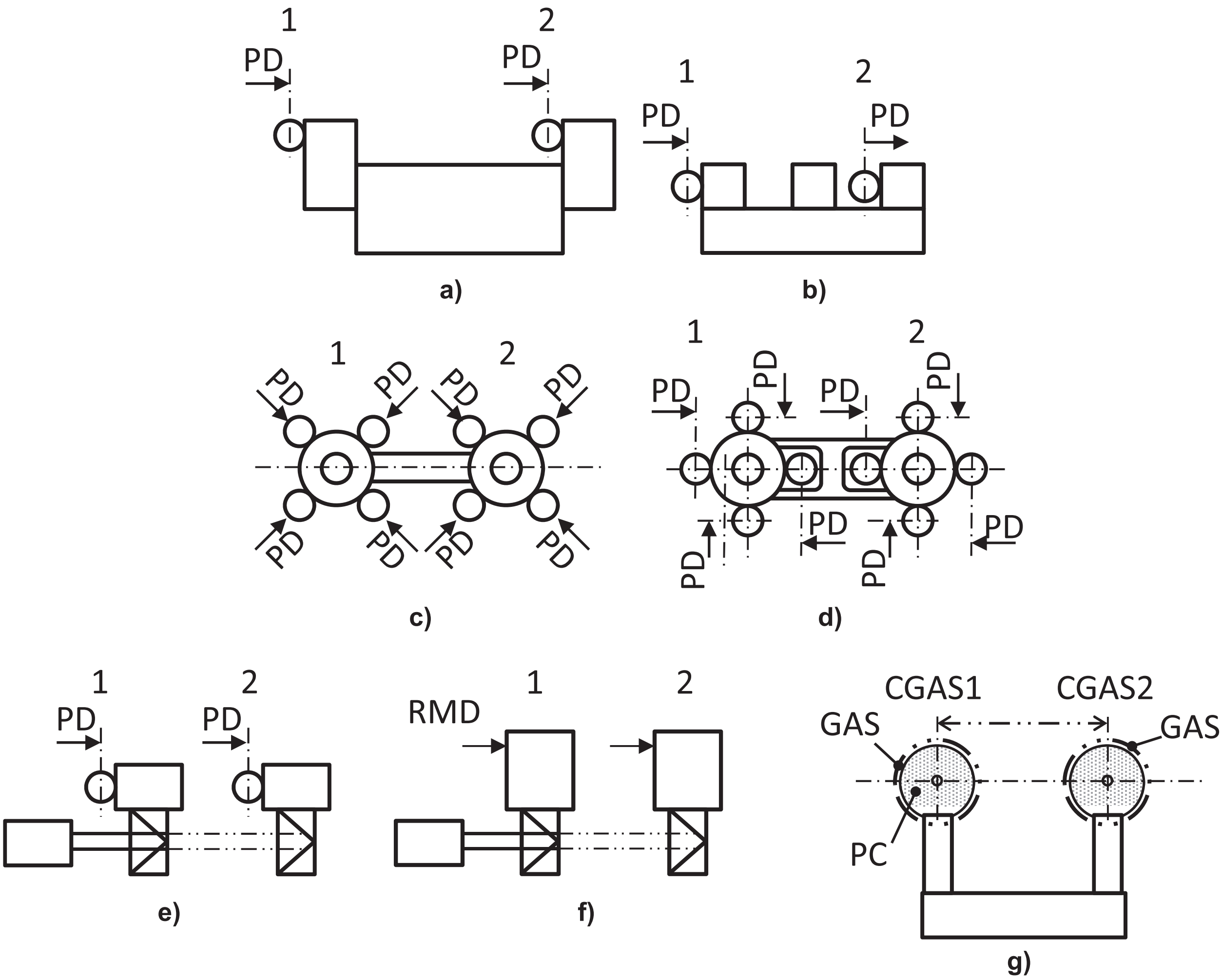
B.4.1 General

For the purposes of this part of ISO 10360, unidirectional measurements may be supplemented with bidirectional measurements, performed in a single-point-to-single-point manner where the point is a single point or a representative point, specifically designed for test-result measurand equivalency. 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.3).

For the purposes of testing according to this part of ISO 10360, the unidirectional measurements described in this clause shall always be combined with bidirectional measurements performed in a single-point-to-single-point manner where the probing point is a single point or a representative point in order to produce a bidirectional calibrated test length. These unidirectional measurements shall not be used alone for testing the length measurement performance of CMMs.

A calibrated test length can be produced using the arithmetic sum of a calibrated unidirectional length and a calibrated bidirectional length specifically described in this clause (default is a short gauge block) with the bidirectional length measured in a single point-to-single-point manner where the point is a single point or a representative point.

A unidirectional length error obtained by point cloud shall not be used for evaluating unidirectional length measuring performance. However, it can be used for bidirectional length error test when derivation procedure described in 6.3.5 is applied.



Key

a	gauge block	1	position one
b	step gauge	2	position two
c	ball bar (five-point measurement)	GAS	Gaussian associated sphere
d	ball bar (five-point measurement)	CGAS	centre of the Gaussian associated sphere
e	laser interferometer with optical probing	PC	point cloud
f	laser interferometer without optical probing	PD	probing direction
g	point cloud	RMD	ram motion direction

Figure B.3 — Unidirectional measurements to be supplemented with bidirectional measurements

B.4.2 Calibrated test length composed of unidirectional measurements and bidirectional short gauge block measurements

For each measurement line under test, measure a short (default 25 mm) calibrated material standard of size in a bidirectional manner as described in B.2.2.

The material standard of size shall be oriented along the measurement line, i.e. its axis shall be approximately in the same direction as the measurement line under test. The location of the material standard of size shall be as close as possible to the measurement line under test; however, for ease of fixturing, the material standard of size may be located near the CMM table surface.

For example, if a body diagonal of the CMM is the measurement line under test, then the material standard of size shall be oriented along the direction of the body diagonal, but may be located "beneath" the diagonal and fixtured near the table surface.

NOTE The test results are affected by the position of the short material standard of size; for instance, locating the material standard of size 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 material standard of size in the middle of the measuring line. However, this may cause fixturing problems. It is up to the tester to choose the best compromise.

If a small sphere of calibrated diameter (default of 25 mm) is used as the material standard of size, a total of four points on the sphere should be measured. Two of these points (or two representative points) shall be located at diametrically opposite points of a sphere diameter that is oriented parallel to the measurement line. The other two points shall be spaced 90° apart, located on the sphere and in a plane orthogonal to the measurement line and containing the sphere centre. The sphere diameter measured in this manner is equivalent to a bidirectional short gauge block measurement.

B.4.3 Material standards for unidirectional measurements to be supplemented with the bidirectional measurements

B.4.3.1 Step gauges measured in a unidirectional manner

A unidirectional measurement of a step gauge shall have each gauging surface measured with three discrete points (at the same target contact point) and the coordinates averaged.

The length is determined using the averaged coordinates. The measurement shall be done in a unidirectional manner (see Figure B.3). See Annex C for alignment procedures.

The averaging of three points on each gauging surface of a unidirectional step gauge is needed, when combined with the short material standard of size errors, to have the test results be equivalent to that of the single-point-to-single-point bidirectional measurement case.

For each measurement line under test, the short material standard of size shall be measured bidirectionally 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 length three times and record the errors of indication in chronological order.

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 calibrated test lengths. Repeat for all five lengths per measurement line; this involves a total of 15 unidirectional measurements and three bidirectional measurements on the short material standard of size per measurement line.

B.4.3.2 Ball plates/ball bars measured in a unidirectional manner with optical probing

A unidirectional measurement of a material standard with spherical gauging surfaces, such as a ball plate or ball bar, consists of each sphere measured with five probing points or five representative points and the (least squares fit) centre-to-centre length determined.

The point sampling strategy is shown in Figure B.3.

For each measurement line under test, the short material standard of size shall be measured bidirectionally 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 length three times and record the errors of indication in chronological order.

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 calibrated test lengths. Repeat for all five lengths per measurement line; this involves a total of

15 unidirectional measurements and three bidirectional measurements on the short material standard of size per measurement line.

B.4.3.3 Laser interferometry measured in a unidirectional manner with optical probing

A unidirectional measurement can be produced using a calibrated laser interferometer and a gauging surface; the gauging surface may be a plane or a sphere.

The measurement involves interferometrically measuring the displacement of the gauging surface that is optically probed by the CMM equipped with optical distance sensors. The gauging surface is typically moved on a carriage or sled that has an attached laser retroreflector.

If the gauging surface is a sphere, the sphere centre location shall be measured with five points or five representative points as described in B.4.3.2. In the case of a plane, the surface is probed with three points or three representative points at each position and the coordinates averaged as described in B.4.3.1; the probing direction is the same for both the initial and final positions (see Figure B.3).

For each measurement line under test, the short material standard of size shall be measured bidirectionally 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 length three times and record the errors of indication in chronological order.

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 calibrated test lengths. Repeat for all five lengths per measurement line; this involves a total of 15 unidirectional measurements and three bidirectional measurements on the short material standard of size per measurement line.

B.4.3.4 Laser interferometry measured in a unidirectional manner without optical probing

In some cases (particularly for large CMMs), it may be convenient to replace the probing system with a retroreflector and to measure the displacement of the ram using laser interferometry.

Each laser displacement measurement is considered a unidirectional measurement to be supplemented with bidirectional measurements (see Figure B.3).

For some CMMs tested with laser interferometry used without a probing system, 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 a probing system. In such cases, a calibrated test length involving optical probing should be employed and an external trigger activating the error compensation may alleviate the problem.

For each measurement line under test, the short material standard of size shall be measured bidirectionally 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 length three times and record the errors of indication in chronological order.

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 calibrated test lengths. Repeat for all five lengths per measurement line; this involves a total of 15 unidirectional measurements and three bidirectional measurements on the short material standard of size per measurement line.

B.4.3.5 Ball plates/ball bars measured in a unidirectional manner by point cloud

A unidirectional measurement of a material standard with spherical gauging surfaces, such as a ball plate or ball bar, consists of the measurement of each sphere by a point cloud and the determination of the (least squares fit) centre-to-centre length.

For each measurement line under test, the short material standard of size shall be measured bidirectionally a total of 15 times. The measurements shall be in a single-point-to-single-point manner where the probing point is a single point or a representative point. The errors of indication shall be recorded in chronological order.

Measure each of the five calibrated unidirectional lengths three times and record the errors of indication in chronological order.

Add the chronologically corresponding bidirectional errors of indication to each of the 15 unidirectional errors of indication (in the usual arithmetical manner) to create the errors of indication of the calibrated test lengths. This involves a total of 15 unidirectional measurements and 15 bidirectional measurements on the short material standard of size per measurement line.

The method of combining the unidirectional errors and the bidirectional errors in this clause is deliberately specified to be different from that of the other clauses in B.4.3. This is due to the significant averaging effect in the calculation of a sphere centre from a point cloud with a significant number of points in practice.

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 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 possible 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 the two 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.

C.3 Ball bar/Ball plate

One method of aligning ball bars or ball plates when they are measured in a bidirectional manner is to ensure that the probing direction is along the gauge axis, i.e. the line passing through the sphere centres. The gauge axis is defined as the centre-to-centre axis between the two spheres. Due to the alignment method, this type of calibrated test length shall only be used on CMMs where the probe approach motion is under computer control.

Another 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. the 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.

In both cases, the bidirectional ball bar or ball plate measurement defines a calibrated test length that consists of the calibrated centre-to-centre distance plus one half of the calibrated diameter of each sphere. And in both cases, the unidirectional ball bar or ball plate measurement defines a calibrated test length that consists of the calibrated centre-to-centre distance plus a subtraction of one half of the calibrated diameter of a sphere from that of the other sphere.

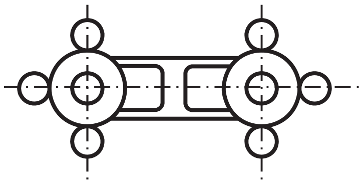


Figure C.1 — View showing a four-point probing pattern per sphere used for a bidirectional ball bar measurement

Ball bars or ball plates measured in the unidirectional manner to be supplemented with bidirectional measurements as described in B.4.3.2 have a geometrically unique centre location of each sphere and therefore do not typically require special alignment methods.

When using ball bars or ball plates, it has to be ensured that the probing pattern during the test is as close as possible to the probing pattern documented in the calibration certificate of the standard and that it is similar to the pattern shown in Figure B.3. If this cannot be achieved, the pattern in Figure B.3 shall be used and additional contributors to the test uncertainty shall be considered.

For measuring a bidirectional ball bar, only computer-controlled CMMs should be used. Follow the artefact's alignment procedures, typically by first determining the gauge axis by measuring the two spheres before performing the bidirectional measurement.

For some multi-ball ball bars, a common measurement axis does not exist. In some cases, only the centre distance between two neighbouring balls is calibrated. For lengths comprised of two non-adjacent balls, the reference value is taken as the sum of the spatial distances; because of the geometry of the intervening sphere locations, additional uncertainties associated with this geometry should be taken into account (see Figure C.2).

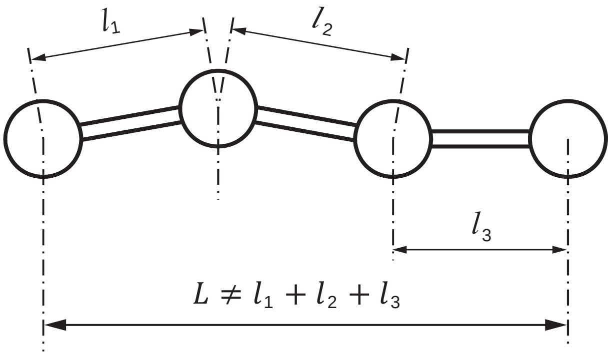


Figure C.2 — Evaluation of ball distances for a multi-ball ball bar

Annex D
(normative)

Articulated location value of CMMs with articulating probing system for optical distance sensors

D.1 General

Typical CMMs with optical distance sensors may be equipped with an articulation function for the articulating probing system to vary the orientation angle of the sensors. The positioning performance of the articulation function may significantly influence the performance of the CMMs.

This annex specifies the test for verifying the performance of CMMs with an articulating probing system to vary the orientation angle of the optical distance sensors.

See Clause 3 for the definitions of the terms "articulated location value" and "maximum permissible limit of the articulated location value".

D.2 Symbols

For the purpose of this annex, the symbols given in Table D.1 apply.

Table D.1 — Symbols

Symbol	Meaning
$L_{\mathrm{Dia.5\times25:Art:ODS}}$	articulated location value
$L_{\mathrm{Dia.5\times25:Art:ODS,MPL}}$	maximum permissible limit of the articulated location value

D.3 Acceptance tests and reverification tests

D.3.1 Principle

The principle of the assessment method for the articulated location value is to establish whether the CMM is capable of measuring within the stated maximum permissible limit of the articulated location value, $L_{\mathrm{Dia.5\times25:Art:ODS,MPL}}$, by determining the dispersion of the centres of five spheres each measured with five different articulating angles.

D.3.2 Measurement equipment

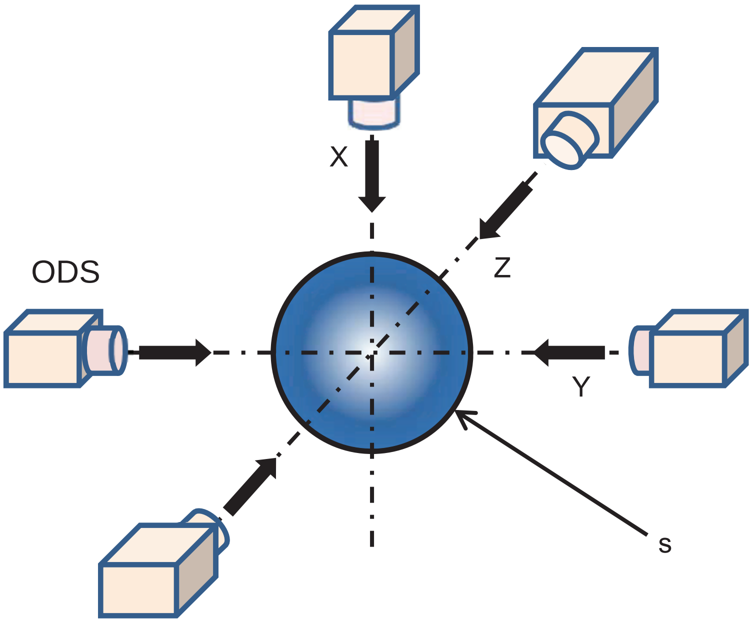
The requirement of the material standard for this test is the same as that for the test sphere described in 6.2.2.

D.3.3 Procedure

Measure the test sphere in each angular position shown in Figure D.1.

Figure D.1 shows a recommended combination of angular positions when an articulating probing system with two degrees of freedom is used. Some CMMs may be equipped with an articulating probing system with more degrees of freedom e.g. three. In this case, it is recommended that all the articulation axes be varied significantly to realize the five different angular positions. A different combination of the angular position in the respective articulation axes may significantly affect the results.

The measurement procedure in each angular position is the same as 6.2.3.



Key

ODS optical distance sensor

S test sphere

Figure D.1 — Recommended sensor arrangement for the articulated location test

D.3.4 Derivation of test results

The location of a test sphere using five different angular positions of an articulating probing system is calculated. At each angular position, 25 representative points are measured on the test sphere, for a total of 125 representative points using all five positions. Associate a least-squares sphere fit with each group of 25 representative points taken at each angular position, for a total of five sphere fits. The minimum circumscribe sphere (MCS) of the centres of all five spheres is calculated. The diameter of the MCS yields the probing-system location value.

The derivation procedure for each representative point is the same as 6.2.4.1.

D.4 Compliance with specifications

D.4.1 Acceptance test

D.4.1.1 Acceptance criteria

The performance of the CMM with optical distance sensors and the articulating probing system is verified if:

— articulated location value, $L_{\text{Dia.5} \times 25\text{:Art:ODS}}$, is not greater than the maximum permissible articulated location value, $L_{\text{Dia.5} \times 25\text{:Art:ODS,MPL}}$, as specified by the manufacturer and taking into account the uncertainty of measurement according to ISO 14253-1.

D.4.1.2 Data rejection and repeated measurements

If the performance of articulated location value is not verified by the test, the probing equipment should be checked for the faults that could be influencing the measurement result. Any faults should be corrected and the relevant test repeated once only, and the original measurement results should be discarded.

No additional repeated measurement should be performed.

D.4.2 Reverification test

The performance of the CMM with optical distance sensors is considered to have been verified if $L_{\text{Dia.5} \times 25\text{:Art:ODS}}$ described in D.4 is not greater than the maximum permissible limit $L_{\text{Dia.5} \times 25\text{:Art:ODS,MPL}}$ as determined in D.5.1.

D.5 Applications

D.5.1 Acceptance test

In a contractual situation between a manufacturer and a user such as that described in a purchasing, maintenance, repair, renovation or upgrade contract, the acceptance tests described in this part may be used to verify the performances of the probe articulation of a CMM with optical distance sensors, in accordance with the specified maximum permissible limits agreed on by the manufacturer and the user.

D.5.2 Reverification test

The reverification tests given in this annex can be used in an organization's internal quality assurance system for verification of the performances of the probe articulation of a CMM with optical distance sensors, in accordance with the specified appropriate maximum permissible limits as stated by the user with all possible and detailed limitations applied.

D.5.3 Interim check

In an organization's internal quality assurance system, reduced reverification tests can be used periodically to demonstrate the probability that the CMM conforms to the requirements for maximum permissible limits. The extent of the interim checks for optical distance sensors specified in this annex may be reduced in respect of the number of actual measuring points being assessed.

It is recommended that the probing system be checked regularly, and after any incident which could have significantly affected the probing performance.

D.6 Indication in product documentation and data sheets

The symbols given in Table D.1 are not well suitable for use in product documentation, drawings, data sheets etc. Table D.2 gives the corresponding indications also allowed.

Table D.2 — Symbols and corresponding indication in product documentation, drawings, data sheets, etc.

Symbol used in this document	Corresponding indication
$L_{\text{Dia.5} \times 25\text{:Art:ODS}}$	L[Dia.5 × 25:Art:ODS]
$L_{\text{Dia.5} \times 25\text{:Art:ODS,MPL}}$	MPL(L[Dia.5 × 25:Art:ODS])

Annex E
(informative)

Relation to the GPS matrix model

E.1 General

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

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

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

This part of ISO 10360 specifies the acceptance test for verifying that the performance of a CMM with optical distance sensors is as stated by the manufacturer. It also specifies the reverification test that enables the user to periodically reverify the performance of a CMM with optical distance sensors.

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 Table E.1.

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

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

E.4 Related standards

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

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

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[5] ISO 15530 (all parts), *Geometrical product specifications (GPS) — Coordinate measuring machines (CMM): Technique for determining the uncertainty of measurement*

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