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

Part 13: Optical 3D CMS

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

Partie 13: SMT optique 3D

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ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

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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 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

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

This document was prepared by Technical Committee ISO/TC 213, *Dimensional and geometrical product specifications and verification*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 290, *Dimensional and geometrical product specification and verification*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

A list of all parts in the ISO 10360 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document is a geometrical product specification (GPS) standard and is to be regarded as a general GPS standard (see ISO 14638). It influences chain link F of the chain of standards on size, distance, form, orientation, location and run-out in the general GPS matrix (see Annex H).

The ISO GPS matrix model given in ISO 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.

This document has two technical objectives:

1) to test the error of indication when measuring a calibrated test length across the global measuring volume of the CMS;

2) to test the errors of indication within a locally intended measuring volume.

These two objectives correspond to:

a) the test performed for a probing system and a moving carrier of the probing system in combination as described in ISO 10360-2, ISO 10360-7, ISO 10360-8, ISO 10360-10, ISO 10360-11[1)] and ISO 10360-12;

b) the test performed dominantly for the probing system as described in ISO 10360-5, ISO 10360-7, ISO 10360-8, ISO 10360-9, ISO 10360-10, ISO 10360-11 and ISO 10360-12.

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

An optical 3D CMS as specified by this document is a contactless area measuring sensor delivering 3D data in several individual single views by an optical measuring principle and transforming it into a common coordinate system. Typical optical measuring principles are pattern projection, fringe projection and projecting-and-sweeping a scanned line, or similar, delivering single views without assistance of external information related to position and orientation of the objects to be scanned relative to the CMS. Typical registration principles are based on a best fitting of commonly captured position information across at least two different single views by using either or both reference features attached or surface features of the objects to be scanned.

This document is not intended to apply to other types of CMSs, for example:

— tactile CMMs (Cartesian metrological moving carrier), see ISO 10360-2;

— imaging CMMs (Cartesian metrological moving carrier), see ISO 10360-7;

— CMMs equipped with optical distance sensors (Cartesian metrological moving carrier), see ISO 10360-8;

— laser trackers, see ISO 10360-10;

— X-ray CTs, see ISO 10360-11;

— articulated arm CMMs, see ISO 10360-12;

— measuring instruments intended to measure surface characteristics, see the ISO 25178 series;

— optical microscopes;

— hand-held laser-line type scanners.

1) Under preparation. Stage at the time of publication: ISO/DIS 10360-11:2021.

Parties can apply this document to the above or other types of CMSs by mutual agreement.

This document specifies:

— performance requirements that can be assigned by the manufacturer or the user of the CMS;

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

— rules for verifying conformance;

— applications for which the acceptance and reverification tests can be used.

NOTE 1 Annex E describes possible limitations with regard to less cooperative surface characteristics, such as colour, glossiness and roughness, and provides a suggested test that can give CMS users an idea of how representative the maximum permissible error would be when measuring their specific industrial part.

NOTE 2 The optical 3D CMS can be moved and positioned by a manually or automated moving unit. The position, orientation or both can be used as additional information for the registration.

NOTE 3 The acceptance and reverification tests are designed to mimic real but simple measurements occurring in practice, subject to the rated operating conditions and the testing procedures. The user is advised to consider the influence of additional or omitted conditions, procedural steps or both when applying the test results according to this document to predict the performance of an actual CMS.

For more detailed information of the relation of this document to other standards and the GPS matrix model, see Annex H.

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

Part 13: Optical 3D CMS

1 Scope

This document specifies the acceptance tests for verifying the performance of an optical 3D coordinate measuring system (CMS) 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 optical 3D CMS.

This document is applicable to verification of the measuring performance of CMSs if the surface characteristics (e.g. glossiness, colour) of the object to be scanned are restricted and within a cooperative range.

This document does not apply to other types of CMSs, including those covered by the other parts of the ISO 10360 series.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

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

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

3 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
optical 3D coordinate measuring system
optical 3D CMS
system performing measurements of spatial coordinates exclusively by optical sensors

3.2
sensor measurement volume
volume of measurement of the sensor realized without movement of the sensor relative to the workpiece fulfilling the specifications stated by the manufacturer

Note 1 to entry: Dimensional indication of sensor measurement volume stated by the manufacturer can significantly differ from that which the sensor shows.

3.3
registration
transformation of coordinate systems that brings single-view coordinates into a unified coordinate system

Note 1 to entry: A transformation is realized for example by a rigid transformation, consisting of either translation, rotation or both.

Note 2 to entry: Each single view holds its own coordinate system and requires a transformation to the unified coordinate system.

Note 3 to entry: The registration is invertible. The inverse registration can be performed by applying the inverse transformation.

Note 4 to entry: In practice, the transformation parameters are derived first, then the transformations occur either immediately or at a later stage.

Note 5 to entry: A registration can require a person to operate the CMS.

3.4
fusion
operation that merges two or more sets of measured coordinates into a unified set of measured coordinates

Note 1 to entry: Fusions are performed to improve the measurement, e.g. to reduce the dispersion and the mismatch of single views.

Note 2 to entry: Fusions are typically irreversible (not invertible).

Note 3 to entry: A fusion can include any number of elementary operations in combination or in sequence, such as coordinate transformation, averaging, outlier rejection, decimation, convolution and filtration.

Note 4 to entry: The fusion can occur either immediately or at a later stage.

3.5
concatenated measurement volume
volume of measurement of the CMS obtained by movement of the sensor relative to the workpiece and the registration fulfilling the specifications stated by the manufacturer

Note 1 to entry: The concatenated measurement volume can be determined by design of a measuring cabin typically having a cuboid boundary or a three-dimensional size of the intended workpiece.

Note 2 to entry: A concatenated measurement volume can have either a significantly larger volume than the sensor measurement volume or a similar volume to the sensor measurement volume.

3.6
single-view measurement
measurement of spatial coordinates done with an optical sensor without movement relative to the workpiece

Note 1 to entry: Single-view measurement is performed with no movement of the carrier, registration or fusion.

Note 2 to entry: Single-view measurement can include repeated measurements, for example multiple exposures, provided that no movement of the optical sensor relative to the workpiece occurs from the first exposure to the last.

3.7
multiple-view measurement
measurement of spatial coordinates through registration and fusion of multiple single-view measurements in different locations and orientations of the optical sensor relative to the workpiece

3.8
probing form dispersion error
$P_{\text{Form.Sph.}i:j\text{:O3D}}$
smallest width of a spherical shell that encompasses a percentile of all measured data

Note 1 to entry: The symbol "*P*" in $P_{\text{Form.Sph.}i:j\text{:O3D}}$ indicates that the error is associated with the probing system performance; the qualifier "Form.Sph" indicates that it is associated with the probing dispersion error when measuring a sphere; and the qualifier "O3D" indicates that it is associated with an optical 3D CMS. The qualifier "*i*" identifies the percentile of probed points selected for the evaluation: either "D95%" denoting 95 % of the population or "All" denoting the whole population, i.e. 100 %. The qualifier "*j*" identifies the measuring conditions of the CMS. "SMV.SV" denotes single-view measurement while "SMV.MV" denotes multiple-view measurement. The measurement is performed within the sensor measurement volume ("SMV") in either case. Examples of such symbols include $P_{\text{Form.Sph.D95\%:SMV.SV:O3D}}$ and $P_{\text{Form.Sph.All:SMV.MV:O3D}}$.

Note 2 to entry: Both percentiles, 95 % and All, are of the measured points according to the rated operating conditions. When these conditions include pre-processing such as prefiltering or meshing, then the percentiles apply to such points after this application.

Note 3 to entry: 5 % of the measured points in the "All" data set is eliminated to determine $P_{\text{Form.Sph.D95\%:}j\text{:O3D}}$. Outliers can be eliminated by this operation.

Note 4 to entry: It can be beneficial to evaluate probing errors from point cloud both from "95 %" population and "All" population. A difference in these two test results can reveal influences of smoothing filters or equivalent functions potentially pre-installed as an integral part of the CMS or the associated software, which is not always transparently visible for users of the CMS.

3.9
probing size error
$P_{\text{Size.Sph.}i:j\text{:O3D}}$
error of indication when measuring a calibrated diameter of a test sphere as associated by an unweighted and unconstrained least-squares fit to a percentile of all measured data

Note 1 to entry: The symbol "*P*" in $P_{\text{Size.Sph.}i:j\text{:O3D}}$ 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 of a sphere; and the qualifier "O3D" indicates that it is associated with the optical 3D CMS. The qualifier "*i*" identifies the percentile of probing points selected for the evaluation: either from "D95%" denoting 95 % of the population or "All" denoting the whole population, i.e. 100 %. The qualifier "*j*" identifies the measuring conditions of the CMS. "SMV.SV" denotes single-view measurement while "SMV.MV" denotes multiple-view measurement. The measurement is performed within the sensor measurement volume ("SMV") in either case. Examples of such symbols include $P_{\text{Size.Sph.D95\%:SMV.SV:O3D}}$ and $P_{\text{Size.Sph.All:SMV.MV:O3D}}$.

Note 2 to entry: Both percentiles, 95 % and All, are of the measured points according to the rated operating conditions. When these conditions include pre-processing such as prefiltering or meshing, then the percentiles apply to such points after this application.

Note 3 to entry: The probing size error is determined by the errors of the sensors (caused by, for example, noise, digitization, image distortion, optical interaction with the surface of the material standard, calibration, faulty algorithms) and of the positioning system.

3.10
distortion error

$D_{CC:j:O3D}$

error of indication when measuring a calibrated centre-to-centre distance within the sensor measurement volume either by single-view measurement operation or multiple-view measurement operation

Note 1 to entry: The symbol "*D*" indicates that the error is associated with the geometrical deformation of the sensor within the sensor measurement volume; the qualifier "CC" indicates that the error of indication is of a centre-to-centre distance; and the qualifier "O3D" indicates that it is associated with an optical 3D CMS. The qualifier "*j*" identifies the measuring conditions of the CMS. "SMV.SV" denotes single-view measurement, while "SMV.MV" denotes multiple-view measurement. The measurement is performed within the sensor measurement volume ("SMV") in either case. Examples of such symbols include $D_{CC:SMV.SV:O3D}$ and $D_{CC:SMV.MV:O3D}$.

3.11
flat-form distortion error

$D_{Form.Pla.i:j:O3D}$

minimum distance between two parallel planes that encompass a percentile of all data measured on the test flat

Note 1 to entry: The symbol "*D*" indicates that the error is associated with the geometrical deformation of the sensor; the qualifier "Form.Pla" indicates that it is associated with the form error of a plane; and the qualifier "O3D" indicates that it is associated with the optical 3D CMS. The qualifier "*i*" identifies the percentile of probing points selected for the evaluation: either "D95%" denoting 95 % of the population or "All" denoting the whole population, i.e. 100 %. The qualifier "*j*" identifies the measuring conditions of the CMS. "SMV.SV" denotes single-view measurement while "SMV.MV" denotes multiple-view measurement. The measurement is performed within the sensor measurement volume ("SMV") in either case. Examples of such symbols include $D_{Form.Pla.D95\%:SMV.SV:O3D}$ and $D_{Form.Pla.All:SMV.MV:O3D}$.

Note 2 to entry: Both percentiles, 95 % and All, are of the measured points according to the rated operating conditions. When these conditions include pre-processing such as prefiltering or meshing, then the percentiles apply to such points after this application.

3.12
volumetric length measurement error in concatenated measurement volume

$E_{Vol:CMV.MV:O3D}$

error of indication when measuring a calibrated test length within the concatenated measurement volume by multiple-view measurement

Note 1 to entry: The symbol "*E*" indicates that the error of indication is of a length in space; the qualifier "Vol" indicates that volumetric geometry errors of the CMS is of interest (not local probing errors); the qualifier "CMV.MV" denotes multiple-view measurement within the concatenated measurement volume; and the qualifier "O3D" indicates that it is associated with an optical 3D CMS.

Note 2 to entry: The multiple-view measurement is to reveal the volumetric length measurement error in the concatenated measurement volume.

Note 3 to entry: A calibrated test length can typically be calibrated by the centre-to-centre distance of a sphere standard. See Annex B for details.

3.13
maximum permissible probing form dispersion error

$P_{Form.Sph.i:j:O3D,MPE}$

extreme value of $P_{Form.Sph.i:j:O3D}$ permitted by specifications as maximum permissible error

Note 1 to entry: The qualifier "*i*" identifies the percentile of probing points selected for the evaluation: either "D95%" denoting 95 % of the population or "All" denoting the whole population, i.e. 100 %. The qualifier "*j*" identifies the measuring conditions of the CMS. "SMV.SV" denotes single-view measurement while "SMV.MV" denotes multiple-view measurement. The measurement is performed within the sensor measurement volume ("SMV") in either case.

3.14
maximum permissible probing size error
$P_{Size.Sph.i:j:O3D,MPE}$
extreme value of $P_{Size.Sph.i:j:O3D}$ permitted by specifications as maximum permissible error

Note 1 to entry: The qualifier "*i*" identifies the percentile of probing points selected for the evaluation: either "D95%" denoting 95 % of the population or "All" denoting the whole population, i.e. 100 %. The qualifier "*j*" identifies the measuring conditions of the CMS. "SMV.SV" denotes single-view measurement while "SMV.MV" denotes multiple-view measurement. The measurement is performed within the sensor measurement volume ("SMV") in either case.

3.15
maximum permissible distortion error
$D_{CC:j:O3D,MPE}$
extreme value of $D_{CC:j:O3D}$ permitted by specifications as maximum permissible error

Note 1 to entry: The qualifier "*j*" identifies the measuring conditions of the CMS. "SMV.SV" denotes single-view measurement while "SMV.MV" denotes multiple-view measurement. The measurement is performed within the sensor measurement volume ("SMV") in either case.

3.16
maximum permissible flat-form distortion error
$D_{Form.Pla.i:j:O3D,MPE}$
extreme value of $D_{Form.Pla.i:j:O3D}$ permitted by specifications as maximum permissible error

Note 1 to entry: The qualifier "*i*" identifies the percentile of probing points selected for the evaluation: either "D95%" denoting 95 % of the population or "All" denoting the whole population, i.e. 100 %. The qualifier "*j*" identifies the measuring conditions of the CMS. "SMV.SV" denotes single-view measurement while "SMV.MV" denotes multiple-view measurement. The measurement is performed within the sensor measurement volume ("SMV") in either case.

3.17
maximum permissible volumetric length measurement error in concatenated measurement volume
$E_{Vol:CMV.MV:O3D,MPE}$
extreme value of $E_{Vol:CMV.MV:O3D}$ permitted by specifications as maximum permissible error

3.18
bi-directional length measurement error in concatenated measurement volume
$E_{Bi:CMV.MV:O3D}$
error of indication when measuring a calibrated test length bi-directionally within the concatenated measurement volume by multiple-view measurement

Note 1 to entry: See Annex A for details of the optional characteristics.

Note 2 to entry: The symbol "*E*" indicates that the error is of a length in space; the qualifier "Bi" indicates that the local probing errors are included (bi-directional probing); the qualifier "CMV.MV" denotes multiple-view measurement within the concatenated measurement volume; and the qualifier "O3D" indicates that it is associated with an optical 3D CMS.

Note 3 to entry: The multiple-view measurement is to reveal the volumetric length measurement error in the concatenated measurement volume.

3.19
maximum permissible bi-directional length measurement error
$E_{Bi:CMV.MV:O3D,MPE}$
extreme value of $E_{Bi:CMV.MV:O3D}$ permitted by specifications as maximum permissible error

4 Symbols

$P_{\text{Form.Sph.}i:j\text{:O3D}}$	probing form dispersion error
$P_{\text{Size.Sph.}i:j\text{:O3D}}$	probing size error
$D_{\text{CC:}j\text{:O3D}}$	distortion error
$D_{\text{Form.Pla.}i:j\text{:O3D}}$	flat-form distortion error
$E_{\text{Vol:CMV.MV:O3D}}$	volumetric length measurement error in concatenated measurement volume
$E_{\text{Bi:CMV.MV:O3D}}$	bi-directional length measurement error in concatenated measurement volume
$P_{\text{Form.Sph.}i:j\text{:O3D,MPE}}$	maximum permissible probing form dispersion error
$P_{\text{Size.Sph.}i:j\text{:O3D,MPE}}$	maximum permissible probing size error
$D_{\text{CC:}j\text{:O3D,MPE}}$	maximum permissible distortion error
$D_{\text{Form.Pla.}i:j\text{:O3D,MPE}}$	maximum permissible flat-form distortion error
$E_{\text{Vol:CMV.MV:O3D,MPE}}$	maximum permissible volumetric length measurement error in concatenated measurement volume
$E_{\text{Bi:CMV.MV:O3D,MPE}}$	maximum permissible bi-directional length measurement error
D95%	95 % percentile of the population
All	whole population (i.e. 100 % percentile)
SMV.SV	single-view measurement within the sensor measurement volume
SMV.MV	multiple-view measurement within the sensor measurement volume
CMV.MV	multiple-view measurement within the concatenated measurement volume

5 Rated operating conditions

5.1 Environmental conditions

Limits for permissible environmental conditions (e.g. 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 is performed within the manufacturer's specified limits given in the CMS data sheet.

The user is responsible for providing the environment enclosing the CMS 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

5.2.1 General

For all the tests described in this document, the optical 3D CMS shall be operated according to the rated operating conditions and the default settings stated by the manufacturer.

If any of the conditions and settings are not specified, the user is free to choose.

The manufacturer may specify extra specifications for special operating conditions and settings at its discretion.

Specific areas in the manufacturer's manual to be adhered to include:

1) machine start-up or warm-up cycles;

2) qualification of the CMS;

3) achievement of thermal stability of the CMS;

4) location, type, number of thermal sensors when these are at least partially applicable;

5) software filters;

6) surface characteristics of the material standards such as colour, roughness, glossiness, light scattering characteristics;

7) default procedures and settings for data registration and data fusion;

8) pre-installed smoothing function;

9) concatenated measurement volume if applicable.

NOTE The CMS qualification can include a number of adjustments and parameter settings, such as those related to the geometry in a sub-system assembly, the illumination, the optical sensing and the numerical filtration.

5.2.2 Material and surface characteristic of material standards

The material used for the material standards shall be stated by the manufacturer. Different materials have different optical characteristics such as reflection factor, optical penetration depth (volume scattering), colour or scattering characteristics, which can influence the test values. The roughness of the material standard shall be negligibly small compared to the maximum permissible error.

Material, surface characteristics and colour of the material standards shall be described in the technical documentation of the instrument that is available to the (potential) user. If the manufacturer fails to specify the material, the surface characteristics of the material standard, or both, then the user is free to choose.

If a specific surface preparation, such as usage of powder spraying or similar, is explicitly stated in the technical data sheet, the surface preparation shall be used in the tests.

NOTE 1 Material standards can be made of diverse materials, such as ceramics or steel.

NOTE 2 Assessment of optical characteristics of the surface to be measured is described in Annex E.

Reference standards used for system qualification shall not be used for the tests described in this document.

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

5.2.3 Pre-processing

Pre-processing of raw measurement data as a part of the rated operating conditions shall be indicated in the technical documentation of the instrument that is available to the (potential) user.

NOTE Pre-processing is typically implemented to realize outlier elimination, smoothing fluctuation in measurement points, supressing thickness of point cloud, and so on.

The influence of pre-processing can be observed by the resolution tests described in Annex F. If the resolution test is performed, the same operating conditions of the CMS shall be used.

6 Acceptance and reverification test

6.1 General

In the following:

— acceptance tests shall be executed according to the manufacturer's specifications and procedures as specified in this document;

— reverification tests shall be executed according to the user's specifications and the manufacturer's procedures as specified in this document.

NOTE 1 The user's specification can be either identical to or different from the manufacturer's specification depending on the interest or requirement of the user. An example of the difference is: an MPE value to be verified is expanded from that of the manufacturer.

At least all mandatory tests according to Table 2 shall be performed.

When conducting multiple-view registration indispensable to multiple-view (MV) measurement, the tester shall carefully choose and combine either or both the reference features attached on the material standard or surface feature(s) belonging to the material standard as required in the manufacturer's operating manuals, which are deemed to be a part of the rated operating conditions.

NOTE 2 A measurement in the sensor measurement volume (SMV) can be performed to verify probing performance, length measuring performance and flat form measuring performance by either single-view measurement (SV), multiple-view measurement (MV) or both. However, a measurement in the concatenated measurement volume (CMV) to verify the length-measuring performance can only be performed by multiple-view measurement (MV).

6.2 Distortion characteristics

6.2.1 General

The performance of optical 3D CMSs suffers from distortion of the sensor optical system.

This type of error is unlikely to be detected in the probing tests or length measurement error test but can have a large influence on the measurement of form in practice. The distortion error shall be specified and the corresponding test shall be performed.

6.2.2 Distortion error

6.2.2.1 Principle

The principle of this test is to establish whether the optical 3D CMS is capable of measuring in the sensor measurement volume within the stated maximum permissible distortion errors. The two characteristics, $D_{\mathrm{CC:SMV.SV:O3D}}$ and $D_{\mathrm{CC:SMV.MV:O3D}}$, are evaluated.

6.2.2.2 Material standard

A material standard consisting of two spheres (e.g. a ball bar or plate), calibrated for the centre-to-centre distance for evaluating the distortion error, the size and the form of the sphere 1 of Figure 1 for evaluating the probing errors as described in 6.3, shall be used (see Annex B). The dimensions of the material standard shall fulfil the following conditions unless specified by mutual agreement:

$$L_p \geq 0{,}3 \times L_0$$

$$0{,}02 \times L_0 \leq \varnothing_p \leq 0{,}2 \times L_0$$

where

L_p is the centre-to-centre distance of the spheres;

$\varnothing_p$ is the nominal diameter of the spheres;

L_0 is the longest distance within the sensor measurement volume.

NOTE 1 To fulfil the requirement described in the first paragraph of 6.2.2.3.1, the centre-to-centre distance of the spheres will need to be greater than 0,3 x L_0 for some positions.

If the ratio of the longest to the shortest distance along directions to be tested within the sensor measurement volume is larger than three, the dimensions of the material standard may be adopted by mutual agreement.

NOTE 2 The longest distance within the sensor measurement volume can be the spatial diagonal, if the shape of the sensor measurement volume is a cuboid. Similarly, the shortest distance can be either in the longitudinal direction or the transversal direction to the optical axis of the CMS.

The artefact supplied with the CMS for the qualification shall not be used as the material standard.

6.2.2.3 Procedure

6.2.2.3.1 General

The sensor measurement volume is divided into eight adjacent sub-volumes (voxels) of similar size. Figure 1 illustrates this subdivision in the case of a sensor measurement volume that is a parallelepiped in shape. When it is a different shape then the subdivision shall follow that shape to correspond with the parallelepiped case as much as possible. The material standard shall be positioned in a way that each of the measurable patches of two spheres is entirely within a voxel and the two patches are in different voxels.

Twenty-eight positions of the material standard are possible (combination of two out of eight voxels) of which the 12 tabled and illustrated in Figure 1 are mandatory. For each of them, at least one of the two spheres shall be close to the outer edge of the sensor measurement volume. It shall be ensured that the diagonal orientations have significant inclination from the horizontal plane.

This standard requires that:

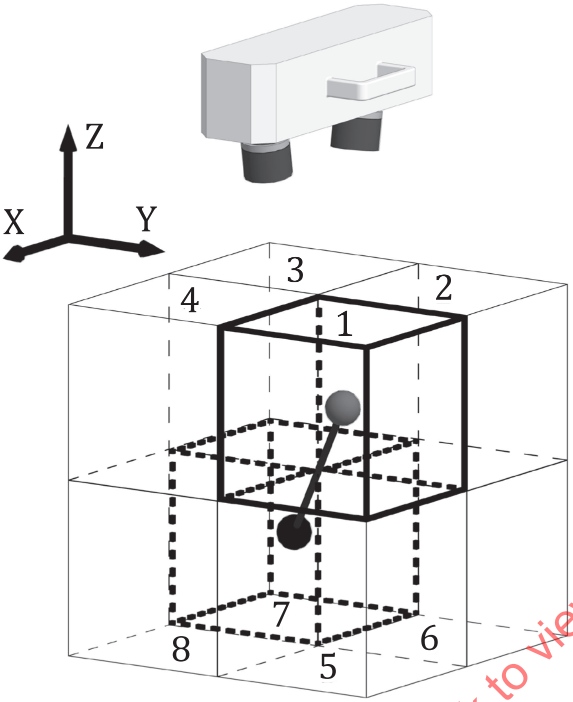
— the distances of at least 25 % of the points probed on the sphere to the outer edge of the sensor measurement volume shall not exceed 10 % of the longest length within the sensor measurement volume;

— or alternatively, if the above condition is difficult to satisfy due to technical reasons, the distance between the sphere centre and the outer edge of the sensor measurement volume shall not exceed 10 % of the longest length within the sensor measurement volume.

The actually tested positions shall be recorded and stated in the test report.

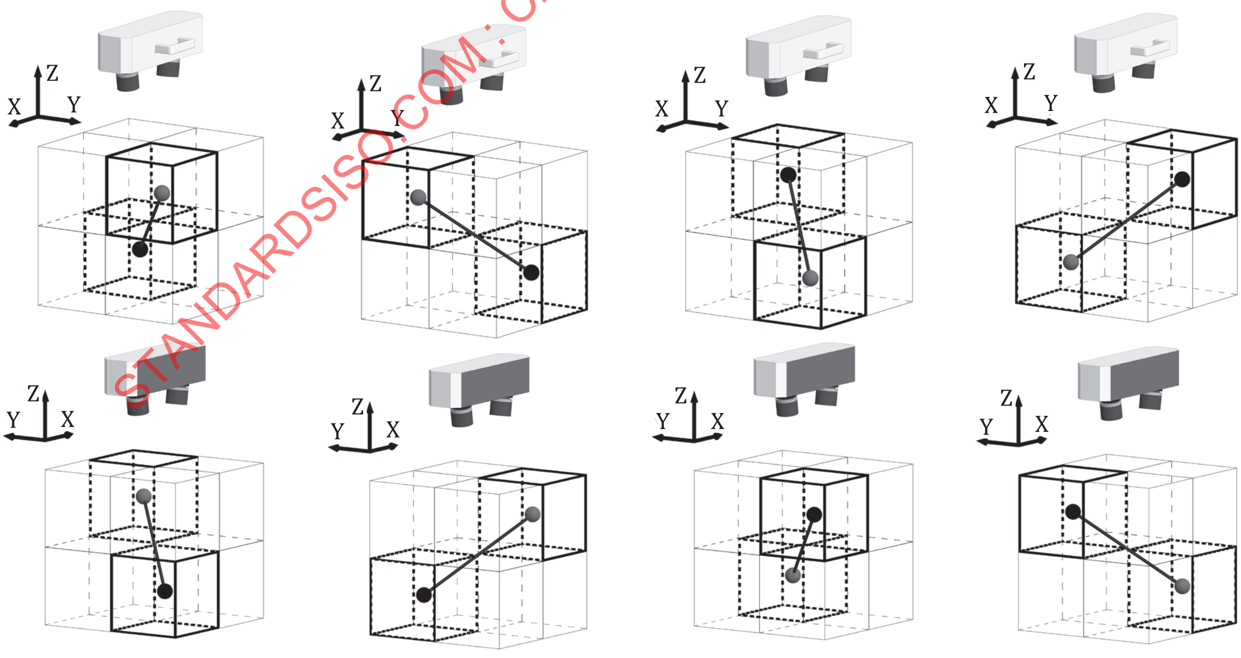
Either the CMS or the material standard or both may be repositioned to achieve the 12 relative combinations.

The centre-to-centre distance of each of the 12 positions shall be measured three times, for a total of 36 distance measurements. If the three repetitions are taken one after another, a slight change in the relative position between the CMS and the material standard after each measurement is required. The magnitude of the change in the position of each sphere shall be greater than the lesser of 2 mm and 0,3 % of the longest distance within the sensor measurement volume in any direction.

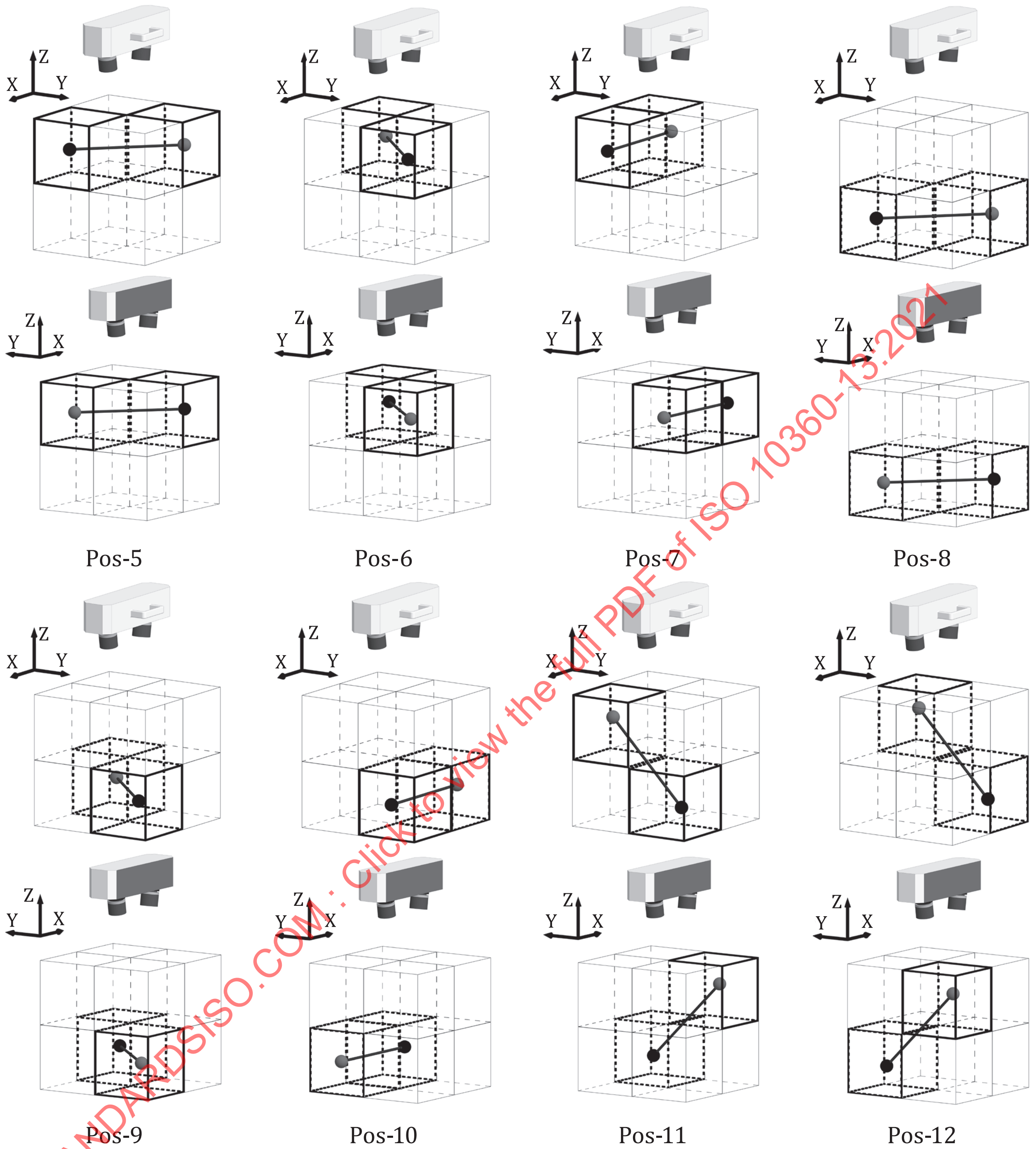


Position	Sphere 1 in voxel	Sphere 2 in voxel
1	1	7
2	4	6
3	5	3
4	8	2
5	2	4
6	3	1
7	3	4
8	6	8
9	7	5
10	6	5
11	4	5
12	3	6

a) Positions of the calibrated test length in the sensor measurement volume, overview



Pos-1 Pos-2 Pos-3 Pos-4



b) Positions of the calibrated test length in the sensor measurement volume, each shown in two different views

Key

X	X-axis
Y	Y-axis
Z	Z-axis
Pos-*i* (*i* = 1, 2, ..., 12)	position-*i*

Figure 1 — Positions of the calibrated test length(s) in the sensor measurement volume (schematic)

6.2.2.3.2 Single-view distortion error

The single-view distortion measurement shall be performed in a single shot measurement in accordance with the normal operating procedure as stated by the manufacturer. A single-view distortion measurement shall be performed with no repositioning either of the CMS or of the material standard.

6.2.2.3.3 Multiple-view distortion error

The multiple-view distortion measurement shall be performed with a combination of the 12 single-view measurements in accordance with the normal operating procedure as stated by the manufacturer.

This results in three distortion error values $D_{\text{CC:SMV.MV:O3D}}$. At least a hemisphere of each sphere shall be captured by the combination of the 12 single-view measurements.

Registration and fusion are necessary to obtain the multiple-view distortion error. Use of reference features attached on the material standard, surface feature(s) belonging to the material standard or both is allowed for the multiple-view registration and fusion, provided that the relevant information is disclosed to the users in the operation manual or by other means.

The manufacturer shall describe the operational details of and give best practice guidance for the multiple-view registration and fusion to the user.

The operational information of the multiple-view registration and fusion shall be recorded and stated in the data sheet to enable the users to reproduce the test.

NOTE 1 The choice and combination of reference features as well as the configuration of the registration, fusion and the associated operational parameters can significantly affect the test result.

NOTE 2 A multiple-view length measurement can be achieved by repositioning either the CMS or the material standard or both.

6.2.2.4 Derivation of test results of distortion error

$D_{\text{CC:}j\text{:O3D}}$ is obtained from the difference between the measured and calibrated values of sphere centre-to-centre distance, as stated in Annex B.

For each of 36 single-view measurements, a distortion error, $D_{\text{CC:SMV.SV:O3D}}$, is obtained as the maximum error. For each of three multi-view measurements, a distortion error, $D_{\text{CC:SMV.MV:O3D}}$, is obtained as the maximum error.

6.3 Probing characteristics

6.3.1 Principle

The principle of the assessment method for the probing errors is to establish whether the optical 3D CMS is capable of measuring in the sensor measurement volume within the stated maximum permissible probing errors. Four characteristics, $P_{\text{Form.Sph.D95\%:}j\text{:O3D}}$, $P_{\text{Form.Sph.All:}j\text{:O3D}}$, $P_{\text{Size.Sph.D95\%:}j\text{:O3D}}$ and $P_{\text{Size.Sph.All:}j\text{:O3D}}$, are evaluated.

6.3.2 Material standard

The same material standard used for evaluating the distortion error is used as a test sphere calibrated for the form and the size of the sphere 1 of Figure 1.

The size (diameter) of the test sphere shall be in the range of 2 % to 20 % of the longest distance within the sensor measurement volume. In cases where the longest distance is equal to or larger than 2,5 m, a minimum size of 50 mm is permitted.

NOTE The longest distance within the sensor measurement volume is the longer spatial diagonal if the shape of the sensor measurement volume is a cuboid.

6.3.3 Procedure

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

The same measurement data obtained for evaluating the distortion error described in 6.2.2.3 shall be used for evaluating the probing errors.

Only the data obtained through the 36 single-view measurements for the sphere shell of sphere 1 of Figure 1 which are collected in the sensor measurement volume shall be used to evaluate $P_{X:SMV.SV:O3D}$.

The data obtained through a multiple-view measurement collected in the sensor measurement volume for the sphere 1 of Figure 1 shall be used to evaluate $P_{X:SMV.MV:O3D}$. The data of repetitive measurements shall not be fused to obtain a multiple view probing error.

It is recommended that the measurement is performed so as to cover the largest surface area on the sphere within the rated operating conditions of the CMS.

6.3.4 Derivation of test results

6.3.4.1 General

For an optical 3D CMS, the difference in the number of data points actually evaluated can significantly influence the test result. This document requires the disclosure of minimum density or the minimum number of points necessary to perform the test.

Some of the measured points can be discarded before evaluating the results, either automatically if a specific software function is available to the user or manually if this is a normal operating procedure as specified in the rated operating conditions. In addition to the points that can be discarded according to the rated operating conditions, points belonging to surfaces other than the material standard can also be discarded. No other measurement points shall be discarded. The automatic or manual data elimination shall not be misused to suppress noise or outliers.

NOTE The data elimination can require specific knowledge about, for example, characteristics of the optical 3D CMS, the optical surface properties, the ambient illumination and the filtration algorithms.

6.3.4.2 Probing metrological characteristics

6.3.4.2.1 General

The tests of all probing metrological characteristics shall be carried out by applying a single set of parameter settings stated by the manufacturer, within the rated operating conditions. The probing metrological characteristics derived from both the 95 % and the 100 % percentiles of the data population are mandatory.

NOTE The difference between test results derived from the 95 % and 100 % percentiles can reveal influences of pre-installed smoothing filters or equivalent functions, which would possibly not be otherwise visible to users of the CMS.

6.3.4.2.2 Probing form dispersion error

Determine the width of the spherical shell that encompasses a designated percentile (either 95 % or 100 %) of all measured points obtained in the sensor measurement volume.

The error corresponding to the 95 % percentile is the probing form dispersion error for a single-view measurement $P_{Form.Sph.D95\%:SMV.SV:O3D}$ or for a multiple-view measurement $P_{Form.Sph.D95\%:SMV.MV:O3D}$.

The error corresponding to the 100 % percentile is the probing form dispersion error for a single-view measurement $P_{\text{Form.Sph.All:SMV.SV:O3D}}$ or for a multiple-view measurement $P_{\text{Form.Sph.All:SMV.MV:O3D}}$.

NOTE The method for calculating the optimal spherical shell is intentionally not given. One approach is to start with a least-squares (Gaussian[2)]) associated sphere to the points and then eliminate some extreme points and compute a new least-squares associated sphere (perhaps using several iterations of this procedure to get to 95 %). The shell would be determined concentric to the final least-squares association. However, this will possibly not be the most optimal shell, and it is not the intention of this document to restrict the methods that can be used.

6.3.4.2.3 Probing size error

The same data used to determine the probing form dispersion error in 6.3.4.2.2 separately for the 95 % and the 100 % percentiles shall be associated to an unconstrained and unweighted Gaussian sphere.

The errors corresponding to the 95 % percentile for a multiple-view measurement $P_{\text{Size.Sph.D95\%:SMV.MV:O3D}}$ and optionally for a single-view measurement $P_{\text{Size.Sph.D95\%:SMV.SV:O3D}}$ are derived as the difference between the measured diameter of the test sphere and its calibrated value.

The errors corresponding to the 100 % percentile for a multiple-view measurement $P_{\text{Size.Sph.All:SMV.MV:O3D}}$ and optionally that for a single-view measurement $P_{\text{Size.Sph.All:SMV.SV:O3D}}$ are derived as the difference between the measured diameter of the test sphere and its calibrated value.

NOTE Calculation of the probing size error can result in ill-conditioned association depending on limitation of areal coverage of the surface measurement on the test sphere when a single-view measurement is performed.

6.3.5 Flat-form distortion error

6.3.5.1 Principle

The principle of the test for flat-form distortion error is to establish whether the optical 3D CMS is capable of measuring in the sensor measurement volume within the stated maximum permissible errors. The four characteristics, i.e. $D_{\text{Form.Pla.D95\%:SMV.SV:O3D}}$, $D_{\text{Form.Pla.D95\%:SMV.MV:O3D}}$, $D_{\text{Form.Pla.All:SMV.SV:O3D}}$ and $D_{\text{Form.Pla.All:SMV.MV:O3D}}$, are evaluated.

6.3.5.2 Material standard

Test planes are used to determine the flat-form distortion error.

The form of the test plane shall be calibrated, since the form deviation influences the test results, and shall be considered when verifying conformity or non-conformity with the specification. The dimensions of the test plane shall be as follows:

— longer side length: at least 50 % of the longest distance in the sensor measurement volume;

— shorter side length: at least 10 % of the longest distance in the sensor measurement volume.

NOTE The longest distance in the sensor measurement volume typically coincides or is close to the position of one or more of the spatial diagonals.

If a test plane which covers the longer side length is not available, multiple single-view measurements, each having a different position of the test flat, shall be performed to cover the sensor measurement volume, subject to mutual agreement. If the multiple-view measurement is tested, all the single-view measurement results shall be processed for the registration and the fusion, and then evaluated. If the single-view measurement is tested, all the single-view measurements shall be evaluated independently.

If a test plane with the shorter side length is not available, a plane with the side no smaller than 50 mm shall be used.

2) For readability of this document, Gaussian refers to a least-squares fit.

It is strongly recommended that the flat-form distortion error test is performed using a large enough test plane.

Careful attention shall be paid for deflection of the test plane potentially caused by gravity influence or by design limitation for supporting it, especially if a test plane with large dimensions is demanded. If the deflection is not negligibly small, deviation from the calibrated geometry shall be taken into account as a test value uncertainty contribution. See Annex G.

The qualification plane supplied with the optical 3D CMS for the qualification shall not be used as the test plane.

6.3.5.3 Procedure

The test plane shall be measured once in each position and in total in six positions.

The recommended set-up is shown in Figure 2. The test plane should be positioned perpendicular either to the *z*-axis of the CMS with the longer side aligned to the *x*-axis (positions 1, 2 and 3), to the *xz* planar diagonal with the longer side parallel to such diagonal (positions 4 and 5) or to the *xyz* spatial diagonal with the longer side parallel to such diagonal (position 6).

The arrangement of the plane adopted shall be reported.

The set-up and the qualification of the CMS shall be performed in accordance with the manufacturer's normal operating procedures.

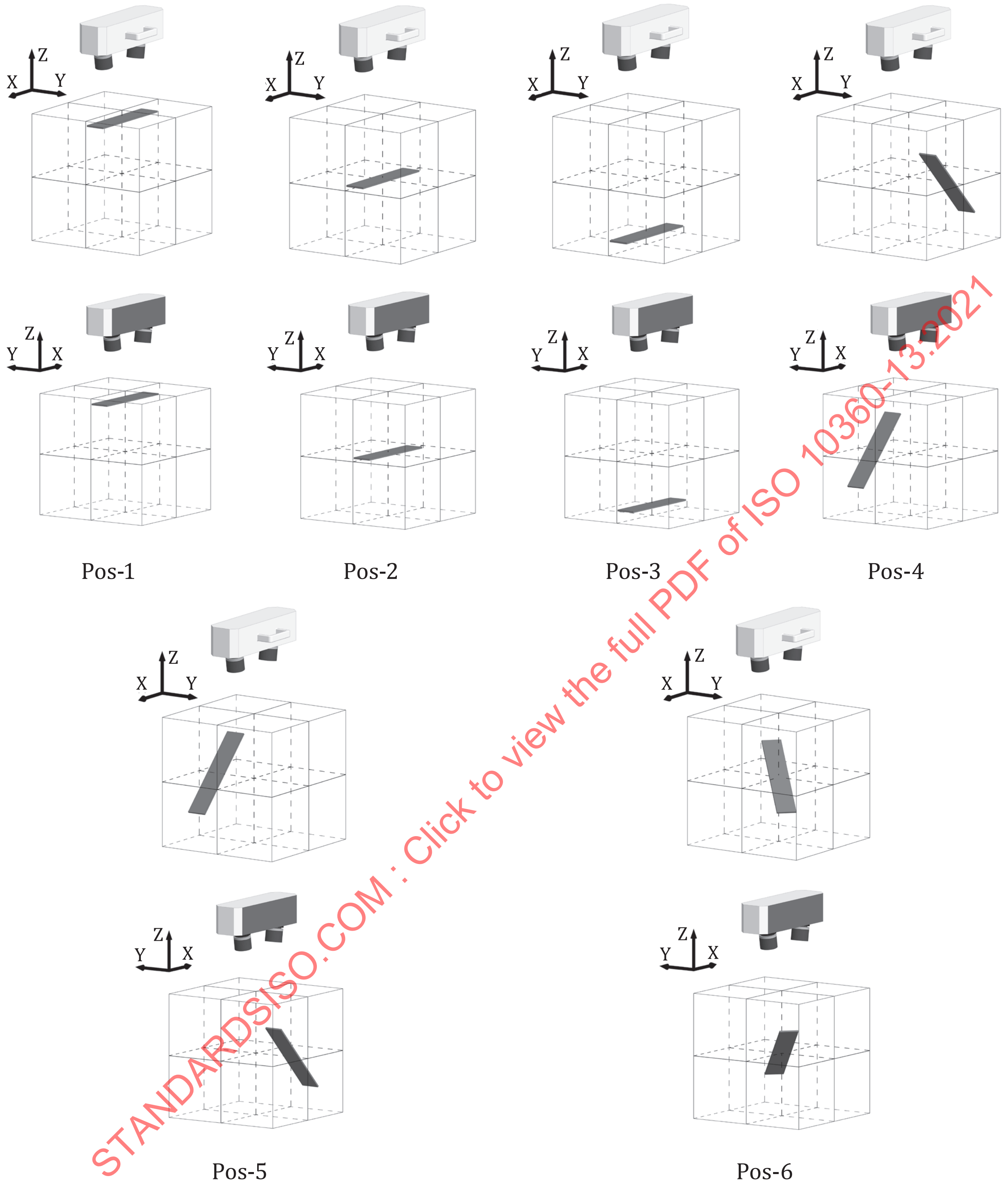
The measured points shall be approximately evenly distributed over the test plane.

The test results can be significantly affected by the position and orientation of the optical sensor. It is recommended that the optical sensor is set at multiple orientations during the test to reveal this effect, i.e. to reposition the optical sensor prior to measuring the test plane in each of the positions.

Some of the measured points (e.g. those lying on another surface) can be discarded before evaluating the results, either automatically if a specific software function is available to the user or manually if this is a normal operating procedure as specified in the rated operating conditions. No other measurement points shall be discarded. The automatic or manual data elimination shall not be misused to suppress noise or outliers. Global filters may not be used when the MPE is tested.

NOTE The data elimination can require specific knowledge about, for example, characteristics of the optical 3D CMS, the optical surface properties, the ambient illumination and the filtration algorithms.

The manufacturer may, at their discretion, specify additional MPEs for special operative conditions, such as a designated filtration.



Key

X	X-axis
Y	Y-axis
Z	Z-axis
Pos-*i* (*i* = 1, 2, ..., 6)	position-*i*

NOTE The figure shows the relative position of the test plane in the sensor measurement volume. This does not imply that the CMS has the same orientation for each position.

Figure 2 — Recommended positions of test planes within sensor measurement volume, each shown in two different views

6.3.5.4 Derivation of test results

Determine the shortest distance between two parallel planes that encompass a designated percentile (either 95 % or 100 %) of the measured points obtained in the sensor measurement volume.

The errors corresponding to the 95 % percentiles obtained at the six positions are the flat-form distortion errors for single-view measurement $D_{\text{Form.Pla.D95\%:SMV.SV:O3D}}$. The error corresponding to the 95 % percentile calculated from all the measured points obtained through the registration and the fusion of the six positions is the flat-form distortion error for the multiple-view measurement $D_{\text{Form.Pla.D95\%:SMV.MV:O3D}}$.

The errors corresponding to the 100 % percentiles (denoted by "All") obtained at the six positions are the flat-form distortion errors for single-view measurement $D_{\text{Form.Pla.All:SMV.SV:O3D}}$. The error corresponding to the 100 % percentile calculated from all the measured points obtained through the registration and the fusion of the six positions is the flat-form distortion error for the multiple-view measurement $D_{\text{Form.Pla.All:SMV.MV:O3D}}$.

6.4 Volumetric length measurement error in concatenated measurement volume

6.4.1 Principle

The principle of this test is to establish whether the optical 3D CMS is capable of measuring lengths in the concatenated measurement volume within stated maximum permissible measurement error $E_{\text{Vol:CMV.MV:O3D,MPE}}$, by comparing the calibrated and the indicated values of calibrated test lengths. As a default, the size of the concatenated measurement volume is determined as the longest linear distance fully encapsulated in the concatenated measurement volume longer than twice the longest linear distance fully encapsulated in the sensor measurement volume, unless otherwise explicitly stated by the manufacturer.

The CMV will either have a predetermined global coordinate system to which all SMVs are registered or will use a common coordinate system constructed as part of registering SMVs sequentially. The presence and use of a global coordinate system for the CMV measurements shall be stated by the manufacturer.

NOTE The longest linear distance fully encapsulated in the concatenated measurement volume or in the sensor measurement volume typically coincides with or is close to the position of each of the spatial diagonals.

6.4.2 Material standard

The material standard of length described in Annex B shall be used. The material standard consists of at least six spheres, calibrated for its centre-to-centre distances and for the sphere forms.

The longest calibrated test length for each position shall be at least 66 % of the maximum length viable along a measurement line through the material standard in the concatenated measurement volume. See Annex D. Each calibrated test length shall differ significantly from the others in length. Their lengths shall be well distributed over the measurement line.

The material standard supplied with the optical 3D CMS for qualification shall not be used as the material standard for the test.

6.4.3 Low CTE case

The default requirement for the material of the calibrated test length shall be normal CTE, i.e. between $8 \times 10^{-6}\ \text{K}^{-1}$ and $13 \times 10^{-6}\ \text{K}^{-1}$.

The manufacturer shall state the upper, and optionally lower, limits of the CTE of the calibrated test length. The manufacturer may calibrate the CTE of a calibrated test length and in this case the manufacturer shall specify the maximum permitted ($k = 2$) uncertainty of the CTE.

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

EXAMPLE $E_{Vol:CMV.MV:O3D,MPE}$ *.

* Artefact is super invar with a CTE not greater than $0{,}5 \times 10^{-6}$ K^{-1} and with a CTE expanded uncertainty (k = 2) not greater than $0{,}3 \times 10^{-6}$ K^{-1}.

If the manufacturer's specification for $E_{Vol:CMV.MV:O3D,MPE}$ requires a CTE no greater than 2×10^{-6} K^{-1}, an additional measurement shall be performed on an auxiliary calibrated test length made of normal CTE material. The normal CTE material test length shall be larger than the lesser of 0,5 m and 50 % of the longest distance of the concatenated measuring volume. This additional measurement shall be performed in the centre of the concatenated measuring volume and repeated three times. The manufacturer may calibrate the CTE of this calibrated 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 ISO 10360-2:2009, Annex D. However, such a calibrated test length is still considered to have a low CTE and is subject to the requirements of this clause.

6.4.4 Procedure

Set up and qualify the optical 3D CMS in full accordance with the normal operating procedure as stated by the manufacturer. This includes qualification of the optical 3D CMS using qualification artefact(s), regarded as integral parts of the CMS, typically supplied by the manufacturer.

Supplementary measurements can be required for alignment purposes of material standards. It is recommended that the alignment method used is consistent with the procedures used for the calibration of the material standard.

Some of the measured points (e.g. those lying on another surface) can be discarded before evaluating the results, either automatically if a specific software function exists or manually if this is normal operating procedure as specified in the rated operating conditions. All other measurement points shall be used. The automatic or manual data elimination shall not be misused to suppress noise or outliers.

NOTE 1 The data elimination can require specific knowledge, e.g. characteristics of the optical 3D CMS, the optical properties of the surface of the material standards, ambient illumination and the filter algorithm.

The manufacturers may, at their discretion, specify additional MPEs for special operative conditions, e.g. a designated filtration.

Five different calibrated test lengths shall be placed in each of seven different positions (locations and orientations) in the concatenated measurement volume of the CMS, 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 1 and Figure 3. The user is free to choose the remaining three positions; the default positions are parallel to each of the coordinate axis, as shown in Table 1.

For each of the measurements performed using calibrated test lengths, obtain three measurement results. See Annex B for details regarding the combination procedure for specific types of test lengths. Repeat for all seven measurement positions from the calibrated test lengths.

Set-up(s) differing from that of Table 1 and Figure 3 can be adopted by mutual agreement, e.g. to adapt to a concatenated measurement volume having a significantly different shape from, for example, a cuboid. In this case the set-up shall be recorded in the data sheet.

The volumetric length measurement in the concatenated measurement volume shall be performed by a combination of single-view measurements as configured by the manufacturer and stated in the operation manual or equivalent accessible by the users.

A volumetric length measurement in the concatenated measurement volume shall be operated with relative repositioning of either the CMS or the calibrated test length or both. A registration in the concatenated measurement volume can be performed either prior to or simultaneously with the test, possibly different from that used in 6.2.2.3.3. Usage of either or both of the following reference features is allowed provided that the information needed for the users to reproduce the test is disclosed in the operation manual or equivalently accessible documentation:

1) markers with a specific form or stickers with specific colours and patterns recommended by the manufacturer to be adhered on or in the vicinity of the material standard;

2) feature(s) belonging to or located in the vicinity of the material standard as recommended by the manufacturer.

If supplementary qualification artefact(s) are used, for example for compensating magnification errors, their details shall be described in the operation manual or equivalently accessible documentation and recorded in the data sheet.

NOTE 2 The choice and combination of reference features, algorithm and operational parameters can significantly affect the test result.

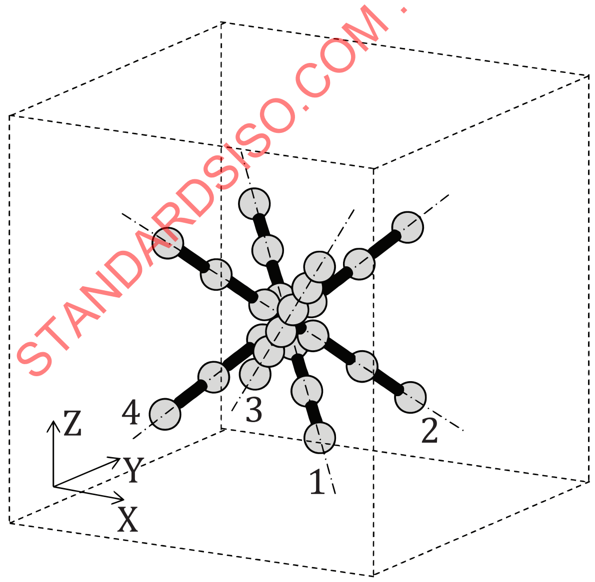
To perform a multiple view registration, the user shall carefully follow the requirements and procedures of the CMS as indicated in the operating manual, which is deemed to be a part of the rated operating conditions.

The manufacturer shall disclose the operational details of and give best practice guidance on the concatenation registration to the user.

If an optical 3D CMS with no global coordinate system is tested, it can be worthwhile to adopt the detoured concatenation pathway prescribed in Annex C to assess the influence of the concatenation path.

Whether the optical 3D CMS has the global coordinate system or not is sometimes difficult for users to identify. Users of the CMS are advised to clarify it by consulting the manufacturer or the representative.

NOTE 3 Error propagation behaviour varies significantly when a measurement in a concatenated measurement volume is performed, depending on whether the CMS has the global coordinate system or not.



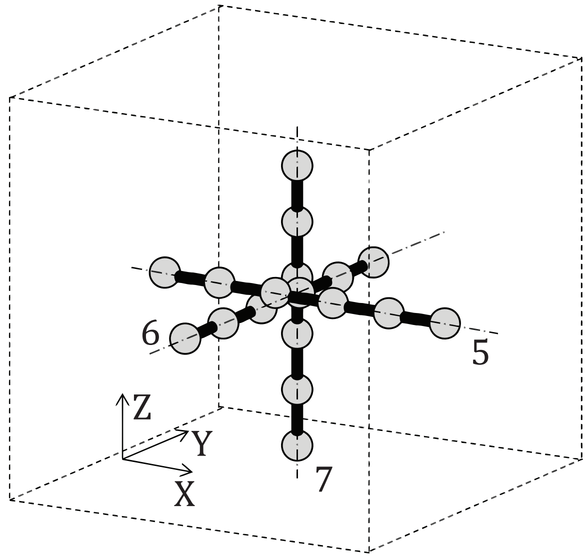


Figure 3 — Example of positions of material standards in the assessment: required four diagonal positions and default three positions along the axes of the coordinate system

Table 1 — 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 axes of concatenated measurement volume from point (0, 1/2, 1/2) to (1, 1/2, 1/2)	Default
6	Parallel to the axes of concatenated measurement volume from point (1/2, 0, 1/2) to (1/2, 1, 1/2)	Default
7	Parallel to the axes of concatenated measurement volume 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).		

6.4.5 Derivation of test results

For all 105 measurements, a volumetric length error in the concatenated measurement volume $E_{\text{Vol:CMV.MV:O3D}}$ is obtained.

$E_{\text{Vol:CMV.MV:O3D}}$ is calculated as the difference of the measured to the calibrated values of a centre-to-centre distance, as stated in B.2.

The indicated value of a particular measurement of a calibrated test length may be corrected by the CMS to account for systematic errors or thermally induced errors (including thermal expansion) if the CMS has accessory devices, including third-party software, for this purpose. Manual correction to account for thermal effects or other corrections is not allowed when the environmental conditions satisfy the rated operating condition specified by the manufacturer.

Plot all the errors (values of $E_{\text{Vol.MV:CMV:O3D}}$) on a diagram that matches one of the forms of $E_{\text{Vol:CMV.MV:O3D,MPE}}$, as indicated in ISO 10360-1:2000, Figures 12, 13 and 14.

7 Conformity with the specification

7.1 Acceptance test

7.1.1 Acceptance criteria

7.1.1.1 General

The performance of the CMS is considered to have been verified in the following cases by taking the corresponding test value uncertainty into the account (see Annex G):

— If each probing form dispersion error with 100 % population, denoted by “All”, $P_{\text{Form.Sph.All:j:O3D}}$, is not greater than the maximum permissible error, $P_{\text{Form.Sph.All:j:O3D,MPE}}$, as specified by the manufacturer and taking into account the uncertainty of measurement according to ISO 14253-1, where “j” denotes “SMV.SV” and “SMV.MV”.

— If each probing form dispersion error with 95 % population, $P_{\text{Form.Sph.D95\%:j:O3D}}$, is not greater than the maximum permissible error, $P_{\text{Form.Sph.D95\%:j:O3D,MPE}}$, as specified by the manufacturer and taking into account the uncertainty of measurement according to ISO 14253-1, where “j” denotes “SMV.SV” and “SMV.MV”.

— If applicable, the absolute value of each probing size error with 100 % population, denoted by “All”, $P_{\text{Size.Sph.All:SMV.SV:O3D}}$, is not greater than the maximum permissible error, $P_{\text{Size.Sph.All:SMV.SV:O3D,MPE}}$, as specified by the manufacturer and taking into account the uncertainty of measurement according to ISO 14253-1.

— If the absolute value of each probing size error with 100 % population, denoted by "All", $P_{Size.Sph.All:SMV.MV:O3D}$, is not greater than the maximum permissible error, $P_{Size.Sph.All:SMV.MV:O3D,MPE}$, as specified by the manufacturer and taking into account the uncertainty of measurement according to ISO 14253-1.

— If applicable, the absolute value of each probing size error with 95 % population, $P_{Size.Sph.D95\%: SMV.SV:O3D}$, is not greater than the maximum permissible error, $P_{Size.Sph.D95\%: SMV.SV:O3D,MPE}$, as specified by the manufacturer and taking into account the uncertainty of measurement according to ISO 14253-1.

— If the absolute value of each probing size error with 95 % population, $P_{Size.Sph.D95\%:SMV.MV:O3D}$, is not greater than the maximum permissible error, $P_{Size.Sph.D95\%: SMV.MV:O3D,MPE}$, as specified by the manufacturer and taking into account the uncertainty of measurement according to ISO 14253-1.

— If the absolute value of each distortion error, $D_{CC:j:O3D}$, is not greater than the maximum permissible error, $D_{CC:j:O3D,MPE}$, as specified by the manufacturer and taking into account the uncertainty of measurement according to ISO 14253-1, where "j" denotes "SMV.SV" and "SMV.MV".

— If each flat-form distortion error with 100 % population, denoted by "All", $D_{Form.Pla.All:j:O3D}$, is not greater than the maximum permissible error, $D_{Form.Pla.All:j:O3D,MPE}$, as specified by the manufacturer and taking into account the uncertainty of measurement according to ISO 14253-1, where "j" denotes "SMV.SV" and "SMV.MV".

— If each flat-form distortion error with 95 % population, $D_{Form.Pla.D95\%:j:O3D}$, is not greater than the maximum permissible error, $D_{Form.Pla.D95\%:j:O3D,MPE}$, as specified by the manufacturer and taking into account the uncertainty of measurement according to ISO 14253-1, where "j" denotes "SMV.SV" and "SMV.MV".

— If each volumetric length measurement error in concatenated measurement volume, $E_{Vol:CMV.MV:O3D}$, is not greater than the maximum permissible error, $E_{Vol:CMV.MV:O3D,MPE}$, as specified by the manufacturer and taking into account the uncertainty of measurement according to ISO 14253-1.

— If applicable, the absolute value of each bi-directional length measurement error in concatenated measurement volume, $E_{Bi:CMV.MV:O3D}$, is not greater than the maximum permissible error, $E_{Bi:CMV.MV:O3D,MPE}$, as specified by the manufacturer and taking into account the uncertainty of measurement according to ISO 14253-1.

Table 2 summarizes the requirements for whether the test is mandatory or optional.

Table 2 — Symbols and corresponding requirement

Symbol	Meaning	Single or multiple view	Mandatory or optional
$P_{Form.Sph.All:SMV.SV:O3D}$	Probing form dispersion error 100 %	Single view	Mandatory
$P_{Form.Sph.All:SMV.MV:O3D}$	Probing form dispersion error 100 %	Multiple view	Mandatory
$P_{Form.Sph.95\ \%:SMV.SV:O3D}$	Probing form dispersion error 95 %	Single view	Mandatory
$P_{Form.Sph.95\ \%:SMV.MV:O3D}$	Probing form dispersion error 95 %	Multiple view	Mandatory
$P_{Size.Sph.All:SMV.SV:O3D}$	Probing size error 100 %	Single view	Optional
$P_{Size.Sph.All:SMV.MV:O3D}$	Probing size error 100 %	Multiple view	Mandatory
$P_{Size.Sph.95\ \%:SMV.SV:O3D}$	Probing size error 95 %	Single view	Optional
$P_{Size.Sph.95\ \%:SMV.MV:O3D}$	Probing size error 95 %	Multiple view	Mandatory
$D_{CC:SMV.SV:O3D}$	Distortion error in sensor measurement volume	Single view	Mandatory
$D_{CC:SMV.MV:O3D}$	Distortion error in sensor measurement volume	Multiple view	Mandatory

Table 2 *(continued)*

Symbol	Meaning	Single or multiple view	Mandatory or optional
$D_{\text{Form.Pla.All:SMV.SV:O3D}}$	Flat-form distortion error in sensor measurement volume 100 %	Single view	Mandatory
$D_{\text{Form.Pla.All:SMV.MV:O3D}}$	Flat-form distortion error in sensor measurement volume 100 %	Multiple view	Mandatory
$D_{\text{Form.Pla.95 \%:SMV.SV:O3D}}$	Flat-form distortion error in sensor measurement volume 95 %	Single view	Mandatory
$D_{\text{Form.Pla.95 \%:SMV.MV:O3D}}$	Flat-form distortion error in sensor measurement volume 95 %	Multiple view	Mandatory
$E_{\text{Vol:CMV.MV:O3D}}$	Volumetric length measurement error in concatenated measurement volume	Multiple view	Mandatory
$E_{\text{Bi:CMV.MV:O3D}}$	Bi-directional length measurement error in concatenated measurement volume, prescribed in Annex A	Multiple view	Optional

7.1.1.2 Probing errors

If the probing error performance is not verified by the test, the equipment shall be checked for any faults that are possibly 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.

7.1.1.3 Distortion error

If the performance of distortion error is not verified by the test, the equipment shall be checked for any faults that are possibly 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.

7.1.1.4 Flat-form distortion error

If the performance of flat-form distortion error is not verified by the test, the equipment shall be checked for any faults that are possibly 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.

7.1.1.5 Volumetric length measurement error in concatenated measurement volume

A maximum of five of 35 sets of three repeated measurements in accordance with 6.4 may have one (and no more than one) of the three values of the length measurement error outside the conformity zone. Each such measurement that is outside the conformity 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 conformity zone (see ISO 14253-1), the performance of the optical 3D CMS is verified at that position.

7.2 Reverification test

The performance of the optical 3D CMS is considered to have been verified if the mandatory characteristics in Table 2 and, if applicable, the optional characteristics as described in Clause 6 and Annex A are not greater than the corresponding maximum permissible errors as determined in 7.1, taking into account the uncertainty of measurement according to ISO 14253-1.

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 document may be used to verify the performance of the probing and the length measurement of an optical 3D CMS, 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 document can be used in an organization's internal quality assurance system for verification of the performance of the probing and the length measurement of an optical 3D CMS, 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 CMS conforms to the requirements for maximum permissible errors. The extent of the interim checks for an optical 3D CMS specified in this document may be reduced in respect of the number of actual measurement data being assessed. It is recommended that the CMS is checked regularly, and after any incident that has possibly significantly affected the probing performance.

9 Indication in product documentation and data sheets

The symbols used in this document are not suitable for use in product documentation, drawings or data sheets. Table 3 gives the corresponding indications.

Table 3 — Symbols and corresponding indications in product documentation, drawings and data sheets

Symbol used in this document	Corresponding indication
$P_{\text{Form.Sph.}i:j:\text{O3D}}$	P[Form.Sph.i:j:O3D]
$P_{\text{Size.Sph.}i:j:\text{O3D}}$	P[Size.Sph.i:j:O3D]
$D_{\text{CC:}j:\text{O3D}}$	D[CC:j:O3D]
$D_{\text{Form.Pla.}i:j:\text{O3D}}$	D[Form.Pla.i:j:O3D]
$E_{\text{Vol:CMV.MV:O3D}}$	E[Vol:CMV.MV:O3D]
$E_{\text{Bi:CMV.MV:O3D}}$	E[Bi:CMV.MV:O3D]
$P_{\text{Form.Sph.}i:j:\text{O3D,MPE}}$	MPE(P[Form.Sph.i:j:O3D])
$P_{\text{Size.Sph.}i:j:\text{O3D,MPE}}$	MPE(P[Size.Sph.i:j:O3D])
$D_{\text{CC:}j:\text{O3D,MPE}}$	MPE(D[CC:j:O3D])
$D_{\text{Form.Pla.}i:j:\text{O3D,MPE}}$	MPE(D[Form.Pla.i:j:O3D])
$E_{\text{Vol:CMV.MV:O3D,MPE}}$	MPE(E[Vol:CMV.MV:O3D])
$E_{\text{Bi:CMV.MV:O3D,MPE}}$	MPE(E[Bi:CMV.MV:O3D])

Annex A
(informative)

Evaluation of bi-directional length measurement characteristics

A.1 General

This annex describes the derivation procedure of bi-directional length measurement error compounded from three errors, namely length measurement error in concatenated measurement volume, probing form dispersion error and probing size error for allowing the optional verification of the optical 3D CMS performance for bi-directional length measurement performance.

The bi-directional length measurement error described in this annex is intended for comparative evaluation of the performance with that of the other parts of the ISO 10360 series. It is recommended that the bi-directional length measurement error described in this annex is not applied to contractual judgement such as conformity or non-conformity determination to the specification due to potentially significant duplication of errors, unless there is explicit mutual agreement between the parties.

A.2 Derivation of bi-directional length measurement test results

A.2.1 General

The indicated value of a particular measurement of a calibrated test length may be corrected by the CMS to account for systematic errors or thermally induced errors (including thermal expansion) if the CMS 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 $E_{\text{Bi:CMV.MV:O3D}}$) on a diagram, as indicated in ISO 10360-1:2000, Figures 12, 13 and 14, which matches the expressed form of $E_{\text{Bi:CMV.MV:O3D,MPE}}$.

A.2.2 Bi-directional length measurement error compounded from test results based on point cloud

$E_{\text{Bi:CMV.MV:O3D}}$ is calculated from the measured values of volumetric length measurement error in concatenated measurement volume $E_{\text{Vol:CMV.MV:O3D}}$, supplemented with both probing form dispersion error $P_{\text{Form.Sph.D95\%:SMV.MV:O3D}}$ and probing size error $P_{\text{Size.Sph.D95\%:SMV.MV:O3D}}$, both based on point cloud, as follows:

If:

$$E_{\text{Vol:CMV.MV:O3D}} + P_{\text{Size.Sph.D95\%:SMV.MV:O3D}} > 0$$

$E_{\text{Bi:CMV.MV:O3D}}$ has an upper limit which can be used for verifying conformity:

$$E_{\text{Bi:CMV.MV:O3D}} < E_{\text{Vol:CMV.MV:O3D}} + P_{\text{Size.Sph.D95\%:SMV.MV:O3D}} + P_{\text{Form.Sph.D95\%:SMV.MV:O3D}}$$

If:

$$E_{\text{Vol:CMV.MV:O3D}} + P_{\text{Size.Sph.D95\%:SMV.MV:O3D}} = 0$$

$E_{\text{Bi:CMV.MV:O3D}}$ has upper and lower limits which can be used for verifying conformity:

$$E_{\text{Bi:CMV.MV:O3D}} < P_{\text{Form.Sph.D95\%:SMV.MV:O3D}} \text{ and } E_{\text{Bi:CMV.MV:O3D}} > -P_{\text{Form.Sph.D95\%:SMV.MV:O3D}}$$

If:

$E_{Vol:CMV.MV:O3D} + P_{Size.\ Sph.D95\%:SMV.MV:O3D} < 0$

$E_{Bi:CMV.MV:O3D}$ has a lower limit which can be used for verifying conformity:

$E_{Bi:CMV.MV:O3D} > E_{Vol:CMV.MV:O3D} + P_{Size.Sph.D95\%:SMV.MV:O3D} - P_{Form.Sph.D95\%:SMV.MV:O3D}$

$P_{Form.Sph.D95\%:SMV.MV:O3D}$ and $P_{Size.Sph.D95\%:SMV.MV:O3D}$ are sampled and calculated once for 105 lengths to be tested.

A.3 Indication in product documentation and data sheets

The symbols given in Clause 4 are not suitable for use in product documentation, drawings or data sheets. Table 3 gives the corresponding indications.

Annex B
(normative)

Artefacts that represent a calibrated test length and corresponding measurement procedures

B.1 General

For economy, availability and practicality, this document allows several types of artefacts to be used in testing a CMS 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 document, is designed to detect three categories of CMS errors:

1) geometrical and thermal errors associated with the length measurement performed on the CMS;

2) if a bi-directional test involving surface determination is performed, size errors caused by an inherent systematic error of the CMS and a function for changing position of the optical 3D CMS if applicable;

3) repeatability problems as evaluated.

All the points measured on gauging surfaces according to the rated operating condition of the CMS shall be used for testing the length measuring performance.

In some cases, these artefacts are not available or sufficiently long, particularly when testing very large CMSs. In these cases, both parties may agree to use other means to generate a calibrated test length. These can 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. In all such cases, the procedure shall be documented and the uncertainties associated with these techniques shall be considered carefully.

A laser interferometer that is corrected for the index of refraction of air has a zero CTE ($\alpha = 0$). Hence, if it is used to produce a calibrated test length, it is considered a low CTE material and is subject to the requirements of 6.4.3. Additionally, if the laser has a workpiece (material) temperature sensor, then the workpiece CTE in the laser's software shall be set to 0. If a laser is used on a temperature-compensated CMS, then the workpiece CTE in the CMS's software shall be set to 0.

When a laser interferometer is used to produce a calibrated test length, the CMS shall be positioned at a point described by nominal coordinates, without probing a surface. In this case, some CMSs cannot arrive at the nominal position exactly. This does not necessarily result in an error of indication as long as the CMS reports the actual position. Consequently, for each test length, the spatial distance between the reported CMS 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 CMS 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" and "A" to "C", 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 remeasured each time a calibrated test length is produced. That is, the "A" to "B" length and the "A" to "C" length shall each have its own "A" measured anew. Similarly, with interferometry, the initial position shall be remeasured for each displacement used to produce a calibrated test length.

In typical cases for testing CMSs, the orientation of the system have to be rotated and adjusted appropriately for CMSs to be able to access target measuring areas, for example on a gauge block or sphere.

B.2 Artefact and procedure for realizing calibrated test length

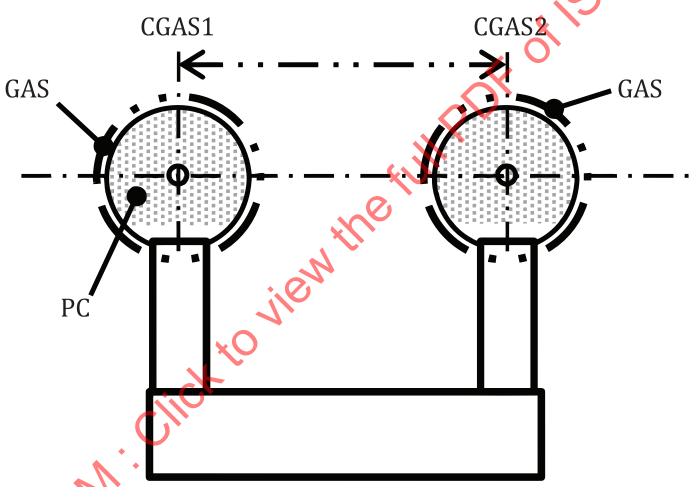
B.2.1 General

A centre-to-centre measurement of a material standard performed by a point cloud and the determination of the corresponding length is described.

B.2.2 Ball plates or ball bars measured in a centre-to-centre manner by point cloud

A centre-to-centre 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 as shown in Figure B.1.

Measure each of the calibrated lengths three times and record the errors of indication, and if applicable, in chronological order.



Key

PC	point cloud
GAS	Gaussian associated sphere
CGAS	centre of the Gaussian associated sphere

Figure B.1 — Centre-to-centre length measurement

B.2.3 Laser interferometry measured in a centre-to-centre manner

A centre-to-centre measurement can be produced using a calibrated laser interferometer and a gauging surface; the gauging surface can be a plane or a sphere.

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

For each of the lengths (per measurement line), measure a calibrated length three times and record the errors of indication.

If the gauging surface is a sphere, the Gaussian associated sphere centre location shall be measured. In the case of a plane, an intersection point between the gauging line and the Gaussian associated plane of respective gauging planes shall be measured.

B.2.4 Step gauges measured in a face-to-face manner

A face-to-face measurement can be produced using a calibrated step gauge by obtaining an intersection point between the gauging line of the step gauge and the Gaussian associated plane of respective gauging planes.

The measurement shall be done in a unidirectional manner.

For each of the lengths (per measurement line), measure a calibrated length three times and record the error of indication.

B.2.5 CMM positioning the gauging surface(s)

A centre-to-centre measurement can be produced using a calibrated CMM, typically a calibrated Cartesian type CMM, and a gauging surface attached on the end effector of the CMM; the gauging surface can be a plane or a sphere.

The measurement involves a displacement of the gauging surface realized by a couple of spatial coordinates successively travelled and positioned by the CMM.

For each of the lengths (per measurement line), measure a calibrated length three times and record the errors of indication.

If the gauging surface is a sphere, the Gaussian associated sphere centre location shall be measured. In the case of a plane, an intersection point between the gauging line and the Gaussian associated plane of respective gauging planes shall be measured.

The traceability of the CMM used to compose the calibrated test length shall carefully be demonstrated, e.g. in accordance with ISO/TS 15530-4.

NOTE There is no widely accepted consensus existing concerning usage of a CMM having been calibrated according to ISO 10360-2 as the calibrated test length prescribed in this document.

Annex C
(informative)

Procedure of concatenated length measurement to assess the influence of the concatenation path on error propagation

C.1 General

The procedure described in this annex applies only to CMSs not utilizing a global coordinate system.

Consider a test artefact for a concatenated length measurement with a triangular form bearing six equidistant spheres on each side and apexes labelled A, B and C. Suppose the length measurement between apexes A and B is of interest. Two paths from A to B are possible: direct (AB) and indirect (ACB). A CMS utilizing a global coordinate system results in the same error of indication along either path. Conversely, a CMS not utilizing a global coordinate system can result in significantly different errors of indication depending on the path. The procedure described in this annex is intended to capture this dependence.

NOTE 1 The global coordinate system can be realized by various technologies, such as:

— a metrological moving carriage;

— an optical tracking system;

— photogrammetry.

NOTE 2 If a tester or a tester counterpart does not have information on whether a CMS to be tested utilizes a global coordinate system, the procedure described in this annex can be used to determine it experimentally.

A typical calibrated test length used for verifying length measuring performance of an optical 3D CMS can be that consisting of six or more equidistant spherical features in line. The typical concatenation pathway can be realized by repeating a single view measurement one after another with each of single view to have nominally the same translational shifting in the longitudinal direction of the calibrated test length.

This annex can in some cases be worthwhile for a tester of the optical 3D CMS without the global coordinate system to perform a concatenated length measurement in the concatenated measurement volume through intentionally detoured concatenation pathway.

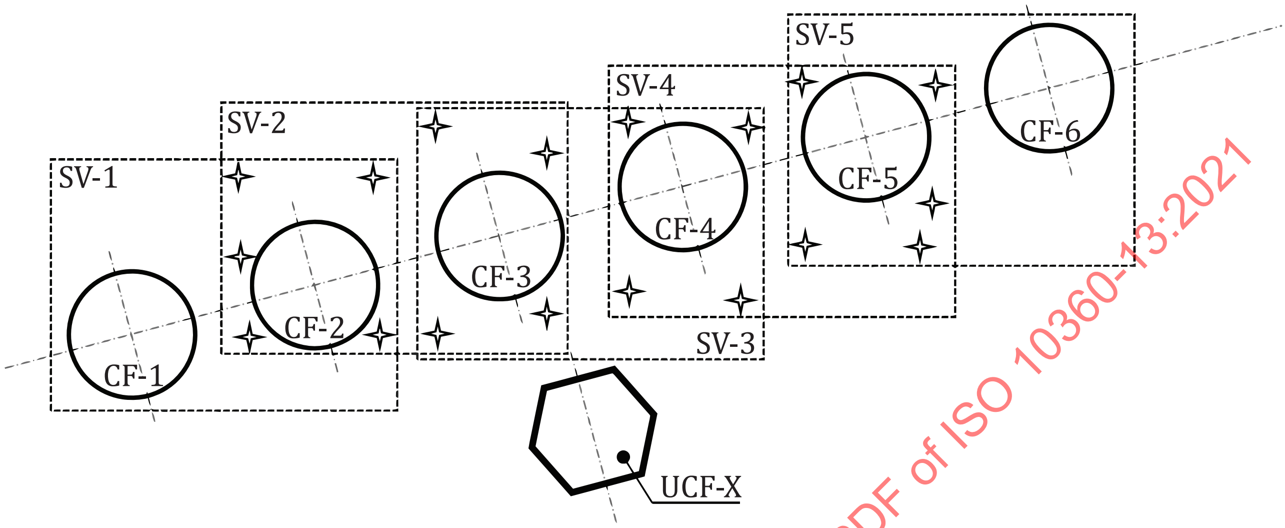
C.2 Concatenated length measurement through detoured concatenation pathway

For the purpose of the performance evaluation of an optical 3D CMS without information of the global coordinate system when the concatenated measurement is performed, it is recommended that a partially detoured concatenation pathway is applied. The partially detoured concatenation pathway can be realized by performing the measurement on the already existing calibrated test length, for example that consisting of six or more spherical features allocated equidistant in line and uncalibrated feature(s) used for creating the partially detoured concatenation pathway with intention allocated besides the calibrated test length.

An indispensable requirement to make the partially detoured pathway become effective in the purpose of the performance evaluation is locally to destroy the conventional straightforward concatenation pathway at least at a single position.

C.3 Example of detoured concatenation pathway

Figure C.1 shows an example of a conventional scenario to perform a concatenated length measurement on an artefact consisting of six spherical features allocated equidistant in line. The concatenation can be performed by allocating certain fractional area of each of a single view to be overlapped with the neighbouring single view.



Key

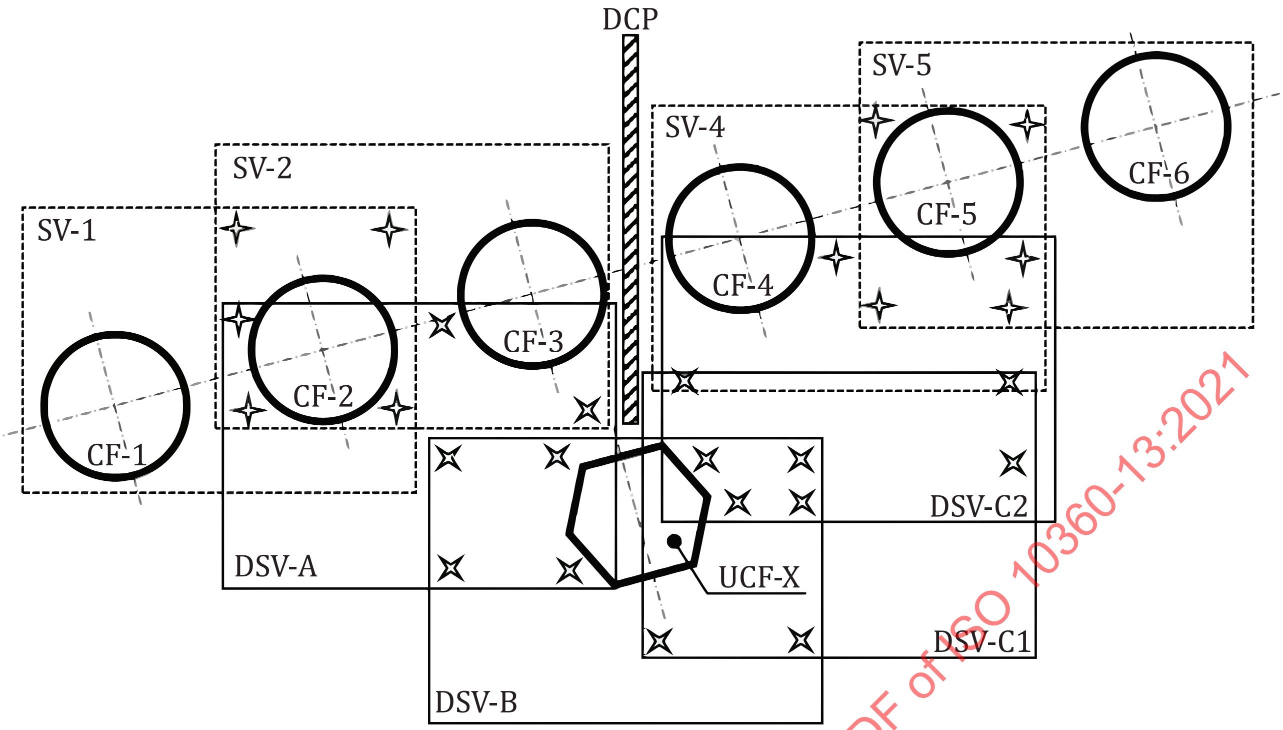
CF-1	calibrated feature 1
CF-2	calibrated feature 2
CF-3	calibrated feature 3
CF-4	calibrated feature 4
CF-5	calibrated feature 5
CF-6	calibrated feature 6
SV-1	single view 1
SV-2	single view 2
SV-3	single view 3
SV-4	single view 4
SV-5	single view 5
UCF-X	uncalibrated feature X
✧	reference feature used for registration

Figure C.1 — Example of conventional concatenation pathway to perform concatenated length measurement on an artefact consisting of six spherical features allocated equidistant in line

An example of a detoured concatenation pathway is shown in Figure C.2. A discontinued concatenation position is created at position between calibrated features 3 and 4.

No single view that concatenates single views capturing calibrated features 3 and 4 is allowed to allocate in the purpose of the test. An example of a detoured concatenation pathway built by detoured single views -A, -B, -C1 and -C2 is positioned in this example. On the way of the detoured concatenation pathway, it is recommended to allocate an uncalibrated feature X to perform a similar feature measurement on the detoured concatenated pathway to that of the conventional concatenation pathway. The measurement result obtained on the uncalibrated feature is not used for demonstrating conformity of the optical 3D CMS to be tested.

NOTE Reference features used for registration between single views can be applied besides the calibrated features and the uncalibrated feature. The choice and combination of reference features as well as the calculation algorithm and the operational parameters can significantly affect the test result.



Key

CF-1 calibrated feature 1
CF-2 calibrated feature 2
CF-3 calibrated feature 3
CF-4 calibrated feature 4
CF-5 calibrated feature 5
CF-6 calibrated feature 6
DCP discontinued concatenated position
DSV-A detoured single view A
DSV-B detoured single view B
DSV-C1 detoured single view C1
DSV-C2 detoured single view C2
SV-1 single view 1
SV-2 single view 2

SV-4 single view 4
SV-5 single view 5
UCF-X uncalibrated feature X
✦ reference feature used for registration
⌘ reference feature used for detoured registration

Figure C.2 — Example of detoured concatenation pathway to perform concatenated length measurement on an artefact consisting of six spherical features allocated equidistant in line and uncalibrated feature on the detoured concatenation pathway

Annex D
(informative)

Alignment of artefacts

D.1 General

To compare the length measured by a CMS with 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 shall 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.

D.2 Parallel face artefacts

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

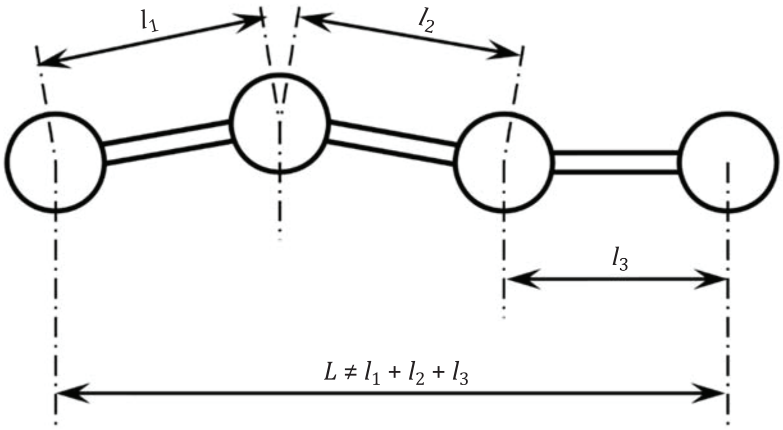
Probe many points on one face of the gauge and establish a (least-squares fit) reference plane. The direction perpendicular to the plane is the reference (gauge axis) direction. Perform measurement on gauging surfaces on the artefact.

Construct the feature-to-feature length, then project this length onto the reference (gauge axis) direction. The projected length is then compared with 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 can 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.

D.3 Ball bar

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 comprising 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 D.1).



Key

l_1, l_2, l_3	calibrated test length between adjacent balls
L	example of distance between non-adjacent spheres not conforming to the calibrated test length

Figure D.1 — Evaluation of ball distances for a multi-ball ball bar

Annex E
(informative)

Surface characteristic of material standard

E.1 General

Since measurement principle of an optical 3D CMS is based on receival of optical light from the object to be scanned, detected optical signal quality can be significantly varied depending on the surface characteristics, e.g. colour, glossiness and roughness. It can impact the measuring performance of the CMS. This annex describes possible limitation of an optical 3D CMS if it is applied to measure an object having less cooperative surface characteristics. A series of suggestions capable of giving the user an idea of how representative the MPE can be when the CMS is used to measure their specific industrial part is described.

E.2 Surface characteristics of material standards potentially impacting measuring performance of optical 3D CMS

E.2.1 Colour

Combination of surface colour of the material standard and wavelength of light emitted from the CMS utilized for the coordinate measurement can vary measuring performance of the CMS.

Surface colour has been standardized, differently, by many national and international standards and guidelines.

NOTE Although surface colour of the material standard and wavelength of light emitted from the CMS for the coordinate measurement are one of the major influence parameters relative to the issue of colour, many other influences can be pointed out, e.g. the measuring principle of the CMS and optical filtration adopted by either the manufacturer or the user of the CMS.

E.2.2 Glossiness

A typical optical 3D CMS captures light intensity reflected from the surface to be measured. Light intensity captured by the CMS is variated depending not only on surface glossiness of the material standard but also on a combination of the local incident angle and the local reflected angle determined by relative orientation between the CMS and the surface of the material standard.

Reflection of light used for the measurement occurring on the surface of the material standard can also cause polarity variation or phase shift. These influences can impact the measuring performance of the CMS in some cases.

E.2.3 Roughness

Typical roughness parameters are not designed to indicate a direct relation with optical scattering characteristics of a solid surface. However, the larger the roughness is, the stronger the optical scattering becomes in general.

Roughness parameters can be useful as an alternative index of the glossiness in some cases.

E.2.4 Other optical characteristics attributed to surface sublayer

The surface of a solid can have a sublayer which potentially influences optical response to incoming light from the outside solid when the light is outgoing back to the space. Types of sublayer include:

— transparent or partially transparent sublayer(s) resulting in subsurface reflection, absorption or scattering;

— fluorescence converting a short wavelength of light into a longer one, resulting in an increase of optical spectral reflectivity in the specific wavelength range of sometimes more than 100 %;

— fragmented reflective boundary of material(s) existing in the sublayer of the solid, resulting in metallic surface finish or a pearl colour finish.

E.2.5 Evaluation of surface characteristics

Practical evaluation of these surface characteristics of a solid surface can be realized by introducing commercially available instruments.

The other method of evaluating these surface characteristics is by a visual comparison between the surface to be tested and that of a standard specimen. Standard specimens with the calibration value for the surface characteristics are also commercially available.

It is recommended that a consensus is built among parties in advance about the condition of evaluation of the surface characteristics if they exchange information concerning this in relation to performance evaluation of CMSs.

E.3 Potential impact behind surface characteristics restricted in the main text of this document

Tests described in this document can be performed by using material standards with well cooperative surface characteristics to the CMS.

This means that the test results of the CMS can represent the measuring performance encompassing the range of the majority of the rated operating conditions of the CMS, except the surface characteristics of the material standard supposed to represent that of user-specific industrial part.

Extended tests can additionally be performed if the user of the CMS is interested in knowing measuring performance of the CMS under the operating conditions covering a wider range of surface characteristics to be measured, including those uncooperative to the CMS.

E.4 Possible performance evaluation of optical 3D CMS with influence of surface characteristics of material standards

E.4.1 Usage of optical spectral transmittancy of colour filter to emulate different surface colour

E.4.1.1 Preparation of optical colour filter and optical aberration compensator

An optical colour filter with a similar optical spectral transmittancy to the intended surface colour represented by optical spectral reflectance is prepared. Each optical filter should have the nominally equivalent optical path length and a known refractive index around the intended optical wavelength.

An optical aberration compensator with both sufficiently high optical transmittancy and sufficiently wide transmittancy wavelength range, and also the nominally equivalent optical path length and a known refractive index around the intended optical length, is prepared for the purpose of the system qualification.

E.4.1.2 Qualification of optical 3D CMS with installation of optical aberration compensator

Qualification of the monochromatic optical 3D CMS is performed in accordance with the manufacturer's operating manual and the material standard(s) for the system qualification under the condition within which the optical aberration compensator is installed somewhere between the projector aperture(s) and the detector aperture(s).

Performance evaluation using the material standard(s) as described in 6.2 is performed, with installation of the optical aberration compensator. The obtained test results provide the reference values.

E.4.1.3 Performance evaluation of optical 3D CMS with installation of optical colour filter

The performance evaluation using the material standard(s) as described in 6.2 is performed two times successively, once with installation of either the optical colour filter or the optical aberration compensator, then with substitutional installation of the other.

The difference between those test results obtained with the optical colour filter installed and those obtained with the optical aberration compensator can indicate measuring performance variation of the optical 3D CMS, depending on the surface colour of the object to be scanned.

E.4.1.4 Adjustment of optical brightness of optical image captured by optical 3D CMS

Installation of the optical aberration compensator or the optical colour filter varies brightness of the optical image captured by the optical 3D CMS. The same variation occurs when the material standard is changed from that described in 5.2.2 to that described in E.4.3 or E.4.4, having different surface colour than the conventional material standards.

It will possibly be necessary to perform adjustment in the optical brightness of the optical 3D CMS depending on which optical colour filter is installed, provided that the optical 3D CMS has the adjustment possibility available to the user. The adjustment in optical brightness of the optical image captured by the optical 3D CMS should be performed in accordance with the manufacturer's operation manual.

NOTE The adjustment possibility of brightness of the optical 3D CMS can be realized by, for example, changing exposure time of the optical detector, changing illumination brightness of the light source or capturing plural optical images with the intention of superimposing them into a single optical image.

E.4.2 Usage of equivalent optical attenuation means to emulate different surface colour in cases of monochromatic optical 3D CMS

E.4.2.1 Application to monochromatic optical 3D CMS

If the CMS adopts monochromatic light source(s), optical filtering mean(s) or both to limit sensitive optical colour into the intended range(s) (a monochromatic optical 3D CMS), the optical 3D CMS is hardly sensitive to light intensity outside the optical wavelength range incoming to the optical 3D CMS.

Information about the sensitive colour range which the manufacturer should disclose is necessary for users of the CMS, if the test described in E.4.2.2 and E.4.2.3 is performed.

A polychromatic optical CMS typically adopting, for example, a halogen lamp or a Xenon lamp and not equipped with any optical filtering mean(s) to limit sensitive optical colour into the intended range(s) cannot be evaluated by the procedure described in E.4.2.2 and E.4.2.3.

E.4.2.2 Calculation of equivalent optical attenuation

Optical intensity reflected from an object to be scanned in cases of the monochromatic optical 3D CMS is primarily determined by optical spectral reflectance of the object only within the sensitive colour range of the CMS. The difference in the surface colour for a monochromatic optical 3D CMS looks as if the surface reflectance is darkened.

The difference in optical attenuation when the surface colour is substituted from the cooperative one to the monochromatic optical 3D CMS can be estimated by knowing the difference in the optical spectral reflectance within the sensitive colour range of the CMS.

E.4.2.3 Performance evaluation of monochromatic optical 3D CMS by decreasing optical intensity

A performance evaluation of the monochromatic optical 3D CMS is done by decreasing the optical intensity setting of the CMS as indicated by calculation result of equivalent optical attenuation described in E.4.2.2. Brightness of the optical image when the light intensity is intentionally decreased is significantly darker for the CMS than that recommended by the manufacturer. The dark setting is purposely chosen to emulate measurement on a less cooperative surface colour.

The concrete adjustment procedure to decrease optical intensity should follow the manufacturer's operation manual typically disclosed to users to perform measurement on an object with the dark coloured surface.

NOTE The adjustment possibility of brightness of the optical 3D CMS can be realized by, for example, changing aperture time of the optical detector, changing illumination brightness of the light source, capturing plural optical images with intention to superimpose them into a single optical image.

The difference in the test results before and after decrease of the light intensity can indicate measuring performance variation of the monochromatic optical 3D CMS depending on the surface colour of the object to be scanned.

E.4.3 Usage of material standards having identical nominal geometries but different intended surface characteristics

It is possible to build plural of material standards of length, form and size with identical nominal geometries, but each having different surface characteristics in the intended manner.

A geometrical feature on the material standards, such as a sphere or a plane, can be finished as its local surface characteristics are different from the other portion.

E.4.4 Usage of planar coupons each having different surface characteristics

Another possibility is to build a material standard independent of the existing one for length, form and size. Material standards for evaluating dependency in the surface characteristics can be realized by putting a number of planar coupons with each having a different value in the surface characteristics together on a nominally flat plane. Lows and highs of each coupon surface scanned by the optical 3D CMS can indicate dependency of the CMS with respect to the surface characteristics.

NOTE A planar coupon can be a test piece typically composed of a base substrate made of, for example, metal or ceramic and intended surface characteristics of, for example, colour, glossiness and roughness.

Annex F
(informative)

Structural resolution test

F.1 General

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 or 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 is specified and tested.

F.2 Test method

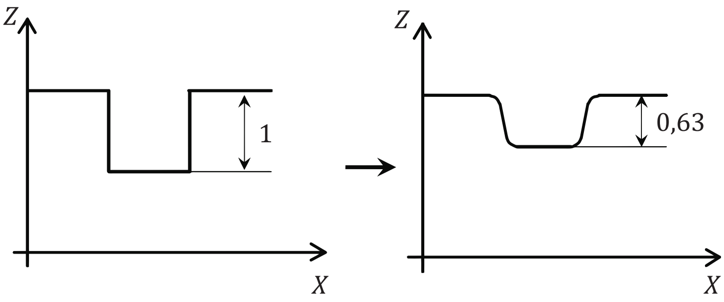
F.2.1 General

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 subclauses are proposed for verifying spatial resolution.

F.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 F.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 with the calibrated depth. The ratio of measured depth over calibrated depth shall be at least 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. (Figure F.1 shows a case where the structural resolution test just passed, the ratio being 0,63.)

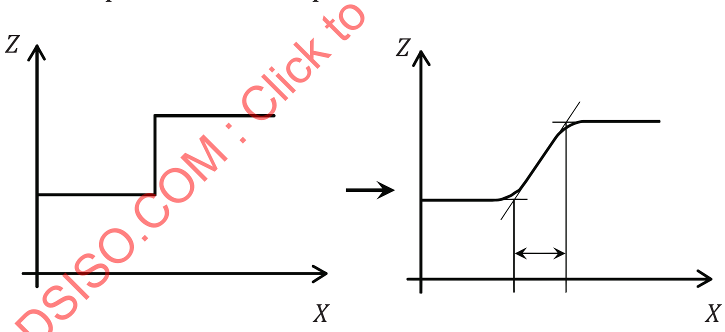


a) Actual profile b) Measured profile

Figure F.1 — Verification of structural resolution using a structure standard with a gap or pit

F.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 F.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 with the specified value.



a) Actual profile b) Measured profile

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

F.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 F.3. This wavelength is characterized by a ratio of measured amplitude over calibrated amplitude greater than 0,7. This wavelength is compared with the specified resolution.

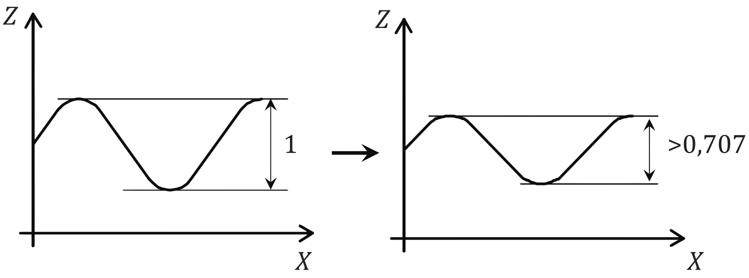


Figure F.3 — Determination of structural resolution by measuring a wave standard

F.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 F.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:

The step response y in the spatial domain is shown in Formula (F.1):

$$y = 1 - e^{-\frac{x}{x_1}} \tag{F.1}$$

The spatial cut-off frequency, υ_g, in lines per millimetre, is the frequency at which the absolute value of the transfer factor $G(j\omega)$ has fallen to $1/\sqrt{2}$ (−3 dB limit), as shown in Formulae (F.2) to (F.4):

$$G(j\omega) = \frac{1}{1 + j\omega X_1}, \tag{F.2}$$

$$|G(j\omega)| = \frac{1}{\sqrt{1 + \omega^2 X_1^2}} = \frac{1}{\sqrt{2}} \Rightarrow \omega_g \cdot X_1 = 1, \tag{F.3}$$

$$X_1 = \frac{1}{2\pi \cdot \upsilon_g} = \frac{\lambda_g}{2\pi} \tag{F.4}$$

where

ω	is the angular frequency;
ω_g	is the cut-off angular frequency;
λg	is the cut-off wavelength.