भारतीय मानक

Indian Standard

IS 15635 (Part 5) : 2024
ISO 10360-5 : 2020

ज्यामितीय उत्पाद विशिष्टि (जी.पी.एस.) — संयोजी मापन प्रणाली (सी.एम.एस.) की स्वीकार्यता और पुनर्जांच परीक्षण

भाग 5 असतत बिंदु और/या स्कैनिंग मापन रीति का उपयोग करने वाले एकल और एकाधिक स्टाइलस संस्पर्शी जांच प्रणाली का उपयोग करने वाले संयोजी मापन मशीन (सी.एम.एम.)

(दूसरा पुनरीक्षण)

Geometrical Product Specifications (GPS) — Acceptance and Reverification Tests for Coordinate Measuring Systems (CMS)

Part 5 Coordinate Measuring Machines (CMMs) Using Single and Multiple Stylus Contacting Probing Systems Using Discrete Point and/or Scanning Measuring Mode

(Second Revision)

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NATIONAL FOREWORD

This Indian Standard (Part 5) (Second Revision) which is identical to ISO 10360-5 : 2020 'Geometrical product specifications (GPS) — Acceptance and reverification tests for coordinate measuring systems (CMS) — Part 5: Coordinate measuring machines (CMMs) using single and multiple stylus contacting probing systems using discrete point and/or scanning measuring mode' issued by the International Organization for Standardization (ISO) was adopted by the Bureau of Indian Standards on the recommendation of the Engineering Metrology Sectional Committee and approval of the Production and General Engineering Division Council.

This standard was first published in 2006 and subsequently revised in 2019. The first revision of this standard was identical with ISO 10360-5 : 2010. The second revision of this standard has been undertaken to align it with ISO 10360-5 : 2020.

This standard incorporates technical revision of the tests contained within IS 15635 (Part 4) : 2006/ ISO 10360-4 : 2000 'Geometrical product specifications (GPS) — Acceptance and reverification tests for coordinate measuring machines (CMM): Part 4 CMMs used in scanning measuring mode and thereby supersede IS 15635 (Part 4) : 2006/ISO 10360-4 : 2020).

The major changes in this revision are as follows:

a) New symbology has been adopted;
b) An optional ring gauge test has been added;
c) Changes have been made in acceptable test parameters, for example test sphere diameter; and
d) Changes have been made to location results evaluation including an 'opposing styli' evaluation.

This standard has been issued in ten parts. Other parts in this series are:

Part 1 Vocabulary

Part 2 CMMs used for measuring linear dimensions

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

Part 6 Estimation of errors in computing Gaussian associated features

Part 7 CMMs equipped with imaging probing systems

Part 8 CMMs equipped with optical distance sensors

Part 9 CMMs with multiple probing systems

Part 10 Laser trackers

Part 12 Articulated arm coordinate measurement machines (CMM)

The text of ISO standard has been approved as suitable for publication as an Indian Standard without deviations. Certain conventions are, however, not identical to those used in Indian Standards. Attention is particularly drawn to the following:

a) Wherever the words 'International Standard' appear referring to this standard, they should be read as 'Indian Standard'; and
b) Comma (,) has been used as a decimal marker while in Indian Standards, the current practice is to use a point (.) as the decimal marker.

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Contents

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 chains of standards on size, distance, form, orientation, location and run-out.

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.

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

The acceptance and reverification tests described in this document are applicable to coordinate measuring machines (CMMs) that use contacting probes, with or without multiple styli or multiple articulated-probe positions, when measuring using discrete point and/or scanning mode.

Experience has shown that the multi-stylus errors calculated using this document are significant and, at times, represent the dominant errors in the CMM. Owing to the virtually infinite variety of modern CMM probing system configurations, the description of the tests specified by this document provides a testing protocol for specification, but the actual test coverage has been limited to provide a practical subset of tests which are intended to reveal typical errors associated with probing configurations in a limited amount of time. The tests are intended to provide information on the ability of a CMM to measure a feature or features using a contacting probe and, when relevant, using multiple styli, multiple probes or multiple articulated-probe positions.

The situations to which they are applicable include:

— single-stylus probing systems;

— multiple styli connected to the CMM probe (e.g. a star);

— installations using an articulating probing system (motorized or manual) that can be prequalified;

— installations using a repeatable probe-changing system;

— installations using a repeatable stylus-changing system;

— installations including a scanning probe, capable of being used in a scanning mode;

— multi-probe installations.

It is believed that the procedures given in this document will be helpful in identifying CMM system uncertainty components for specific measurement tasks, and that the user will be able to reduce errors by removing contributing elements such as long probe extensions and styli, and then by retesting the new configuration set.

The tests in this document are sensitive to many errors, attributable to both the CMM and the probing system, and are intended to be performed in addition to the length-measuring tests given in ISO 10360-2.

The primary objective is to determine the practical performance of the complete CMM and probing system. Therefore, the tests are designed to reveal measuring errors which are likely to occur when such a combined system is used on real workpieces, for example errors generated by the interaction between large probe-tip-offset lengths and uncorrected CMM rotation errors. The errors found here differ from those found in the EL tests in ISO 10360-2, because with multiple styli the net CMM travel may be very different from the measured length. See Annex C for more information.

This document complements ISO 10360-7 (CMMs equipped with imaging probing systems), ISO 10360-8 (CMMs with optical distance sensors), ISO 10360-9 (CMMs with multiple probing systems) and ISO 10360-2 (CMMs used for measuring linear dimensions).

Indian Standard

GEOMETRICAL PRODUCT SPECIFICATIONS (GPS) — ACCEPTANCE AND REVERIFICATION TESTS FOR COORDINATE MEASURING SYSTEMS (CMS)

PART 5 COORDINATE MEASURING MACHINES (CMMS) USING SINGLE AND MULTIPLE STYLUS CONTACTING PROBING SYSTEMS USING DISCRETE POINT AND/OR SCANNING MEASURING MODE

(Second Revision)

1 Scope

This document specifies acceptance and periodic reverification tests of CMM performance with contacting probing systems and is only applicable to CMMs using:

— any type of contacting probing system; and

— spherical or hemispherical stylus tip(s).

NOTE CMM probing performance tests are specified by the maximum permissible errors (MPEs), due to the impracticality of isolating the performance of the probing system from that of the CMM, even on a small artefact such as a test sphere.

This document applies to CMMs supplied with any of the following:

a) single-stylus probing systems;

b) multi-stylus probing systems with fixed multiple styli attached to a single probe (e.g. “star” stylus);

c) multiple probing systems such as those with a stylus for each of their probes;

d) systems with articulating probing systems;

e) stylus and probe changing systems;

f) manual (non-driven) and automated CMMs;

g) installations including a scanning probe, capable of being used in a scanning mode.

This document is not applicable to non-contacting probing systems, which require different testing procedures.

The term ‘combined CMM and multi-stylus probing system size error’ has been shortened to ‘multi-stylus size error’ for convenience. This applies in similar cases.

If it is desirable to isolate the probing system performance as far as is practical, the influence of the CMM can be minimized but not eliminated. See Annex C for more information.

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

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

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 99:2007, *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, 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/

NOTE 1 This clause contains fifteen definitions (3.7 to 3.9, 3.11 to 3.15, 3.19 to 3.21, 3.23 and 3.25 to 3.27) which supersede eighteen similar definitions in ISO 10360-1:2000, Clause 9. Some of these revised definitions are required to avoid ambiguities which would otherwise have been introduced with this document. Others effectively supersede identical definitions in ISO 10360-1, because the symbols used have been revised and expanded for clarification. The superseded definitions in ISO 10360-1:2000 are 9.3, 9.4 and 9.11 to 9.26.

NOTE 2 All the symbols used in this document are listed in Clause 4.

NOTE 3 The definitions in this clause are intended to concisely state the meaning of terms. For metrological characteristics that have numerical values, the complete description of the procedure and derivation of test results in Clause 6 are to be followed in determining values.

NOTE 4 For all definitions and evaluations in this document we assume the form and location values to be zero, i.e. perfect form or zero location distance for a single test sphere. See 6.2.1 for limitations on test sphere calibrated form.

3.1
rated operating condition
operating condition that needs to be fulfilled during measurement in order for a measuring instrument or measuring system to perform as designed

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

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

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

[SOURCE: ISO/IEC Guide 99:2007, 4.9, modified — Notes 2 and 3 to entry added.]

3.2
inferred qualification
probing system qualification method where the parameters for each probing system attached to an articulation system are inferred by interpolation, extrapolation or another relevant model, for significantly different angular position(s) from parameters acquired by *empirical qualification* (3.3) at a few angular positions

3.3
empirical qualification
probing system qualification method where the parameters for each probing system attached to an articulation system need to be acquired by measurement of the reference sphere at each angular position used

Note 1 to entry: "Reference sphere" is sometimes in industry referred to as "qualification sphere".

3.4
effective diameter
stylus diameter used with the tip correction vector, for compensating stylus centre points to obtain surface points

Note 1 to entry: For the position of the tip correction vector, see ISO 10360-1:2000, Figure 4.

Note 2 to entry: The effective stylus tip diameter may be a parameter established by a probing system qualification.

3.5
multi-stylus probing system
fixed orientation single probe that carries star styli or which through stylus changing can present styli at the relevant orientations to be equivalent to a star stylus

Note 1 to entry: See Figure 6.

3.6
multi-probe system
system in which multiple probes with different fixed orientations are carried simultaneously

Note 1 to entry: See Figure 7.

3.7
multi-stylus form error
$P_{\text{Form.Sph.5×25:}j\text{:Tact}}$
observed form of a test sphere, the measurements being taken with five different styli, each taking 25 points (5 × 25) on the one test sphere using the discrete-point probing mode

Note 1 to entry: See ISO 10360-1:2000, Figure 15.

Note 2 to entry: The symbol P in $P_{\text{Form.Sph.5×25:}j\text{:Tact}}$ indicates that the error is associated with the system performance when local sampling, and the subscript $_{\text{Form}}$ indicates that it is a form error. The subscript $_{\text{Sph}}$ indicates that the test is performed using a sphere as a test artefact. The subscript $_{\text{Tact}}$ indicates that the probing system conforms to Clause 1 of this document (i.e. tactile), thus enabling any alternative probing system to be clearly identified by the use of a different set of characters at * in $P_{\text{Form.Sph.5×25:}j\text{:*}}$.

Note 3 to entry: There are four multi-stylus form errors based on different probing systems and methods of operation. These are designated as follows:

— j = MS, a fixed *multi-stylus probing system* (3.5);

— j = MP, a fixed *multi-probe system* (3.6);

— j = Emp, an articulating probing system using *empirical qualification* (3.3);

— j = Inf, an articulating probing system using *inferred qualification* (3.2).

3.8
multi-stylus size error
$P_{\text{Size.Sph.5×25:}j\text{:Tact}}$
error of indication of the diameter of a test sphere, the measurements being taken with five different styli, each taking 25 points on the one test sphere by a CMM using the discrete-point probing mode

Note 1 to entry: The subscript $_{\text{Size}}$ in $P_{\text{Size.Sph.5×25:}j\text{:Tact}}$ indicates that it is a diameter size error.

Note 2 to entry: Where j is replaced by MS, MP, Emp or Inf as applicable.

3.9
multi-stylus location error
$L_{\text{Dia.5×25:}j\text{:Tact}}$
error of indication of the location of a test sphere as measured using the discrete-point probing mode from five different orientations

Note 1 to entry: The symbol L in $L_{\text{Dia.5×25:}j\text{:Tact}}$ indicates that it is a location error.

Note 2 to entry: Where j is replaced by MS, MP, Emp or Inf as applicable.

3.10
opposing-styli projected location error on a sphere
$L_{\text{Dia.Proj.Sph.2×25:}j\text{:Tact}}$
error of indication of the location of a test sphere as measured using discrete-point probing from opposing orientations

Note 1 to entry: This gives the user an indication as to the performance of the system when measuring, for example, co-axiality of crank shaft journals using styli from opposing orientations.

Note 2 to entry: Where j is replaced by MS, MP, Emp or Inf as applicable.

3.11
single-stylus form error
$P_{\text{Form.Sph.1×25:SS:Tact}}$
observed form of a test sphere, the measurements being performed by a CMM with a single stylus (SS), using the discrete-point probing mode taking 25 points on a single sphere (1 × 25)

Note 1 to entry: See ISO 10360-1:2000, Figure 15.

Note 2 to entry: The subscript SS in $P_{\text{Form.Sph.1×25:SS:Tact}}$ indicates use of a single stylus.

3.12
single-stylus size error
$P_{\text{Size.Sph.1×25:SS:Tact}}$
error of indication of the diameter of a test sphere, the measurements being performed by a CMM with a single stylus, using the discrete-point probing mode

3.13
scanning mode form error on a sphere
$P_{\text{Form.Sph.Scan:}k\text{:Tact}}$
observed form of a test sphere, the measurements being performed by a CMM with a single stylus, using scanning mode

Note 1 to entry: Where k is replaced by the following designates as applicable: k = PP or NPP depending on system scanning mode, pre-defined path (PP) or not pre-defined path (NPP).

3.14
scanning mode size error on a sphere
$P_{\text{Size.Sph.Scan:}k\text{:Tact}}$
error of indication of the size of a test sphere, the measurements being performed by a CMM with a single stylus, using scanning mode

Note 1 to entry: Where k is replaced by the following designates as applicable: k = PP or NPP depending on system scanning mode, pre-defined path or not pre-defined path.

3.15
scanning mode time
$\tau_{\text{Sph.Scan}:k:\text{Tact}}$
time taken to perform the scanning test

Note 1 to entry: Where *k* is replaced by the following designates as applicable: *k* = PP or NPP depending on system scanning mode, pre-defined path or not pre-defined path.

Note 2 to entry: Time is stated in seconds.

3.16
scanning mode form error on a ring gauge
$P_{\text{Form.Cir.Scan}:k.lo:\text{Tact}}$
observed form of a ring gauge, the measurements being performed by a CMM using scanning mode with a single stylus aligned to the ram axis if l_0 = 0 mm, or a single stylus orthogonal to the ram axis with l_0 = 150 mm as the default

Note 1 to entry: Where *k* is replaced by the following designates as applicable: *k* = PP or NPP depending on system scanning mode, pre-defined path or not pre-defined path.

Note 2 to entry: Where l_0 is replaced with the relevant length of ram axis stylus tip offset in the specification of the manufacturer.

Note 3 to entry: See Annex A for the test definition for this optional test.

Note 4 to entry: Ram axis stylus tip offset l_0 in this document is normally equivalent to ram axis stylus tip offset L used in ISO 10360-2. An example where it is different is a horizontal arm machine where the articulated head is mounted vertically.

3.17
scanning mode size error on a ring gauge
$P_{\text{Size.Cir.Scan}:k.lo:\text{Tact}}$
error of indication of the size of a ring gauge, the measurements being performed by a CMM using scanning mode with a single stylus aligned to the ram axis if l_0 = 0 mm; or a single stylus orthogonal to the ram axis with l_0 = 150 mm as the default unless otherwise specified

Note 1 to entry: Where *k* is replaced by the following designates as applicable: *k* = PP or NPP depending on system scanning mode, pre-defined path or not pre-defined path.

Note 2 to entry: Where l_0 is replaced with the relevant length of ram axis stylus tip offset in the specification of the manufacturer.

Note 3 to entry: See Annex A for the test definition for this optional test.

3.18
opposing-styli projected location error on a ring gauge
$L_{\text{Dia.Proj.Cir.Scan}:j:\text{Tact}}$
error of indication of the location of a ring gauge as measured using scanning mode probing from opposing orientations

Note 1 to entry: This gives the user an indication as to the performance of the system when measuring, for example, co-axiality of crank shaft journals using styli from opposing orientations.

Note 2 to entry: Where *j* is replaced by MS, MP, Emp or Inf as applicable.

3.19
maximum permissible multi-stylus form error
$P_{\text{Form.Sph.5×25}:j:\text{Tact,MPE}}$
extreme value of the *multi-stylus form error* (3.7), $P_{\text{Form.Sph.5×25}:j:\text{Tact}}$, permitted by specifications

Note 1 to entry: See Annex D for how this MPE may be expressed.

Note 2 to entry: Where *j* is replaced by MS, MP, Emp or Inf as applicable.

3.20
maximum permissible multi-stylus size error
$P_{\text{Size.Sph.5×25:}j\text{:Tact,MPE}}$
extreme value of the *multi-stylus size error* (3.8), $P_{\text{Size.Sph.5×25:}j\text{:Tact}}$, permitted by specifications

Note 1 to entry: See Annex D for how this MPE may be expressed.

Note 2 to entry: Where *j* is replaced by MS, MP, Emp or Inf as applicable.

3.21
maximum permissible multi-stylus location error
$L_{\text{Dia.5×25:}j\text{:Tact,MPE}}$
extreme value of the *multi-stylus location error* (3.9), $L_{\text{Dia.5×25:}j\text{:Tact}}$, permitted by specifications

Note 1 to entry: See Annex D for how this MPE may be expressed.

Note 2 to entry: Where *j* is replaced by MS, MP, Emp or Inf as applicable.

3.22
maximum permissible opposing-styli projected location error on a sphere
$L_{\text{Dia.Proj.Sph.2×25:}j\text{:Tact,MPE}}$
extreme value of the *opposing-styli projected location error on a sphere* (3.10), $L_{\text{Dia.Proj.Sph.2×25:}j\text{:Tact}}$, permitted by specifications

Note 1 to entry: See Annex D for how this MPE may be expressed.

Note 2 to entry: Where *j* is replaced by MS, MP, Emp or Inf as applicable.

3.23
maximum permissible single-stylus form error
$P_{\text{Form.Sph.1×25:SS:Tact,MPE}}$
extreme value of the *single-stylus form error* (3.11), $P_{\text{Form.Sph.1×25:SS:Tact}}$, permitted by specifications

Note 1 to entry: See ISO 10360-1:2000, Figure 15.

Note 2 to entry: $P_{\text{Form.Sph.1×25:SS:Tact}}$ is specified against an unambiguous description of the probe and stylus make up.

3.24
maximum permissible single-stylus size error
$P_{\text{Size.Sph.1×25:SS:Tact,MPE}}$
extreme value of the *single-stylus size error* (3.12), $P_{\text{Size.Sph.1×25:SS:Tact}}$, permitted by specifications

Note 1 to entry: $P_{\text{Size.Sph.1×25:SS:Tact,MPE}}$ is specified against an unambiguous description of the probe and stylus make up.

3.25
maximum permissible scanning mode form error on a sphere
$P_{\text{Form.Sph.Scan:}k\text{:Tact,MPE}}$
extreme value of the *scanning mode form error on a sphere* (3.13), $P_{\text{Form.Sph.Scan:}k\text{:Tact}}$, permitted by specifications

Note 1 to entry: Where *k* is replaced by the following designates as applicable: *k* = PP or NPP depending on system scanning mode, pre-defined path or not pre-defined path.

3.26
maximum permissible scanning mode size error on a sphere
$P_{\text{Size.Sph.Scan:}k\text{:Tact,MPE}}$
extreme value of the *scanning mode size error on a sphere* (3.14), $P_{\text{Size.Sph.Scan:}k\text{:Tact}}$, permitted by specifications

Note 1 to entry: Where *k* is replaced by the following designates as applicable: *k* = PP or NPP depending on system scanning mode, pre-defined path or not pre-defined path.

3.27
maximum permissible scanning mode time
$\tau_{Sph.Scan:k:Tact,MPL}$
extreme value of the *scanning mode time* (3.15), $\tau_{Sph.Scan:k:Tact}$

Note 1 to entry: Where k is replaced by the following designates as applicable: k = PP or NPP depending on system scanning mode, pre-defined path or not pre-defined path.

Note 2 to entry: Maximum permissible scanning mode time is stated in seconds.

3.28
maximum permissible scanning mode form error on a ring gauge
$P_{Form.Cir.Scan:k.lo:Tact,MPE}$
extreme value of the *scanning mode form error on a ring gauge* (3.16) with a ram axis stylus tip offset of l_o, $P_{Form.Cir.Scan:k.lo:Tact}$, permitted by specifications

Note 1 to entry: Where k is replaced by the following designates as applicable: k = PP or NPP depending on system scanning mode, pre-defined path or not pre-defined path.

Note 2 to entry: Where l_o is replaced with the relevant length of ram axis stylus tip offset in the specification of the manufacturer.

Note 3 to entry: See Annex A for the test definition for this optional test.

3.29
maximum permissible scanning mode size error on a ring gauge
$P_{Size.Cir.Scan:k.lo:Tact,MPE}$
extreme value of the *scanning mode size error on a ring gauge* (3.17) with a ram axis stylus tip offset of l_o , $P_{Size.Cir.Scan:k.lo:Tact}$, permitted by specifications

Note 1 to entry: Where k is replaced by the following designates as applicable: k = PP or NPP depending on system scanning mode, pre-defined path or not pre-defined path.

Note 2 to entry: Where l_o is replaced with the relevant length of ram axis stylus tip offset in the specification of the manufacturer.

Note 3 to entry: See Annex A for the test definition for this optional test.

3.30
maximum permissible opposing-styli projected location error on a ring gauge
$L_{Dia.Proj.Cir.Scan:j:Tact,MPE}$
extreme value of the *opposing-styli projected location error on a ring gauge* (3.18), $L_{Dia.Proj.Cir.Scan:j:Tact}$, permitted by specifications

Note 1 to entry: See Annex D for how this MPE may be expressed.

Note 2 to entry: Where j is replaced by MS, MP, Emp or Inf as applicable.

Note 3 to entry: See Annex A for the test definition for this optional test.

4 Symbols

For the purposes of this document, the following symbols apply. Alternative, unformatted presentations that may be used in product documentation, drawings or data sheets are provided in the third column.

Description	Symbol used in this document	Alternative, unformatted presentations
Positive constant, expressed in micrometres and supplied by the manufacturer, used to express a maximum permissible limit or error (in accordance with Annex D)	A	Not applicable
Dimensionless positive constant supplied by the manufacturer, used to express a maximum permissible limit or error (in accordance with Annex D)	K	Not applicable
Distance in 3D between the centres of the reference sphere and the test sphere, in millimetres (also see Annex C and Annex D)	L_{P}	L[P]
Maximum permissible error in micrometres as stated by the manufacturer (in accordance with Annex D)	B	Not applicable
Least-squares radial distance	R	Not applicable
Maximum least-squares radial distance	R_{max}	Not applicable
Minimum least-squares radial distance	R_{min}	Not applicable
Ram axis stylus tip offset	l_{o}	l[o]
Sphere or ring gauge diameter as measured	D_{meas}	Not applicable
Sphere or ring gauge diameter as calibrated	D_{cal}	Not applicable
Single-stylus test related symbols		
Single-stylus form error	$P_{\mathrm{Form.Sph.1\times25:SS:Tact}}$	P[Form.Sph.1×25:SS:Tact]
Single-stylus size error	$P_{\mathrm{Size.Sph.1\times25:SS:Tact}}$	P[Size.Sph.1×25:SS:Tact]
Maximum permissible single stylus form error	$P_{\mathrm{Form.Sph.1\times25:SS:Tact,MPE}}$	MPE(P[Form.Sph.1×25:SS:Tact])
Maximum permissible single stylus size error	$P_{\mathrm{Size.Sph.1\times25:SS:Tact,MPE}}$	MPE(P[Size.Sph.1×25:SS:Tact])
Scanning mode test related symbols		
Scanning mode test using pre-defined path	k = PP	Not applicable
Scanning mode test using not pre-defined path	k = NPP	Not applicable
Scanning mode form error on a sphere, $P_{\mathrm{Form.Sph.Scan:}k\mathrm{:Tact}}$	$P_{\mathrm{Form.Sph.Scan:PP:Tact}}$	P[Form.Sph.Scan:PP:Tact]
	$P_{\mathrm{Form.Sph.Scan:NPP:Tact}}$	P[Form.Sph.Scan:NPP:Tact]
Scanning mode size error on a sphere, $P_{\mathrm{Size.Sph.Scan:}k\mathrm{:Tact}}$	$P_{\mathrm{Size.Sph.Scan:PP:Tact}}$	P[Size.Sph.Scan:PP:Tact]
	$P_{\mathrm{Size.Sph.Scan:NPP:Tact}}$	P[Size.Sph.Scan:NPP:Tact]
Scanning mode time taken, $\tau_{\mathrm{Sph.Scan:}k\mathrm{:Tact}}$	$\tau_{\mathrm{Sph.Scan:PP:Tact}}$	τ[Sph.Scan:PP:Tact]
	$\tau_{\mathrm{Sph.Scan:NPP:Tact}}$	τ[Sph.Scan:NPP:Tact]

Description	Symbol used in this document	Alternative, unformatted presentations
Maximum permissible scanning mode form error on a sphere, $P_{\text{Form.Sph.Scan:}k\text{:Tact,MPE}}$	$P_{\text{Form.Sph.Scan:PP:Tact,MPE}}$	MPE(P[Form.Sph.Scan:PP:Tact])
	$P_{\text{Form.Sph.Scan:NPP:Tact,MPE}}$	MPE(P[Form.Sph.Scan:NPP:Tact])
Maximum permissible scanning mode size error on a sphere, $P_{\text{Size.Sph.Scan:}k\text{:Tact,MPE}}$	$P_{\text{Size.Sph.Scan:PP:Tact,MPE}}$	MPE(P[Size.Sph.Scan:PP:Tact])
	$P_{\text{Size.Sph.Scan:NPP:Tact,MPE}}$	MPE(P[Size.Sph.Scan:NPP:Tact])
Maximum permissible scanning mode time, $\tau_{\text{Sph.Scan:}k\text{:Tact,MPL}}$	$\tau_{\text{Sph.Scan:PP:Tact,MPL}}$	MPL(τ[Sph.Scan:PP:Tact])
	$\tau_{\text{Sph.Scan:NPP:Tact,MPL}}$	MPL(τ[Sph.Scan:NPP:Tact])
Scanning mode form error on a ring gauge with l_o = 0 (Annex A), $P_{\text{Form.Cir.Scan:}k\text{.0:Tact}}$	$P_{\text{Form.Cir.Scan:PP.0:Tact}}$	P[Form.Cir.Scan:PP.0:Tact]
	$P_{\text{Form.Cir.Scan:NPP.0:Tact}}$	P[Form.Cir.Scan:NPP.0:Tact]
Scanning mode size error on a ring gauge with l_o = 0 (Annex A), $P_{\text{Size.Cir.Scan:}k\text{.0:Tact}}$	$P_{\text{Size.Cir.Scan:PP.0:Tact}}$	P[Size.Cir.Scan:PP.0:Tact]
	$P_{\text{Size.Cir.Scan:NPP.0:Tact}}$	P[Size.Cir.Scan:NPP.0:Tact]
Scanning mode form error on a ring gauge with l_o = 150 (Annex A), $P_{\text{Form.Cir.Scan:}k\text{.150:Tact}}$	$P_{\text{Form.Cir.Scan:PP.150:Tact}}$	P[Form.Cir.Scan:PP.150:Tact]
	$P_{\text{Form.Cir.Scan:NPP.150:Tact}}$	P[Form.Cir.Scan:NPP.150:Tact]
Scanning mode size error on a ring gauge with l_o = 150 (Annex A), $P_{\text{Size.Cir.Scan:}k\text{.150:Tact}}$	$P_{\text{Size.Cir.Scan:PP.150:Tact}}$	P[Size.Cir.Scan:PP.150:Tact]
	$P_{\text{Size.Cir.Scan:NPP.150:Tact}}$	P[Size.Cir.Scan:NPP.150:Tact]
Maximum permissible scanning mode form error on a ring gauge with l_o = 0 (Annex A), $P_{\text{Form.Cir.Scan:}k\text{.0:Tact,MPE}}$	$P_{\text{Form.Cir.Scan:PP.0:Tact,MPE}}$	MPE(P[Form.Cir.Scan:PP.0:Tact])
	$P_{\text{Form.Cir.Scan:NPP.0:Tact,MPE}}$	MPE(P[Form.Cir.Scan:NPP.0:Tact])
Maximum permissible scanning mode size error on a ring gauge with l_o = 0 (Annex A), $P_{\text{Size.Cir.Scan:}k\text{.0:Tact,MPE}}$	$P_{\text{Size.Cir.Scan:PP.0:Tact,MPE}}$	MPE(P[Size.Cir.Scan:PP.0:Tact])
	$P_{\text{Size.Cir.Scan:NPP.0:Tact,MPE}}$	MPE(P[Size.Cir.Scan:NPP.0:Tact])
Maximum permissible scanning mode form error on a ring gauge with l_o = 150 (Annex A), $P_{\text{Form.Cir.Scan:}k\text{.150:Tact,MPE}}$	$P_{\text{Form.Cir.Scan:PP.150:Tact,MPE}}$	MPE(P[Form.Cir.Scan:PP.150:Tact])
	$P_{\text{Form.Cir.Scan:NPP.150:Tact,MPE}}$	MPE(P[Form.Cir.Scan:NPP.150:Tact])
Maximum permissible scanning mode size error on a ring gauge with l_o = 150 (Annex A), $P_{\text{Size.Cir.Scan:}k\text{.150:Tact,MPE}}$	$P_{\text{Size.Cir.Scan:PP.150:Tact,MPE}}$	MPE(P[Size.Cir.Scan:PP.150:Tact])
	$P_{\text{Size.Cir.Scan:NPP.150:Tact,MPE}}$	MPE(P[Size.Cir.Scan:NPP.150:Tact])
Multi-stylus test		
Fixed multi-stylus probing system	j = MS	Not applicable
Fixed multi-probe system	j = MP	Not applicable
Articulating probing system using empirical qualification	j = Emp	Not applicable
Articulating probing system using inferred qualification	j = Inf	Not applicable
Multi-stylus form error, $P_{\text{Form.Sph.5×25:}j\text{:Tact}}$	$P_{\text{Form.Sph.5×25:MS:Tact}}$	P[Form.Sph.5×25:MS:Tact]
	$P_{\text{Form.Sph.5×25:MP:Tact}}$	P[Form.Sph.5×25:MP:Tact]
	$P_{\text{Form.Sph.5×25:Emp:Tact}}$	P[Form.Sph.5×25:Emp:Tact]
	$P_{\text{Form.Sph.5×25:Inf:Tact}}$	P[Form.Sph.5×25:Inf:Tact]
Multi-stylus size error, $P_{\text{Size.Sph.5×25:}j\text{:Tact}}$	$P_{\text{Size.Sph.5×25:MS:Tact}}$	P[Size.Sph.5×25:MS:Tact]
	$P_{\text{Size.Sph.5×25:MP:Tact}}$	P[Size.Sph.5×25:MP:Tact]
	$P_{\text{Size.Sph.5×25:Emp:Tact}}$	P[Size.Sph.5×25:Emp:Tact]
	$P_{\text{Size.Sph.5×25:Inf:Tact}}$	P[Size.Sph.5×25:Inf:Tact]

Description	Symbol used in this document	Alternative, unformatted presentations
Multi-stylus location error, $L_{\mathrm{Dia.5\times25:}j\mathrm{:Tact}}$	$L_{\mathrm{Dia.5\times25:MS:Tact}}$	L[Dia.5×25:MS:Tact]
	$L_{\mathrm{Dia.5\times25:MP:Tact}}$	L[Dia.5×25:MP:Tact]
	$L_{\mathrm{Dia.5\times25:Emp:Tact}}$	L[Dia.5×25:Emp:Tact]
	$L_{\mathrm{Dia.5\times25:Inf:Tact}}$	L[Dia.5×25:Inf:Tact]
Opposing-styli projected location error on a sphere using 25 points, $L_{\mathrm{Dia.Proj.Sph.2\times25:}j\mathrm{:Tact}}$	$L_{\mathrm{Dia.ProjSph..2\times25:MS:Tact}}$	L[Dia.Proj.Sph.2×25:MS:Tact]
	$L_{\mathrm{Dia.Proj.Sph.2\times25:MP:Tact}}$	L[Dia.Proj.Sph.2×25:MP:Tact]
	$L_{\mathrm{Dia.Proj.Sph.2\times25:Emp:Tact}}$	L[Dia.Proj.Sph.2×25:Emp:Tact]
	$L_{\mathrm{Dia.Proj.Sph.2\times25:Inf:Tact}}$	L[Dia.Proj.Sph.2×25:Inf:Tact]
Opposing-styli projected location error on a ring gauge using scanning mode (Annex A), $L_{\mathrm{Dia.Proj.Cir.Scan:}j\mathrm{:Tact}}$	$L_{\mathrm{Dia.Proj.Cir.Scan:MS:Tact}}$	L[Dia.Proj.Cir.Scan:MS:Tact]
	$L_{\mathrm{Dia.Proj.Cir.Scan:MP:Tact}}$	L[Dia.Proj.Cir.Scan:MP:Tact]
	$L_{\mathrm{Dia.Proj.Cir.Scan:Emp:Tact}}$	L[Dia.Proj.Cir.Scan:Emp:Tact]
	$L_{\mathrm{Dia.Proj.Cir.Scan:Inf:Tact}}$	L[Dia.Proj.Cir.Scan:Inf:Tact]
Maximum permissible multi-stylus form error, $P_{\mathrm{Form.Sph.5\times25:}j\mathrm{:Tact,MPE}}$	$P_{\mathrm{Form.Sph.5\times25:MS:Tact,MPE}}$	MPE(P[Form.Sph.5×25:MS:Tact])
	$P_{\mathrm{Form.Sph.5\times25:MP:Tact,MPE}}$	MPE(P[Form.Sph.5×25:MP:Tact])
	$P_{\mathrm{Form.Sph.5\times25:Emp:Tact,MPE}}$	MPE(P[Form.Sph.5×25:Emp:Tact])
	$P_{\mathrm{Form.Sph.5\times25:Inf:Tact,MPE}}$	MPE(P[Form.Sph.5×25:Inf:Tact])
Maximum permissible multi-stylus size error, $P_{\mathrm{Size.Sph.5\times25:}j\mathrm{:Tact,MPE}}$	$P_{\mathrm{Size.Sph.5\times25:MS:Tact,MPE}}$	MPE(P[Size.Sph.5×25:MS:Tact])
	$P_{\mathrm{Size.Sph.5\times25:MP:Tact,MPE}}$	MPE(P[Size.Sph.5×25:MP:Tact])
	$P_{\mathrm{Size.Sph.5\times25:Emp:Tact,MPE}}$	MPE(P[Size.Sph.5×25:Emp:Tact])
	$P_{\mathrm{Size.Sph.5\times25:Inf:Tact,MPE}}$	MPE(P[Size.Sph.5×25:Inf:Tact])
Maximum permissible multi-stylus location error, $L_{\mathrm{Dia.5\times25:}j\mathrm{:Tact,MPE}}$	$L_{\mathrm{Dia.5\times25:MS:Tact,MPE}}$	MPE(L[Dia.5×25:MS:Tact])
	$L_{\mathrm{Dia.5\times25:MP:Tact,MPE}}$	MPE(L[Dia.5×25:MP:Tact])
	$L_{\mathrm{Dia.5\times25:Emp:Tact,MPE}}$	MPE(L[Dia.5×25:Emp:Tact])
	$L_{\mathrm{Dia.5\times25:Inf:Tact,MPE}}$	MPE(L[Dia.5×25:Inf:Tact])
Maximum permissible opposing-styli projected location error on a sphere using 25 points, $L_{\mathrm{Dia.Proj.Sph.2\times25:}j\mathrm{:Tact,MPE}}$	$L_{\mathrm{Dia.Proj.Sph.2\times25:MS:Tact,MPE}}$	MPE(L[Dia.Proj.2×25:MS:Tact])
	$L_{\mathrm{Dia.Proj.Sph.2\times25:MP:Tact,MPE}}$	MPE(L[Dia.Proj.2×25:MP:Tact])
	$L_{\mathrm{Dia.Proj.Sph.2\times25:Emp:Tact,MPE}}$	MPE(L[Dia.Proj.2×25:Emp:Tact])
	$L_{\mathrm{Dia.Proj.Sph.2\times25:Inf:Tact,MPE}}$	MPE(L[Dia.Proj.2×25:Inf:Tact])
Maximum permissible opposing-styli projected location error on a ring gauge using scanning mode (Annex A), $L_{\mathrm{Dia.Proj.Cir.Scan:}j\mathrm{:Tact,MPE}}$	$L_{\mathrm{Dia.Proj.Cir.Scan:MS:Tact,MPE}}$	MPE(L[Dia.Proj.Cir.Scan:MS:Tact])
	$L_{\mathrm{Dia.Proj.Cir.Scan:MP:Tact,MPE}}$	MPE(L[Dia.Proj.Cir.Scan:MP:Tact])
	$L_{\mathrm{Dia.Proj.Cir.Scan:Emp:Tact,MPE}}$	MPE(L[Dia.Proj.Cir.Scan:Emp:Tact])
	$L_{\mathrm{Dia.Proj.Cir.Scan:Inf:Tact,MPE}}$	MPE(L[Dia.Proj.Cir.Scan:Inf:Tact])

5 Rated operating conditions

5.1 Environmental conditions

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

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

— the user, in the case of reverification tests.

In both cases, the user is free to choose the environmental conditions under which the testing in this document will be performed within the manufacturer's specified limits given in the CMM data sheet.

The user is responsible for providing the environment enclosing the CMM as specified by the manufacturer in the CMM data sheet. If the environment does not meet the specifications, then none of the maximum permissible errors in this document can be required to be verified.

5.2 Operating conditions

For the tests specified in Clause 6, the CMM shall be operated using the procedures given in the manufacturer's operating manual. Especially important areas of the manufacturer's manual to be adhered to include:

a) machine start up/warm up cycles;

b) stylus system configuration and assembly (as per manufacturer's specification as per Figure 1 and Figure 5);

c) cleaning procedures for the stylus tip, test sphere and reference sphere;

d) probing system qualification;

e) when specified by the manufacturer, the location of the reference sphere as stated in the operating manual.

All stylus tips, the reference sphere and the test sphere shall be cleaned before the probing system qualification to eliminate residual film which might affect the measuring or test results.

IMPORTANT — Ensuring that approximate thermal equilibrium of the probing system is achieved during the probing system qualification and testing procedure is critical.

6 Acceptance tests and reverification tests

6.1 General

In the following subclauses:

— acceptance tests are executed according to the manufacturer's specifications and procedures; and

— reverification tests are executed according to the user's specifications and the manufacturer's procedures;

where specifications include the limits of the probing system configuration to which the stated MPE values apply and keeping within the rated operating conditions. In the case of reverification tests, use of a stylus relevant to a typical workpiece measuring task is recommended.

The tests of Clause 6 are designed for typical industrial CMMs. For the case of very small probing systems that are incapable of achieving suitable coverage of the test spheres described in 6.2 without collisions with the test sphere, Annex F shall be used for alternative test equipment and procedures for this case only.

The distance between the reference sphere and the test sphere is denoted L_P. For each of the tests specified in Clause 6, the location of the test sphere shall be chosen by the user anywhere in the measuring volume and hence L_P can have any physically realisable value. The CMM manufacturer may specify MPE as a function of L_P, see Annex D. To avoid interference between the probing system and the reference sphere, the reference sphere may be removed from the table during the test.

When the test sphere is located closely (small L_P) to the reference sphere used for probing system qualification, the errors can likely be attributed to the probing system; when the test sphere is located at a distance (large L_P) from the reference sphere, the errors are a combination of probing errors and machine geometry errors (see Annex C for further explanation).

The single-stylus, multi-stylus, opposing-styli and scanning mode errors and their corresponding maximum permissible errors shall be expressed in micrometres.

For each test specified in Clause 6 the same data set shall be used to evaluate both size and form as requested. It is not permitted to take two data sets, one for size and one for form.

For articulating systems, data for at least one method of qualification, either inferred or empirical, is required.

NOTE 1 The single-stylus probing error also applies to CMMs used with fixed multiple probes, fixed multiple styli and articulating probing systems (see 6.3.1).

NOTE 2 Multi-stylus probing performance is broadly categorized into form-related ($P_{\text{Form.Sph.5×25:}j\text{:Tact}}$), size-related ($P_{\text{Size.Sph.5×25:}j\text{:Tact}}$), and location-related ($L_{\text{Dia.5×25:}j\text{:Tact}}$ and $L_{\text{Dia.Proj.Sph.2×25:}j\text{:Tact}}$) errors. Different combinations of these will be important for the uncertainty of the different measurement tasks. For example, the form and size results might contain information on the ability of the CMM system to use multiple stylus tip diameters in the measurement of a single geometrical feature where j is replaced by MS, MP, Emp, or Inf, as applicable. See also Annex C.

NOTE 3 An articulating probing system used at multiple angular positions, even when used with a single stylus, is deemed to be a multi-stylus probing system.

NOTE 4 The limits of the probing system configuration for the single-stylus, scanning mode test and the multi-stylus test are allowed to differ from each other.

6.2 Measuring equipment

6.2.1 Test sphere

For both single-stylus and multi-stylus tests in this document, the test sphere shall have a diameter not less than 10 mm and not greater than 51 mm.

For the scanning mode test, the test sphere shall have a diameter not less than 24,9 mm and not greater than 25,5 mm.

The test sphere shall be calibrated for size and form. For the tests in this document, the measurand for sphere size is the least-squares diameter and the measurand for sphere form is sphericity. Calibration organisations use different approaches for sphericity. Common approaches for sphericity are for example: a minimum of 3 orthogonal great circle traces; or using 25 or more points well distributed on the sphere. For size, common approaches are for example: measuring the distance between two diametrically opposite points and other approaches that fit to more than two measured points.

For MPE form specifications, this document includes the sphere form as a rated operating condition to be able to exclude the influence of the test sphere form (with its uncertainty) from the test value uncertainty. However, a manufacturer is still permitted to explicitly state that the imperfect form of the test sphere is not a rated operating condition, in which case the influence of the form of the test sphere (with its uncertainty) shall be included in the test value uncertainty (as in ISO/TS 17865).

Unless the manufacturer states that the imperfect form of the test sphere is not a rated operating condition, or different percentages (for the below conditions), or an absolute maximum value for the calibrated form (F_{Cal}) (i.e. a different rated operating condition), then the calibrated form (F_{Cal}) and calibration uncertainty ($u(F_{\text{Cal}})$) of the test sphere shall meet all the following requirements for all of the associated MPEs shown below that will be tested using the test sphere:

— F_{Cal} shall not exceed 20 % of $P_{\text{Form.Sph.1×25:SS:Tact,MPE}}$ or $P_{\text{Form.Sph.5×25:}j\text{:Tact,MPE}}$ or $P_{\text{Form.Sph.Scan:}k\text{:Tact,MPE}}$ where j is replaced with MS, MP, Emp or Inf as applicable and where k is replaced with PP or NPP as applicable;

— $F_{\text{Cal}} + 1{,}65u(F_{\text{Cal}})$ shall not exceed 25 % of $P_{\text{Form.Sph.1×25:SS:Tact,MPE}}$ or $P_{\text{Form.Sph.5×25:}j\text{:Tact,MPE}}$ or $P_{\text{Form.Sph.Scan:}k\text{:Tact,MPE}}$ where j is replaced with MS, MP, Emp or Inf as applicable and where k is replaced with PP or NPP as applicable;

— F_{Cal} + 1,65u(F_{Cal}) shall not exceed 2,5 micrometres.

If the manufacturer does wish to specify different percentages then both percentages (the one relating to F_{Cal} in isolation and the one relating to F_{Cal} + 1,65u(F_{Cal})) shall be specified. Alternatively, the manufacturer may specify an absolute limit for the calibrated form (F_{Cal}) and if so, may also specify an absolute limit for calibration uncertainty (u(F_{Cal})).

NOTE 1 The test sphere's sphericity is treated as zero in the evaluation of probing errors in this document. For example, in 6.3.4, the calibrated form value is not subtracted from the measured sphere form even though the calibrated diameter is subtracted from the measured diameter.

NOTE 2 In order to avoid double-counting the effect of the test sphere form (present in the test result and historically in the test value uncertainty), the calibrated form and its calibration uncertainty are included as a rated operating condition and therefore do not need to be considered in the test value uncertainties. See Clause 7.

NOTE 3 Establishing the contribution from the calibrated form and its calibration uncertainty on the test results is challenging. However, having no limit on their values could leave the manufacturer exposed, hence the limit on a combination of the calibrated form plus its uncertainty.

NOTE 4 The factor 1,65 is associated with the 95 % criterion of ISO 14253-1.

NOTE 5 The exclusion of the effects of the form and uncertainty of form, on test value uncertainty in this document overrides the guidance in ISO/TS 17865.

The test sphere material shall be any one of: steel, stainless steel, tungsten carbide, diamond, ceramic, silicon carbide, or fused silica, unless otherwise agreed between manufacturer and user.

The reference sphere supplied with the CMM for probing system qualification purposes shall not be used for these tests.

The test sphere should be mounted rigidly to minimize errors due to bending. Non-rigid mounting contributes to test value uncertainty.

Hardness and surface roughness values for the test sphere may be stated by manufacturers as part of their rated operating conditions.

6.2.2 Styli specification and information

The styli used in the tests specified shall be those approved by the CMM manufacturer for use with the CMM unless otherwise specified, i.e. made of the same materials, of the same nominal stylus-shaft diameter and nominal length, with the same nominal stylus-tip diameter and quality, and in good condition.

For the single-stylus test two lengths of styli, chosen by the user from those specified, should be tested.

For the scanning mode test, a ball-ended stylus with a nominal stylus tip diameter of 3 mm shall be used. It is recommended that a stylus orientation is chosen which will ensure all axes of the CMM are exercised simultaneously when performing the scans.

For the multi-stylus test, only one of the lengths specified by the CMM manufacturer as applicable to the stylus system shall be chosen by the user and tested, however they needn't be the same for both the single-stylus and multi-stylus tests.

When a multi-stylus system is used, the results of these tests may be highly dependent on the stylus system and the offset lengths to the stylus tips.

For the single-stylus, scanning mode and multi-stylus test the manufacturer shall unambiguously state the probing and stylus configuration for which the MPE applies, including the l_o achieved for the multi-stylus test (see Figure 1, Figure 5, Figure 6, Figure 7, and Figure 8).

NOTE Stylus stiffness, quality and condition can have a significant impact on performance. When stylus-tip diameters become small their shafts become small and as such stiffness suffers adversely, the same effect is seen when styli become very long.

6.3 Single-stylus probing test

6.3.1 Application

6.3 applies to the single-stylus probing configuration and CMMs used with scanning mode probes, fixed multiple probes, fixed multiple styli and articulating probing systems. One of the multiple probes, or one of the multiple styli, or one of the articulating orientations, may be used for this test. See 6.3.3.1 for their orientation.

6.3.2 Principle

The principle of this test procedure is to measure a test sphere using 25 points probed with a single stylus and to observe the size and form error.

The results of these tests may be highly dependent on the stylus length, stiffness and diameter.

Single-stylus test probing system configuration	***Stylus configuration***	$P_{\text{Size.Sph.1×25:SS:Tact,MPE}}$ µm	$P_{\text{Form.Sph.1×25:SS:Tact,MPE}}$ µm
Fixed probe *name*	Ruby D8 × 50 mm M5 ceramic stem	1	1,2
	Ruby D5 × 30 mm M5 steel stem	0,9	1,1
Articulating head *name*, scanning probe *name*	*stylus holder name*, Ruby D5 × 20 M3 steel stem	1	1,2
	stylus holder name, Ruby D5 × 20 M3 steel stem	1,3	1,8

Figure 1 — Example Single-stylus configuration specification sheet

NOTE The purpose of this test is to give an indication of the system performance when measuring local features and includes bi-directional performance of the system in single (discrete) point probing mode.

6.3.3 Procedure

6.3.3.1 The stylus orientation shall be parallel to the ram axis, unless otherwise specified. Any change of orientation of the stylus may significantly affect the test result.

On dual ram CMMs, two separate tests should be run, one with each ram, both in simplex operating mode, in accordance with ISO 10360-2.

6.3.3.2 Set up and qualify the probing system in accordance with the manufacturer's normal procedures (see 6.2.2).

6.3.3.3 If an automated stylus or probe changing system is supplied with the CMM, return the stylus or probe to the rack before running this test. Additionally, if an articulating head is included, articulate the probe away and back again before running this test.

If no automated stylus or probe change system is available, it is not recommended that this is changed manually as this will have a detrimental effect on performance.

6.3.3.4 Measure and record 25 points. The points shall be approximately evenly distributed over at least a hemisphere of the test sphere keeping within any system limitations as specified by the manufacturer. Where the manufacturer has system limitations that mean this distribution is not possible, this shall be stated clearly with their specifications. The point positions shall be at the discretion of the user and, if not specified, the following probing pattern is recommended (see Figure 2):

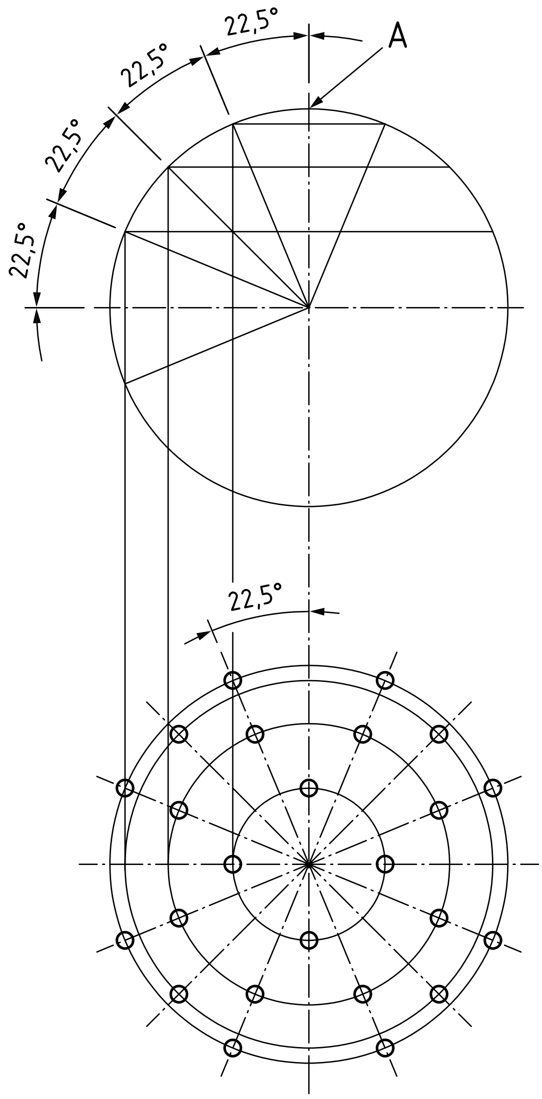
— one point on the pole (defined by the direction of the stylus shaft) of the test sphere;

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

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

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

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



Key

A pole

Figure 2 — Target contact points

6.3.4 Data analysis

Fit an unconstrained least-squares sphere to the 25 measured points ensuring that D_{meas} is compensated by the effective tip diameter or tip correction vectors as used in the machine's normal operating procedure.

The probing size error, $P_{Size.Sph.1×25:SS:Tact}$, is obtained from the difference between the measured diameter of the sphere, D_{meas} , and the calibrated diameter, D_{cal} , as follows:

$$P_{Size.Sph.1×25:SS:Tact} = D_{meas} - D_{cal}$$

Record the range of radii of the 25 points with respect to the least-squares sphere centre i.e. $R_{max} - R_{min}$, the apparent sphere form, to give the single-stylus form error, $P_{Form.Sph.1×25:SS:Tact}$. See Figure 4.

NOTE See also Annex B when running this test prior to the tests in ISO 10360-2.

6.4 Scanning mode test

6.4.1 Principle

The principle of this test procedure is to measure the form, and size of a test sphere using the CMM in scanning mode whilst timing the duration of the test.

The scanning mode test described here is applicable for systems capable of:

a) scanning on a pre-defined path (PP); and/or

b) scanning on a not pre-defined path (NPP).

NOTE The test is not able to fully quantify the uncertainty when a CMM is used for either a form measurement or associated feature calculation on a workpiece. Surface roughness, surface discontinuities and lubricity of workpiece and stylus influence scanning performance. In this test these influence parameters are controlled producing results that may not reflect those obtained in real workpieces (see Annex E).

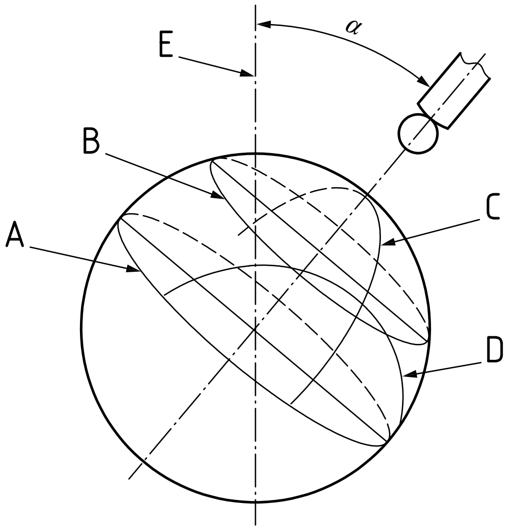
6.4.2 Procedure

6.4.2.1 Set up and qualify the probing system in accordance with the manufacturer's normal procedures (see 6.2.2).

6.4.2.2 If an automated stylus or probe changing system is supplied with the CMM, return the stylus or probe to the rack before running this test. Also, if an articulating head is fitted articulate away and back again before running this test.

If no automated stylus or probe change system is available, it is not recommended that this is changed manually as this will have a detrimental effect on performance.

6.4.2.3 Take and record measurements of scan points on the test sphere for corrected scan lines on the surface of the test sphere in the four target scan planes defined (see Figure 3). The scan planes are defined as the ball on sphere contact planes, not the stylus ball centre planes.



Key

A target scan plane A

B target scan plane B

C target scan plane C

D target scan plane D

E parallel to the axis of the ram

α angle in which the stylus shaft is offset from the axis of the ram

The pole and equator of the test sphere are defined by the axis of the stylus shaft. It is recommended that a value of approximately 45° is chosen for α.

NOTE 1 Target scan plane A is on the equator.

NOTE 2 Target scan plane A and target scan plane B are parallel planes 8 mm apart.

NOTE 3 Target scan planes B, C and D are mutually perpendicular.

NOTE 4 Target scan plane C goes through the pole.

NOTE 5 Target scan plane D is a plane offset 8 mm from the pole axis.

Figure 3 — Four target scan planes on a test sphere

The Cartesian distance between consecutive corrected measured points shall not exceed 0,1 mm. None of the corrected measured points may have a normal distance more than 0,2 mm from the relevant target scan plane.

Each of the four scan sequences shall commence with the stylus at an intermediate point a minimum of 10 mm away from the test sphere. The stylus should always approach the sphere along a surface normal. Each of the four scan sequences shall end with the stylus at an intermediate point a minimum of 10 mm away from the test sphere.

Record the time for the scanning mode test, from the intermediate point at the start of the first scan sequence to the intermediate point at the end of the fourth scan sequence, $\tau_{\text{Sph.Scan:}k\text{:Tact}}$ where k is replaced by PP or NPP as applicable.

The algorithms and parameters used shall be those used for normal workpiece measurement on the machine. Any such software applied filtering shall be specified by the manufacturer. No additional filtering or other optimization shall be used on the data set obtained from the scan paths as defined.

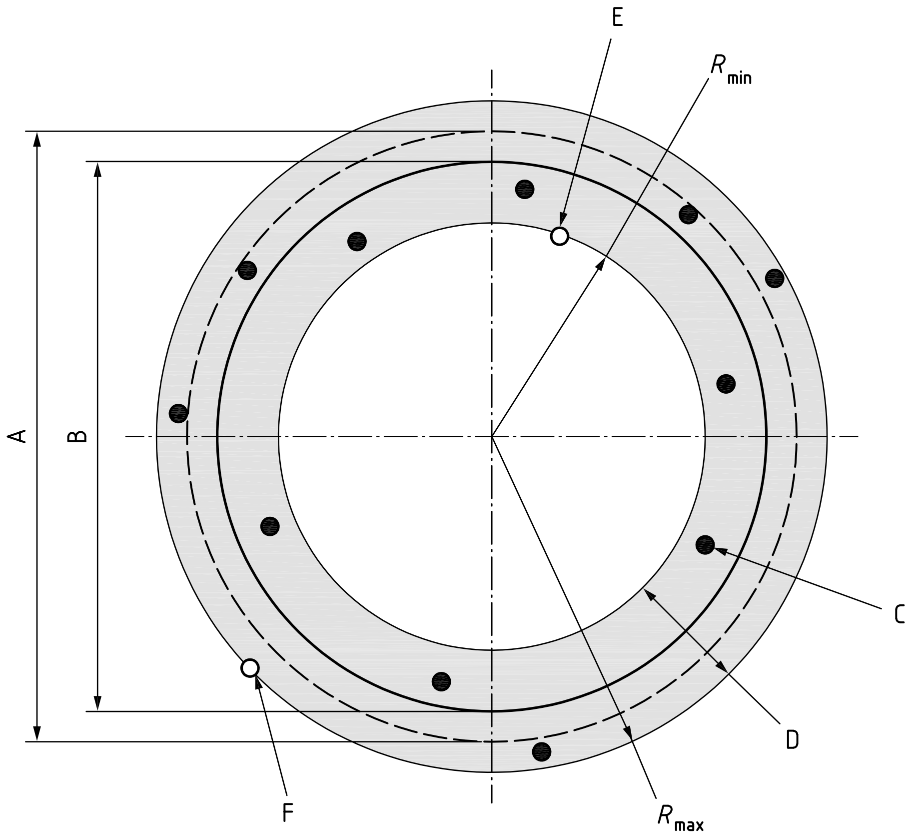
6.4.3 Data analysis

Fit an unconstrained least-squares sphere to all points taken from the four scans ensuring that D_{meas} is compensated by the effective tip diameter or tip correction vectors.

The scanning mode size error on a sphere, $P_{Size.Sph.Scan:k:Tact}$, is obtained from the difference between the measured diameter of the sphere, D_{meas}, and the calibrated diameter, D_{cal}, as follows:

$$P_{Size.Sph.Scan:k:Tact} = D_{meas} - D_{cal}$$

Record the range of radii of all points with respect to the least-squares sphere centre, i.e. $R_{max} - R_{min}$, the apparent sphere form, to give the scanning mode form error on a sphere, $P_{Form.Sph.Scan:k:Tact}$, where k is replaced by PP or NPP as applicable. See Figure 4.



Key

A D_{cal}, calibrated diameter of test sphere

B D_{meas}, measured least squares diameter of test sphere

C measured points, only a subset of points are illustrated for clarity

D $P_{Form.Sph.n:k:Tact}$ where n is replaced by Scan, 1×25 or 5×25 and k is replaced by SS, PP, NPP, MS, MP, Emp or Inf as appropriate

E extreme point defining the minimum radius

F extreme point defining the maximum radius

Figure 4 — 2D simplified illustration of $P_{Form.Sph.n:k:Tact}$, D_{cal} and D_{meas}

6.5 Multi-stylus test: Fixed multi-probe and multi-stylus probing systems

6.5.1 Principle

The principle of this test procedure is to measure the form, size and location of a test sphere using five different fixed probes or styli. For each probe or stylus, 25 points are measured on the test sphere, for a total of 125 points using all five positions.

If specified, opposing-styli projected location errors are evaluated to give an indication of performance for measurements where opposing-styli measurements are combined in a feature measurement, for example measuring the co-axiality of crank shaft journals from opposing ends. Please see Annex A for a more comprehensive optional test to identify performance for such opposing-styli measurements using a ring gauge.

The specification of the opposing-styli projected location error on a sphere ($L_{\text{Dia.Proj.Sph.2×25:}j\text{:Tact,MPE}}$) is optional. If specified, then it shall be evaluated as per 6.7.2 and Clause 7.

A series of ram axis stylus tip offsets are considered (see Figure 5, Figure 6, Figure 7 and Figure 8), all measured from the centre of the ram and orthogonally to the ram axis. In cases where the ram axis stylus tip offsets for the four offset styli cannot be equal, the manufacturer shall use the smallest ram axis stylus tip offset as the specified ram axis stylus tip offset.

Probing configuration specified	Actual l_o achieved (mm)	$P_{\text{Form.Sph.5×25:}j\text{:Tact,MPE}}$ (µm)	$P_{\text{Size.Sph.5×25:}j\text{:Tact,MPE}}$ (µm)	$L_{\text{Dia.5x25:}j\text{:Tact,MPE}}$ (µm)	$L_{\text{Dia.Proj.Sph.2x25:}j\text{:Tact,MPE}}$ (µm)
Fixed scanning probe *name*; 5 off: 100 mm M5 extension; D6 × 50 mm ruby stylus with ceramic stem	160	6	2	4	3
Articulating head *name*; probe *name*; stylus holder *name*, ruby stylus D5 × 20 mm steel stem	147	5,5	2	3,8	3,1

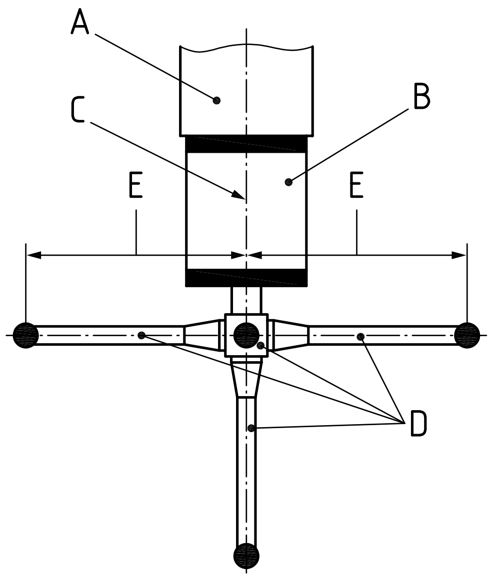
Figure 5 — Example multi-stylus-system specification sheet where *j* is replaced by one of: MS, MP, Emp or Inf as appropriate to the system (see Clause 4 and Figure 6, Figure 7, and Figure 8)

Only those ram axis stylus tip offsets applicable to the CMM under consideration should be assigned MPE values when constructing a specification table similar to that shown in Figure 5.

6.5.2 Procedure

6.5.2.1 When a multi-stylus system is used, construct a “star” stylus system composed of one stylus parallel to the axis of the probe and four styli in a plane perpendicular to the axis, each oriented 90° with respect to those adjacent to it. The orientation of the four styli in a plane with respect to machine axes is up to the user. The distance from the probe to the styli connection point shall be the minimum distance possible (consistent with the manufacturer's recommendations) using the stylus components normally supplied with the CMM (see Figure 6).

On dual ram CMMs, three of the stylus tips shall be mounted on one ram, and two of the stylus tips on the other ram, all in duplex operating mode, in accordance with ISO 10360-2.



Key

A ram

B probe

C centre line of probing cluster, typically ram axis centre line

D stylus

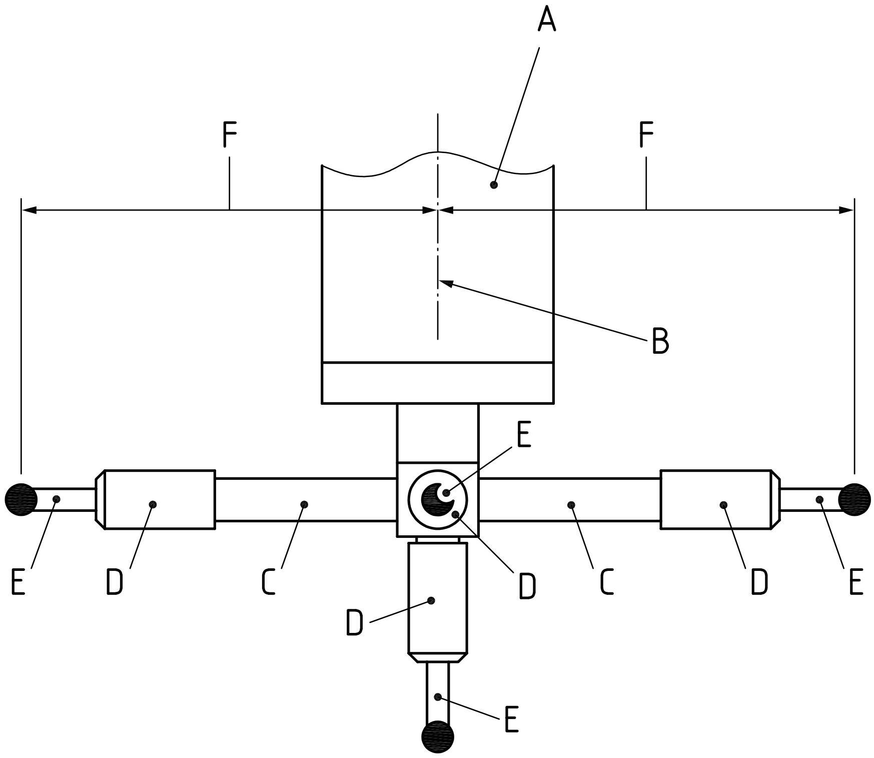
E ram axis stylus tip offset l_o

NOTE For clarity, only four of the five styli and only three shafts are visible.

Figure 6 — Fixed multi-stylus probing system

6.5.2.2 When a multi-probe system is used, attach a suitable straight stylus to each of the five probes. Assemble them with suitable probe extension components to form a "star" probe system composed of one probe parallel to the axis of the ram and four probes in a plane perpendicular to the axis, each oriented 90° with respect to those adjacent to it. The distances from each of the five stylus tips to a single reference point on the ram axis, the ram axis stylus tip offset, shall all be approximately equal (see Figure 7).

On dual ram CMMs, three of the probes shall be mounted on one ram, and two of the probes on the other ram, all in duplex operating mode, in accordance with ISO 10360-2.



Key

A ram

B centre line of probing cluster, typically ram axis centre line

C probe extension if applicable

D probe

E stylus

F ram axis stylus tip offset l_o

NOTE For clarity, only four of the five probes and only two probe extensions are visible.

Figure 7 — Multi-probe system with ram axis stylus tip offset length l_o

6.5.2.3 The five stylus tips shall not be restricted to a single nominal diameter unless such a restriction is explicit in the CMM manufacturer's specification (see 6.2.2).

6.5.2.4 Set up and qualify the probing system in accordance with the manufacturer's normal procedures (see 6.2.2).

6.5.2.5 If a stylus or probe changing system is supplied with the CMM, all five styli shall be qualified, and the styli or probes returned to the rack, before running this test. Five changes shall be performed during the test, each stylus or probe being changed once. However, if fewer than five styli or probe stations are available in the changing system, the maximum number shall be used, with some styli or probes changed more than once to achieve a total of five changes. In the case of a “star” stylus or “star” probe system, the star system shall be returned to the rack and picked up again before the first and in between each sphere measurement to achieve the total of five changes. Five mutually orthogonal positions shall always be measured, so if less than five tool stations are used then some of the positions shall be “star” styli or “star” probes.

If the probing system assembly is identical to that chosen for the single-stylus probing test (see 6.3), the results of the single-stylus probing test may utilise the measurement data from the corresponding stylus used in this multi-stylus test, such that there is no need to make the same measurements twice with the one stylus.

If no automated stylus or probe change system is available, it is not recommended that this is changed manually as this will have a detrimental effect on performance.

6.5.2.6 Measure the test sphere using 25 points with each stylus, for a total of 125 points. The points shall be approximately evenly distributed over at least a hemisphere of the test sphere keeping within any system limitations as specified by the manufacturer. Their position shall be at the discretion of the user. The recommended point-sampling strategy is the same as for the single-stylus test (see 6.3.3.4).

When the support stalk for the test sphere is located on the vertical centre line and a horizontal stylus is used, then access should be optimized by orienting the probing pattern so that each of the eight points on the equator is at 22,5° to a CMM axis, and the four points in the adjacent plane are at 45° to the Z axis. This is illustrated in Figure 2, if the lower view is considered to be an elevation.

However, if the test sphere is small relative to its support stalk diameter and/or the stylus tip diameter, so that the eight points on the equator cannot be equispaced at 45° over an arc of 315°, then it is recommended that the eight points are equispaced over the available arc.

6.5.3 Data analysis

Evaluate the data according to 6.7.

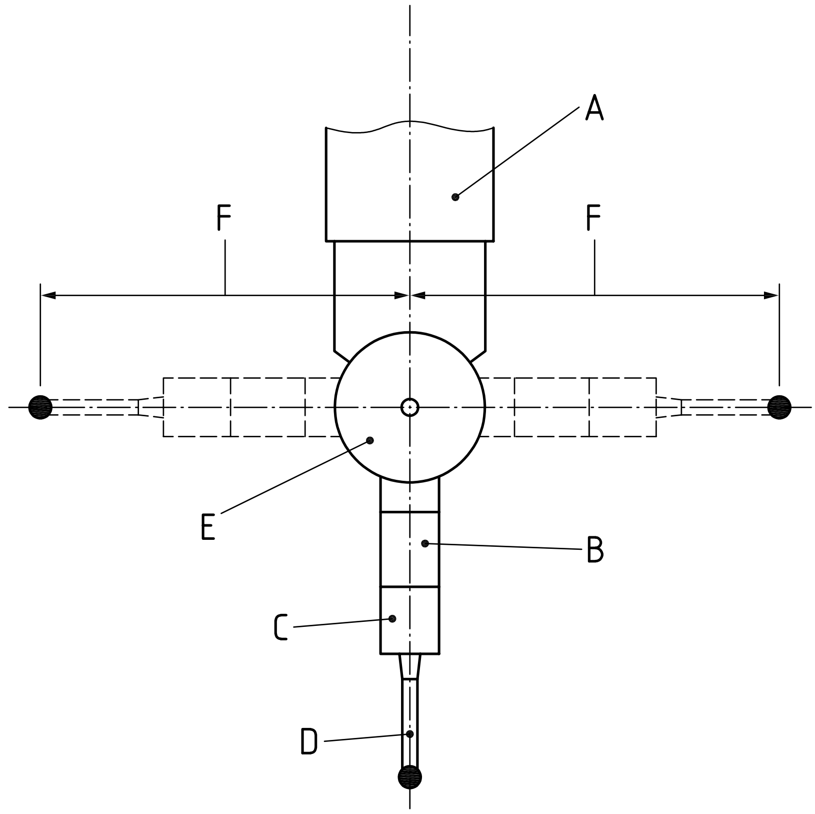
6.6 Multi-stylus test: Articulating probing systems

6.6.1 Principle

The principle of these tests is to measure the form, size and location of a test sphere using five different angular positions of an articulating probing system (see Figure 8). At each angular position, 25 points are measured on the test sphere, for a total of 125 points using all five positions.

If specified, opposing-styli projected location errors are evaluated to give an indication of performance for measurements where opposing-styli measurements are combined in a feature measurement, for example measuring the co-axiality of crank shaft journals from opposing ends. Please see Annex A for a more comprehensive optional test to identify performance for such opposing-styli measurements using a ring gauge.

The specification of the opposing-styli projected location error on a sphere ($L_{\mathrm{Dia.Proj.Sph.2\times25:}j\mathrm{:Tact,MPE}}$) is optional. If specified, then it shall be evaluated as per 6.7.2 and Clause 7.



Key

A ram

B probe extension if applicable

C probe

D stylus

E articulating probing system

F ram axis stylus tip offset l_o

Figure 8 — Articulating probing system showing 3 of the 5 positions

CMMs with articulating probing systems may use either empirical or inferred qualification data for measurement. Therefore, to prevent ambiguity, the maximum permissible errors for a CMM using empirical qualification are labelled $P_{\text{Form.Sph.5×25:Emp:Tact,MPE}}$, $P_{\text{Size.Sph.5×25:Emp:Tact,MPE}}$ and $L_{\text{Dia.5×25:Emp:Tact,MPE}}$, while the maximum permissible errors for a CMM using inferred qualification are labelled $P_{\text{Form.Sph.5×25:Inf:Tact,MPE}}$, $P_{\text{Size.Sph.5×25:Inf:Tact,MPE}}$ and $L_{\text{Dia.5×25:Inf:Tact,MPE}}$. Similarly, the errors obtained when using empirical qualification are labelled $P_{\text{Form.Sph.5×25:Emp:Tact}}$, $P_{\text{Size.Sph.5×25:Emp:Tact}}$ and $L_{\text{Dia.5×25:Emp:Tact}}$, while the errors obtained when using inferred qualification are labelled $P_{\text{Form.Sph.5×25:Inf:Tact}}$, $P_{\text{Size.Sph.5×25:Inf:Tact}}$ and $L_{\text{Dia.5×25:Inf:Tact}}$.

6.6.2 Procedure

6.6.2.1 Build up the probe and stylus assembly and attach them to the articulating probing system according to the manufacturer's specification.

6.6.2.2 It is recommended that the five angular positions consist of one stylus parallel to the ram axis and four styli whose tips lie perpendicular to the ram axis, each stylus oriented 90° with respect to those adjacent to it, as viewed down the ram axis (see Figure 8), however the specification from the manufacturer applies to any five orientations and as such the user may choose any five.

On some CMM configurations (especially on horizontal-arm CMMs), some of the above recommended five angular positions may be unattainable or impractical. In such cases, the recommended pattern of angular positions should be rotated by ±90° about either the X or Y axis, as appropriate to the CMM configuration.

If the axis of the first articulation axis of the articulating probe system is not aligned with the ram axis then this axis of the first articulation axis should be considered the “ram axis” in terms of the recommended orientations in this clause and in terms of the ram axis stylus tip offsets.

On dual ram CMMs, three of the angular positions should be qualified using one ram, and two of the angular positions using the other ram, all in duplex operating mode, in accordance with ISO 10360-2.

6.6.2.3 When testing in empirical mode of operation (i.e. j = “Emp”) is required, qualify the probing system in each of five angular positions in accordance with the CMM manufacturer's normal operating procedures (see 6.2.2).

When testing in inferred mode of operation (i.e. j = “Inf”) is required, then the qualification of the probing system shall be executed in accordance with the CMM manufacturer's normal operating procedure for inferred qualification (see 6.2.2). The user shall then choose any five widely spaced angular positions of the articulating probing system for this test.

The user is advised to choose angular test positions for inferred qualification which are remote both from those which were used to qualify the articulating system (if known) and from those which were used to qualify the probing system under test.

On dual ram CMMs, three of the angular positions should be qualified using one ram, and two of the angular positions using the other ram, all in duplex operating mode, in accordance with ISO 10360-2.

It is not permitted to combine test data from inferred and empirical modes of operation.

6.6.2.4 Before starting the measurement, ensure the head has performed at least one articulation since its last qualification. If a stylus or probe changing system is supplied with the CMM, return the stylus or probe to the rack before running this test.

If no automated stylus or probe change system is available, it is not recommended that this is changed manually as this will have a detrimental effect on performance.

6.6.2.5 Measure the test sphere using 25 points measured in each angular position, for a total of 125 points.

The points shall be approximately evenly distributed over at least a hemisphere of the test sphere keeping within any system limitations as specified by the manufacturer. Their position shall be at the discretion of the user. The recommended point-sampling strategy is the same as for the single-stylus test (see 6.3.3.4).

When the support stalk for the test sphere is located on the vertical centre line and a horizontal stylus is used, then access should be optimized by orienting the probing pattern so that each of the eight points on the equator is at 22,5° to a CMM axis and the four points in the adjacent plane are at 45° to the Z axis. This is illustrated in Figure 2, if the lower view is considered to be an elevation.

However, if the test sphere is small relative to its support stalk diameter and/or the stylus tip diameter, so that the eight points on the equator cannot be equispaced at 45° over an arc of 315°, then it is recommended that the eight points are equispaced over the available arc.

If a stylus or probe changing system is supplied with the CMM, five changes shall be performed during the test, the stylus or probe being returned to the rack after measuring the test sphere in each angular position.

NOTE If the probing system assembly and one of the angular positions are both identical to those chosen for the single-stylus probing test (6.3), there is no need to make the same measurements twice at that angular position.

6.6.3 Data analysis

Evaluate the data according to 6.7.

6.7 Data analysis for multi-stylus tests

6.7.1 Location error

Fit an unconstrained least-squares sphere fit to each group of 25 points taken at the five angular positions, for a total of five sphere fits. Calculate the diameter of the minimum circumscribed sphere that encompasses the five sphere centres: this diameter is the location error $L_{\text{Dia.5×25:}j\text{:Tact}}$ where j is replaced with MS, MP, Emp or Inf as applicable.

6.7.2 Opposing-styli projected location error

If the opposing-styli projected location error on a sphere is specified, this is the 2D distance between two sphere centres measured from opposing directions as projected onto a plane. The plane includes the target centre of the sphere and is orthogonal to the vector from the target centre of the sphere to the target pole point from the first of the two applicable spheres. Repeat for the 2 sphere centres measured from the other opposing directions. The larger of these two distances is the opposing-styli projected location error on a sphere, $L_{\text{Dia.Proj.Sph.2×25:}j\text{:Tact}}$, where j is replaced with MS, MP, Emp or Inf as applicable.

NOTE 1 If the user has chosen alternative angles to the recommended default then only if they have retained opposing-styli will it be possible to evaluate $L_{\text{Dia.Proj.Sph.2×25:}j\text{:Tact}}$.

NOTE 2 The subscript “Dia” in the symbol $L_{\text{Dia.Proj.Sph.2×25:}j\text{:Tact}}$ refers to the diameter of the minimum circumscribing sphere containing the two reported locations. For two locations, this diameter is simply the distance between the two projected locations.

6.7.3 Multi-stylus size and form error

Fit an unconstrained least-squares sphere to all 125 points taken with all five angular positions ensuring that D_{meas} is compensated by the effective tip diameter or tip correction vectors.

The multi-stylus size error, $P_{\text{Size.Sph.5×25:}j\text{:Tact}}$, is obtained from the difference between the measured diameter of the sphere, D_{meas}, and the calibrated diameter, D_{cal}, as follows:

$$P_{\text{Size.Sph.5×25:}j\text{:Tact}} = D_{\text{meas}} - D_{\text{cal}}$$

Record the range of radii of the 125 points with respect to the least-squares sphere centre, i.e. $R_{\text{max}} - R_{\text{min}}$, the apparent sphere form, giving the multi-stylus form error, $P_{\text{Form.Sph.5×25:}j\text{:Tact}}$, where j is replaced with MS, MP, Emp or Inf as applicable. See Figure 4.

For the multi-stylus or multi-probe test, according to 6.5.2.3, the five tips are permitted (unless explicitly specified otherwise) to have significantly different nominal diameters, and even when they have the same nominal diameters, generally no two tips will have identical effective diameters. If the CMM software does not correctly handle multiple tip diameters when measuring a single feature, then these five different effective tip diameters might cause increased error values $P_{\text{Size.Sph.5×25:}j\text{:Tact}}$ and $P_{\text{Form.Sph.5×25:}j\text{:Tact}}$, where j is replaced with MS or MP as applicable.

NOTE For the multi-stylus articulation test, although just one physical stylus tip is used in these tests, the effective diameter of that tip might not be identical in all five angular positions. If the CMM software does not correctly handle multiple tip diameters when measuring a single feature, then these five different effective tip diameters might cause increased error values $P_{\text{Size.Sph.5×25:}j\text{:Tact}}$ and $P_{\text{Form.Sph.5×25:}j\text{:Tact}}$, where j is replaced with Emp or Inf as applicable.

7 Conformance with specification: Acceptance and reverification tests

In this clause “taking into account the test value uncertainty” means applying the default rule of ISO 14253-1 unless otherwise agreed between the parties.

For size evaluations, the uncertainty associated with its calibrated size, as well as the difference between the calibration measurand and the test measurand, shall be accounted for in the test value uncertainty.

For form evaluations, unless the manufacturer has explicitly stated that the imperfect form of the test sphere is not a rated operating condition, the test sphere calibrated form and its calibration uncertainty are included as rated operating conditions, and hence accounted for in the MPE specifications to eliminate the need to include their effects in test value uncertainty.

NOTE Evaluation of test value uncertainty is discussed in ISO 14253-5.

The following points apply:

a) When relevant, the single-stylus probing performance is verified if

   1) the absolute value of the measured single-stylus size error, $P_{\text{Size.Sph.1×25:SS:Tact}}$, is not greater than the relevant maximum permissible single-stylus size error, $P_{\text{Size.Sph.1×25:SS:Tact,MPE}}$, as specified and taking into account the test value uncertainty;

   2) the measured single-stylus form error, $P_{\text{Form.Sph.1×25:SS:Tact}}$, is not greater than the relevant maximum permissible single-stylus form error, $P_{\text{Form.Sph.1×25:SS:Tact,MPE}}$, as specified and taking into account the test value uncertainty.

b) When relevant, the scanning mode performance is verified if

   1) the absolute value of the measured scanning mode size error on a sphere, $P_{\text{Size.Sph.Scan:}k\text{:Tact}}$, is not greater than the relevant maximum permissible scanning mode size error on a sphere, $P_{\text{Size.Sph.Scan:}k\text{:Tact,MPE}}$, as specified and taking into account the test value uncertainty;

   2) the measured scanning mode form error on a sphere, $P_{\text{Form.Sph.Scan:}k\text{:Tact}}$, is not greater than the relevant maximum permissible scanning mode form error on a sphere, $P_{\text{Form.Sph.Scan:}k\text{:Tact,MPE}}$, as specified and taking into account the test value uncertainty;

   3) the measured scanning mode time, $\tau_{\text{Sph.Scan:}k\text{:Tact}}$, is not greater than $\tau_{\text{Sph.Scan:}k\text{:Tact,MPL}}$ as specified;

where k is replaced by PP or NPP as applicable.

c) When relevant, the multi-stylus probing performance is verified if

   1) the absolute value of the measured multi-stylus size error, $P_{\text{Size.Sph.5×25:}j\text{:Tact}}$, is not greater than the relevant maximum permissible multi-stylus size error, $P_{\text{Size.Sph.5×25:}j\text{:Tact,MPE}}$, as specified and taking into account the test value uncertainty;

   2) the measured multi-stylus form error, $P_{\text{Form.Sph.5×25:}j\text{:Tact}}$, is not greater than the relevant maximum permissible multi-stylus form error, $P_{\text{Form.Sph.5×25:}j\text{:Tact,MPE}}$, as specified and taking into account the test value uncertainty;

3) the measured multi-stylus location error, $L_{\text{Dia.5×25:}j\text{:Tact}}$, is not greater than the relevant maximum permissible multi-stylus location error, $L_{\text{Dia.5×25:}j\text{:Tact,MPE}}$, as specified and taking into account the test value uncertainty;

4) the measured opposing-styli projected location error on a sphere value, $L_{\text{Dia.Proj.Sph.2×25:}j\text{:Tact}}$, where specified, is not greater than the relevant maximum permissible opposing-styli projected location error on a sphere, $L_{\text{Dia.Proj.Sph.2×25:}j\text{:Tact,MPE}}$, as specified and taking into account the test value uncertainty;

where *j* is replaced with MS, MP, Inf, or Emp as applicable.

d) The maximum permissible errors and the maximum permissible limit, are specified by:

1) the manufacturer, in the case of acceptance tests; or

2) the user, in the case of reverification tests.

If the performance is not verified by all the relevant tests, all probing equipment shall be thoroughly checked for dust, dirt or any operator-induced faults in stylus-system assembly that could influence the measurement result, including the critical issue of ensuring that all probing system components are in thermal equilibrium. Any faults shall be corrected, and the relevant test repeated once only, starting from probing system qualification and using the same target contact points.

8 Applications

8.1 Acceptance tests

In a contractual situation between a supplier and a customer 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 single-stylus probing performance, and (when relevant) the multi-stylus CMM system performance, in accordance with the specified maximum permissible errors agreed by the supplier and the customer.

8.2 Reverification tests

The reverification tests given in this document can be used in an organization's internal quality assurance system for verification of the single-stylus probing performance and (when relevant) the multi-stylus CMM system performance, in accordance with the specified appropriate maximum permissible errors as stated by the user with all possible and detailed limitations applied.

8.3 Interim checks

In an organization's internal quality assurance system, reduced reverification tests can be used periodically to demonstrate the probability that the CMM conforms to the requirements for maximum permissible errors specified in Clause 7.

The extent of the interim checks for multi-stylus systems specified in this document may be reduced in respect of the number of actual measuring points being assessed.

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

Annex A
(informative)

Ring gauge tests

A.1 General

This annex details parameters for allowing the optional specification and verification of the CMM performance with a ring gauge as a test artefact.

A.2 Rated operating conditions

The rated operating conditions as per Clause 5 apply with the addition of the following to 5.2:

For MPE form specifications, this annex includes the test ring gauge form as a rated operating condition to be able to exclude the influence of the test ring gauge form (with its uncertainty) from the test value uncertainty. However, a manufacturer is still permitted to explicitly state that the imperfect form of the test ring gauge is not a rated operating condition, in which case the influence of the form of the test ring gauge (with its uncertainty) shall be included in the test uncertainty.

Unless the manufacturer states that the imperfect form of the test ring gauge is not a rated operating condition, or states different percentages (for the below conditions), or an absolute maximum value for the calibrated form (F_{Cal}) (i.e. a different rated operating condition), then the calibrated form (F_{Cal}) and calibration uncertainty ($u(F_{\text{Cal}})$) of the test ring gauge shall meet all the following requirements for all of the associated MPEs shown below that will be tested using the test ring gauge:

— F_{Cal} shall not exceed 20 % of $P_{\text{Form.Cir.Scan:}k\text{.0:Tact,MPE}}$ or $P_{\text{Form.Cir.Scan:}k\text{.150:Tact,MPE}}$ or $L_{\text{Dia.Proj.Cir.Scan:}j\text{:Tact,MPE}}$ where k is replaced with PP or NPP as applicable and j is replaced with MS, MP, Emp or Inf as applicable.

— F_{Cal} + 1,65$u(F_{\text{Cal}})$ shall not exceed 25 % of $P_{\text{Form.Cir.Scan:}k\text{.0:Tact,MPE}}$ or $P_{\text{Form.Cir.Scan:}k\text{.150:Tact,MPE}}$ or $L_{\text{Dia.Proj.Cir.Scan:}j\text{:Tact,MPE}}$ where k is replaced with PP or NPP as applicable and j is replaced with MS, MP, Emp or Inf as applicable.

If the manufacturer does wish to specify different percentages then both percentages: the one relating to F_{Cal} in isolation and the one relating to F_{Cal} + 1,65$u(F_{\text{Cal}})$ shall be specified. Alternatively, the manufacturer may specify an absolute limit for the calibrated form (F_{Cal}) and if so, may also specify an absolute limit for calibration uncertainty ($u(F_{\text{Cal}})$).

If available, use the calibrated form value associated with a 50 UPR Gaussian filter.

NOTE 1 The test ring gauge's form is treated as zero in the evaluation of probing errors in this document. For example, in A.6, the calibrated form value is not subtracted from the measured ring gauge form even though the calibrated diameter is subtracted from the measured diameter.

NOTE 2 In order to avoid double-counting the effect of the test ring gauge form (present in the test result), the calibrated form and its calibration uncertainty are included as a rated operating condition and therefore do not need to be considered in the test value uncertainties. See A.8.

A.3 General

Clause 6 applies, replacing "test ring gauge" for "test sphere".

Ring gauge test errors are expressed in micrometres.

A.4 Test equipment

Use a test ring gauge sized between 49,9 mm and 50,9 mm and calibrated for size and form. If this size is not practical due to machine size limitations, then given a manufacturer's specification a smaller ring gauge may be used.

Use a test ring gauge which is in a good and clean condition with particular attention being paid to ensure corrosion is not present on its metrology surface.

Care shall be taken when mounting the test ring gauge such that forces are not induced into the test ring gauge that might distort its form; mounting distortions contribute to test value uncertainty.

Use a ball-ended stylus with a nominal stylus tip diameter of 3 mm for the ring gauge tests unless otherwise specified, but not to exceed 3,3 mm.

For the offset stylus ring gauge test use a stylus with an l_0 of 150 mm unless otherwise specified. If a different l_0 to 150 mm is used, then this shall be included in the symbol.

A.5 The tests

There are proposed two tests to evaluate size and form measuring capability with a ring gauge mounted in 2 different orientations.

The MPE associated with a 50 UPR Gaussian filter will be stated. Other filtering normally available in the CMM may be specified in addition by the manufacturer, appending the UPR value to the specification.

The Cartesian distance between consecutive corrected measured points shall not exceed 0,1 mm.

The option of measuring the ring gauge orientated with its axis orthogonal to the ram axis with two opposing styli to establish the location error observed with this technique is also defined.

A.6 Procedure: Size and form test

a) Mount the test ring gauge on the CMM with its axis aligned with the ram axis of the machine.

b) Qualify the stylus according to the manufacturer's standard procedures.

c) Establish the direction of the axis of the test ring gauge as per the method used in the calibration of the test ring gauge if available. Otherwise measure the bore of the test ring gauge as an unconstrained least-squares cylinder fit in order to establish its axis direction.

   NOTE The front face of the test ring gauge is an example of the definition of the vector of the axis used by some calibration organisations.

d) Using the established axis, scan a circle in the test ring gauge at one of the calibrated heights using the manufacturer's specified speeds.

e) Evaluate an unconstrained least-squares circle fit to the measured points projected into a plane perpendicular to the axis established ensuring that D_{meas} is compensated by the effective tip diameter or tip correction vectors. The size error, $P_{Size.Cir.Scan:\mathit{k}.0:Tact}$, is obtained from the difference between the measured diameter of the test ring gauge, D_{meas}, and the calibrated diameter, D_{cal}, as follows:

$$P_{Size.Cir.Scan:\mathit{k}.0:Tact} = D_{meas} - D_{cal}$$

where k is replaced with PP or NPP as applicable.

f) Record the range of radii of the corrected measured points with respect to the least-squares ring gauge centre, i.e. $R_{max} - R_{min}$, the apparent test ring gauge form giving the ring gauge form error, $P_{Form.Cir.Scan:\mathit{k}.0:Tact}$, where k is replaced with PP or NPP as applicable.

g) If desired, mount the test ring gauge with its axis perpendicular to the ram axis of the machine. The user is free to choose the direction of the ring gauge axis in the plane orthogonal to the ram axis.

h) Qualify the offset stylus according to the manufacturer's standard procedures.

i) Establish the direction of the axis of the test ring gauge as per the method used in the calibration of the test ring gauge if available. Otherwise, measure the bore of the test ring gauge as an unconstrained least-squares cylinder fit in order to establish its axis direction.

j) Scan a circle in the test ring gauge at one of the calibrated heights using the manufacturer's specified speeds.

k) Evaluate an unconstrained least-squares circle fit to the measured points projected into a plane perpendicular to the axis established ensuring that D_{meas} is compensated by the effective tip diameter or tip correction vectors.

l) The size error, $P_{\text{Size.Cir.Scan:}k\text{.150:Tact}}$, is obtained from the difference between the measured diameter of the ring gauge, D_{meas}, and the calibrated diameter, D_{cal}, as follows:

$$P_{\text{Size.Cir.Scan:}k\text{.150:Tact}} = D_{\text{meas}} - D_{\text{cal}}$$

where k is replaced with PP or NPP as applicable.

m) Record the range of radii of the corrected measured points with respect to the least-squares ring gauge centre, i.e. $R_{\text{max}} - R_{\text{min}}$, the apparent test ring gauge form giving the ring gauge form error, $P_{\text{Form.Cir.Scan:}k\text{.150:Tact}}$, where k is replaced with PP or NPP as applicable.

A.7 Procedure: Opposing styli projected location

a) Mount the test ring gauge on the CMM with its axis perpendicular to the ram axis of the machine, aligned with one of the other two axes of the machine — the user is free to choose either of the two orientations.

b) Qualify two opposing styli according to the manufacturer's standard procedures.

c) Using the first orientation stylus, establish the direction of the axis of the test ring gauge as per the method used in the calibration of the test ring gauge, if available. Otherwise, measure the bore of the test ring gauge as an unconstrained least-squares cylinder fit in order to establish its axis direction.

d) Using the established axis, scan a circle in the test ring gauge at one of the calibrated heights using the manufacturer's specified speeds.

e) Project the measured points into a plane which is orthogonal to the established axis and nominally passes through the measured points.

f) Evaluate an unconstrained least-squares circle fit to the projected points.

g) Using the opposing stylus and using the established axis, scan the same circle in the test ring gauge using the manufacturer's specified speeds.

h) Using the established projection plane from the first circle scan, project the "opposing stylus" set of measured points into the same plane.

i) Evaluate an unconstrained least-squares circle fit to the "opposing stylus" projected points.

j) Calculate the distance between the two least-squares circle centres to give the opposing-styli projected location error on a ring gauge, $L_{\text{Dia.Proj.Cir.Scan:}j\text{:Tact}}$, where j is replaced with MS, MP, Emp or Inf as applicable.

A.8 Conformance with specification

For size evaluations, the uncertainty, including the difference between the calibration measurand and the test measurand, shall be accounted for in the test value uncertainty.

For form evaluations, unless the manufacturer has explicitly stated that the imperfect form of the test ring gauge is not a rated operating condition, the test ring gauge calibrated form and its calibration uncertainty are included as rated operating conditions, and thus accounted for in the MPE specifications, to eliminate the need to include their effects in test value uncertainty.

The following points apply:

a) When relevant, the ring gauge performance aligned to the ram is verified if

1) the measured ring gauge form, $P_{\text{Form.Cir.Scan:}k\text{.0:Tact}}$, is not greater than the relevant maximum permissible ring gauge form error, $P_{\text{Form.Cir.Scan:}k\text{.0:Tact,MPE}}$, as specified and taking into account the test value uncertainty;

2) the absolute value of the measured ring gauge size error, $P_{\text{Size.Cir.Scan:}k\text{.0:Tact}}$, is not greater than the relevant maximum permissible ring gauge size error, $P_{\text{Size.Cir.Scan:}k\text{.0:Tact:MPE}}$, as specified and taking into account the test value uncertainty;

where k is replaced with PP or NPP as applicable.

b) When relevant, the ring gauge performance orthogonal to the ram is verified if

1) the measured ring gauge form, $P_{\text{Form.Cir.Scan:}k\text{.150:Tact}}$, is not greater than the relevant maximum permissible ring gauge form error, $P_{\text{Form.Cir.Scan:}k\text{.150:Tact,MPE}}$, as specified and taking into account the test value uncertainty;

2) the absolute value of the measured ring gauge size error, $P_{\text{Size.Cir.Scan:}k\text{.150:Tact}}$, is not greater than the relevant maximum permissible ring gauge size error, $P_{\text{Size.Cir.Scan:}k\text{.150:Tact:MPE}}$, as specified and taking into account the test value uncertainty;

where k is replaced with PP or NPP as applicable.

c) When relevant, the opposing styli ring gauge location performance is verified if

1) the measured opposing styli ring gauge location, $L_{\text{Dia.Proj.Cir.Scan:}j\text{:Tact}}$, is not greater than the relevant maximum permissible opposing styli ring gauge location, $L_{\text{Dia.Proj.Cir.Scan:}j\text{:Tact:MPE}}$ as specified and taking into account the test value uncertainty;

where j is replaced with MS, MP, Emp or Inf as applicable.

Annex B
(informative)

Checking the probing system prior to the ISO 10360-2 test

B.1 ISO 10360-2:2009, 6.3.1 recommends that the tests in this document be run prior to beginning the extensive testing described in ISO 10360-2, to ensure that the probing system is operating within specifications. For each tip required to perform the testing in ISO 10360-2, perform the following routine.

B.2 Run the Single-stylus probing test (6.3), and check that $P_{\text{Form.Sph.1×25:SS:Tact}}$ and $P_{\text{Size.Sph.1×25:SS:Tact}}$ are within specification.

B.3 Repeat B.2 as necessary until a satisfactory result is obtained for all relevant tips, before starting the ISO 10360-2 tests.

B.4 Until the ISO 10360-2 test is verified, performing the multi-stylus test is not advised - this reflects the multi-stylus test's sensitivity to machine geometry errors which is checked in ISO 10360-2, see C.2.

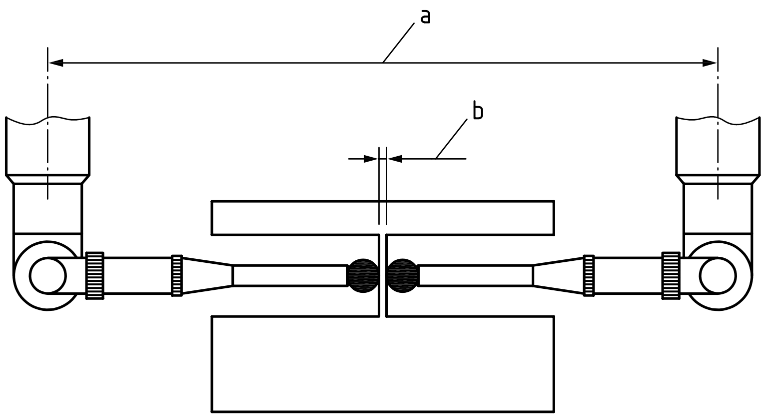
Annex C
(informative)

Interpretation of multi-stylus test results

C.1 Comparison of the multi-stylus test results with ISO 10360-2 results

In ISO 10360-2, each length measurement is made with a single stylus in a single orientation. Therefore, the net distance moved by the CMM in making each measurement is similar to the length measured.

Consequently, the length measuring errors found are typically a function of the measured length, with shorter lengths usually experiencing smaller errors. However, in this document, most of the measurements are made by CMMs with multiple styli. When multiple styli are used on a workpiece, the net distance moved by the CMM when measuring a short length is not necessarily small, see Figure C.1.



Key

a CMM travel distance

b measured length

Figure C.1 — Example of measurement where the measured length is small compared to the CMM travel distance

Therefore, the measuring errors when using multiple styli are not necessarily within the limits defined for the measured length per ISO 10360-2. Closely adjacent features which are measured with different styli may have large errors between them. Also, multiple styli tend to be associated with significant lengths of probe-tip-offset length. These offset lengths may increase the measuring errors, as may be seen by comparing the “Length measurement error with minimal probe-tip-offset length” and the “Length measurement error with probe-tip-offset length L”.

C.2 Influence of the distance, L_P, between reference sphere and test sphere

Due to the geometry errors (including imperfect error compensation) of the CMM, the distance between reference and test sphere can strongly influence the test result. When this distance is small, many repeatable CMM errors are corrected/compensated by the qualification procedure and hence the probing system performance may become dominant. When this distance is large, the geometry errors may become dominant.

Both tests are relevant to workpiece measurement.

The specifications for a small distance (L_P) represent the performance of the system when measuring small features close to the location of the reference sphere.

The specifications for a large distance (L_P) represent the performance of the system when measuring small features remote from the location of the reference sphere.

In addition, the test results with small distances may also be the preferred test for comparing the multi-stylus probing performance of different probing systems on a CMM, since it is not dominated by the repeatable geometry errors of the CMM.

For the scanning mode test on a sphere, the placement of the test sphere away from the reference sphere in both the XY plane and Z has the effect of showing stiffness variation in the machine which may increase the observed errors. Setting the distance to something similar to what is likely to be seen in normal use of the machine between the reference sphere location and the point of use of the probe might give the user an estimate of the performance likely to be observed in practice.

Annex D
(normative)

Maximum permissible error/limit specification methods

The maximum permissible value of the multi-stylus form, size, and location error and the opposing-styli projected location errors, $P_{\text{Form.Sph.5×25:}j\text{:Tact,MPE}}$, $P_{\text{Size.Sph.5×25:}j\text{:Tact,MPE}}$, $L_{\text{Dia.5×25:}j\text{:Tact,MPE}}$, $L_{\text{Dia.Proj.Sph.2×25:}j\text{:Tact,MPE}}$ and $L_{\text{Dia.Proj.Cir.Scan:}j\text{:Tact,MPE}}$, can be expressed in one of three forms:

a) = minimum of $(A + L_P/K)$ and B; or

b) = $(A + L_P/K)$; or

c) = B

where

- A is a positive constant, expressed in micrometres and supplied by the manufacturer;
- K is a dimensionless positive constant supplied by the manufacturer;
- L_P is the distance in 3D between the centres of the reference sphere and the test sphere, in millimetres;
- B is the maximum permissible error, in micrometres, as stated by the manufacturer.

See Figures D.1, D.2 and D.3.

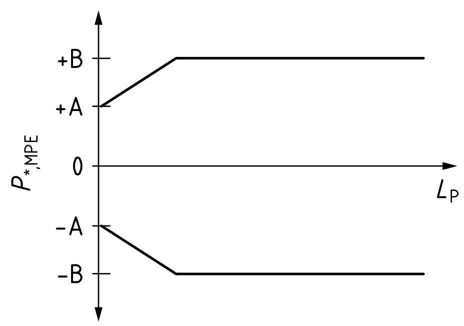


Figure D.1 — Maximum permissible error, $P_{*,\text{MPE}}$

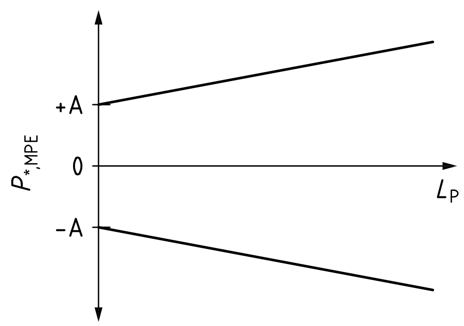


Figure D.2 — Maximum permissible error, $P_{*,\text{MPE}}$

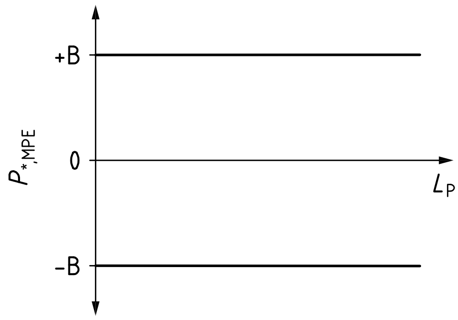


Figure D.3 — Maximum permissible error, $P_{*,\ MPE}$

NOTE 1 Some MPEs are positive only (e.g. for form and location).

NOTE 2 The figures in Annex D apply to $L_{*,MPE}$ as well as $P_{*,MPE}$.

Annex E
(informative)

Workpiece related influences

The relationship between CMM probing specifications (the MPEs), and the accuracy of measurements on workpieces is often of significant interest to CMM users. This Annex briefly describes this issue.

The CMM performance specifications in this document are limits on the test results typically performed on nearly geometrically perfect test artefacts, for example highly spherical test spheres. One advantage of this type of test artefact is that it is readily obtainable and can be calibrated with a small uncertainty at a relatively low cost. It is important to note that because of the high degree of geometrical perfection, the diameter and centre location can be accurately determined using only 5 points in the absence of any CMM or probing errors.

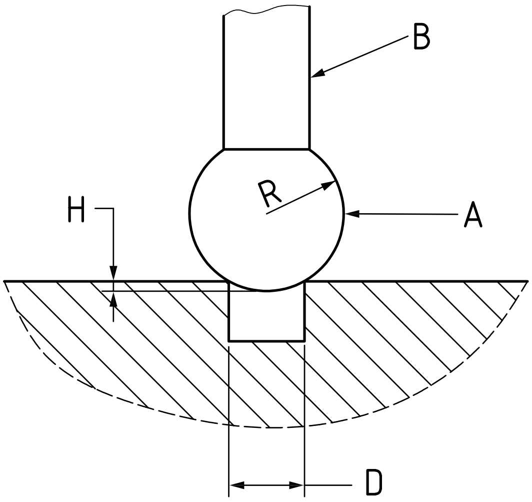
In contrast, real workpieces have machined surfaces that can include roughness, waviness, chatter marks, porosity, burrs, scratches, warpage, different lubricity, and other undesirable surface irregularities. The geometrical and dimensional controls on the workpiece surface, as specified by the engineering drawing, require that all or some of these irregularities be within their respective tolerance zones for a conforming workpiece.

Consequently, real workpieces require a dense set of probing points to determine the coordinates of points on the irregular surface so that it can be fully characterized before conformance to the engineering drawing can be determined. Hence, it should be noted that the small number, for example 25 or 125 probing points used in the tests of this standard to demonstrate conformance to MPE specifications will generally be vastly insufficient to obtain a similar accuracy on actual workpieces.

The probing form specifications in this document ($P_{\mathrm{Form.*,MPE}}$), have additional complexities relative to the measurement of form as specified on an engineering drawing. The need for a dense set of measurement points on the workpiece surface is particularly important for workpiece form measurements because the measurement result will be determined by the most extreme surface irregularities, and these irregularities must be measured in order to characterise the surface. Additionally, the stylus tip size is a significant morphological filter of the workpiece surface, i.e. the stylus tip cannot probe the bottom of a small pit, or scratch on the surface. Hence, a contact probing system has a type of asymmetric behaviour with regard to surface irregularities. It can easily contact, and hence measure, the dimensional characteristics of a convex flaw such as a bump or burr but cannot contact a concave irregularity such as a small pit or dig. This filtering effect is not assessed in the probing tests of this document because the test spheres are almost geometrically perfect and so do not contain concave irregularities. The CMM user is advised to consider the effect of the stylus morphological filter prior to verifying conformity of a workpiece to its form specification given on an engineering drawing. Fortunately, the stylus morphological filter effect is entirely geometrical in nature and the extent that a stylus tip can physically probe the bottom of a concave feature can be calculated entirely by geometry and so its effect can be known without experimental testing see Figure E.1.

Additional tests may be carried out by the CMM user which determine the performance of the CMM used in scanning mode for the measurement tasks to be carried out. A method applicable in most cases is to compare the results of a measurement in a scanning mode with the results from a measurement in discrete point probing on the same workpiece.

The parameters used in scanning mode (for example scanning speed, data density, filter settings) should correspond to those defined in advance and be appropriate for the workpiece under consideration. It is particularly important that this test include the scanning of discontinuities (for example an internal corner) if these occur in practice.



Key

A stylus tip

B stylus

R stylus tip radius

D width of feature

H depth of the feature perceived by the probing system

Figure E.1 — Depth of a feature perceived by the probing system

Where D < 2R, the depth of the feature perceived by the probing system (H) is given by:

$$H = R - \sqrt{R^2 - \left(\frac{D}{2}\right)^2}$$

When the width of the feature is small in relation to the probe tip radius, the depth can be approximated by:

$$H = \frac{D^2}{8R}$$

Annex F
(normative)

Acceptance tests and reverification tests using small sphere test equipment

F.1 General

Only for small probing systems where the probe configuration to be tested is unable to achieve suitable coverage of the test spheres described in 6.2 without collisions with the test sphere, the following alternative shall be employed if specified. All other testing procedures and data analysis shall be that of Clause 6 except as explicitly described in this Annex. Specifications shown on a data sheet that use the procedures and equipment of this Annex shall use the notation of Clause 4 replacing "$_{\mathrm{Sph}}$" with "$_{\mathrm{SmSp}}$" (small sphere).

F.2 Small sphere single-stylus and multi-stylus test

The standard minimum 10 mm diameter sphere used for both single-stylus and multi-stylus tests shall be replaced with a smaller test sphere with a diameter between 1 mm and 5 mm. Run the relevant tests in 6.3, 6.5 and 6.6.

F.3 Small sphere scanning mode test

Table F.1 provides the requirements for the small sphere scanning test. The adapted test conditions of Table F.1 do not allow comparability of the scanning test results with those obtained in 6.4. We do not evaluate $\tau_{\mathrm{SmSp.Scan:}k\mathrm{:Tact}}$ for the small sphere test because the scanned distance and the distance to intermediate points are significantly different with this small sphere scanning mode test.

Run the test in 6.4 but with the adapted test conditions in Table F.1.

Table F.1 — Adapted test conditions for small sphere scanning test

Test condition qualifier	Test condition value
Stylus tip diameter	3 mm or less; to be stated by the manufacturer
Test sphere nominal diameter	2 mm
Target scan plane location (see 6.4.2.3)	Target scan plane A and target scan plane B are parallel planes 0,64 mm apart. Target scan plane D is a plane 0,64 mm from the pole. For this small sphere scanning mode test, a value of 0° is chosen for α. Planes C and D shall be rotated 45° about E in Figure 3 such that they lie at 45° to the X and Y axes of the machine when viewed from above.
Maximum allowed Cartesian distance between consecutive corrected measured points	0,01 mm
Maximum allowed normal distance of the corrected measured points from the relevant target scan plane	0,1 mm
Minimum distance of the intermediate points to the test sphere	0,8 mm

Annex G
(informative)

Relation to the GPS matrix model

G.1 General

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

G.2 Information about this document and its use

This document specifies the verification methods for proving conformance of coordinate measuring machines with the specified MPEs. The tests given in this document are:

— applicable to CMMs using contacting probing systems; and

— performed in addition to the length measuring tests given in ISO 10360-2.

When relevant, they are:

a) applicable to CMMs capable of using multiple styli, multiple probes, or multiple articulated probe positions, in discrete point and/or scanning mode;

b) designed to provide information about the ability of a CMM to measure a feature or features using single stylus, multiple styli, multiple probes, or multiple articulated probe positions.

G.3 Position in the GPS matrix model

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

Table G.1 — Position in the GPS matrix model

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

G.4 Related standards

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

Bibliography

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

[2] ISO 10360-4:2000, *Geometrical Product Specifications (GPS) — Acceptance and reverification tests for coordinate measuring machines (CMM) — Part 4: CMMs used in scanning measuring mode*

[3] ISO 10360-7, *Geometrical product specifications (GPS) — Acceptance and reverification tests for coordinate measuring machines (CMM) — Part 7: CMMs equipped with imaging probing systems*

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

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

[6] ISO 14253 (all parts), *Geometrical product specifications (GPS) — Inspection by measurement of workpieces and measuring equipment*

[7] ISO 14638:2015, *Geometrical product specifications (GPS) — Matrix model*

[8] ISO/TS 17865, *Geometrical product specifications (GPS) — Guidelines for the evaluation of coordinate measuring machine (CMM) test uncertainty for CMMs using single and multiple stylus contacting probing systems*

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

(Continued from second cover)

In this adopted standard, references appear to the following International Standards for which Indian Standards also exist. The corresponding Indian Standards which are to be substituted in their respective places are listed below along with their degree of equivalence for the editions indicated:

International Standard	*Corresponding Indian Standard*	*Degree of Equivalence*
ISO 10360-1 Geometrical product specifications (GPS) — Acceptance and reverification tests for coordinate measuring machines (CMM) — Part 1: Vocabulary	IS 15635 (Part 1) : 2006/ ISO 10360-1 : 2000 Geometrical product specifications (GPS) — Acceptance and reverification tests for coordinate measuring machines (CMM): Part 1 Vocabulary	Identical
ISO 10360-2 Geometrical product specifications (GPS) — Acceptance and reverification tests for coordinate measuring machines (CMM) — Part 2: CMMs used for measuring linear dimensions	IS 15635 (Part 2) : 2014/ ISO 10360-2 : 2009 Geometrical product specifications (GPS) — Acceptance and reverification tests for coordinate measuring machines (CMM): Part 2 CMMs used for measuring linear dimensions (*first revision*)	Identical
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	IS 15371 (Part 1) : 2023/ ISO 14253-1 : 2017 Geometrical product specifications (GPS) — Inspection by measurement of workpieces and measuring equipment: Part 1 Decision rules for verifying conformity or nonconformity with specifications (*first revision*)	Identical
ISO/IEC Guide 99 : 2007 International vocabulary of metrology — Basic and general concepts and associated terms (VIM)	IS/ISO/IEC Guide 99 : 2007 International vocabulary of metrology — Basic and general concepts and associated terms (VIM)	Identical

In reporting the result of a test or analysis made in accordance with this standard, if the final value, observed or calculated, is to be rounded off, it shall be done in accordance with IS 2 : 2022 'Rules for rounding off numerical values (*second revision*)'.

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