INTERNATIONAL STANDARD

ISO 10360-10

First edition
2016-04-15

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

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

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

Partie 10: Laser de poursuite pour mesurer les distances de point à point

Reference number
ISO 10360-10:2016(E)

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Foreword

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

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

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

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

For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT), see the following URL: Foreword — Supplementary information.

The committee responsible for this document is ISO/TC 213, *Dimensional and geometrical product specifications and verification*.

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

— *Part 1: Vocabulary*

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

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

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

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

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

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

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

— *Part 8: CMMs with optical distance sensors*

— *Part 9: CMMs with multiple probing systems*

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

The following part is under preparation:

— *Part 12: Articulated-arm CMMs*

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

Introduction

This part of ISO 10360 is a geometrical product specification (GPS) standard and is to be regarded as a general GPS standard (see ISO 14638). It influences link F of the chains of standards on size, distance, radius, angle, 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 part of ISO 10360 and the default decision rules given in ISO 14253-1 apply to specifications made in accordance with this part of ISO 10360, unless otherwise indicated.

More detailed information on the relation of this part of ISO 10360 to other standards and the GPS matrix model can be found in Annex I.

The objective of this part of ISO 10360 is to provide a well-defined testing procedure for a) laser tracker manufacturers to specify performance by maximum permissible errors (MPEs), and b) to allow testing of these specifications using calibrated, traceable test lengths, test spheres, and flats. The benefits of these tests are that the measured result has a direct traceability to the unit of length, the metre, and that it gives information on how the laser tracker will perform on similar length measurements.

This part of ISO 10360 is ***distinct*** from that of ISO 10360-2, which is for coordinate measuring machines (CMMs) equipped with contact probing systems, in that the orientation of the test lengths reflect the different instrument geometry and error sources within the instrument.

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

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

1 Scope

This part of ISO 10360 specifies the acceptance tests for verifying the performance of a laser tracker by measuring calibrated test lengths, test spheres and flats according to the specifications of the manufacturer. It also specifies the reverification tests that enable the user to periodically reverify the performance of the laser tracker. The acceptance and reverification tests given in this part of ISO 10360 are applicable only to laser trackers utilizing a retro-reflector as a probing system. Laser trackers that use interferometry (IFM), absolute distance meter (ADM) measurement, or both can be verified using this part of ISO 10360. This part of ISO 10360 can also be used to specify and verify the relevant performance tests of other spherical coordinate measurement systems that use cooperative targets, such as “laser radar” systems.

NOTE Systems, such as laser radar systems, which do not track the target, will not be tested for probing performance.

This part of ISO 10360 does not explicitly apply to measuring systems that do not use a spherical coordinate system (i.e. two orthogonal rotary axes having a common intersection point with a third linear axis in the radial direction). However, the parties can apply this part of ISO 10360 to such systems by mutual agreement.

This part of ISO 10360 specifies

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

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

— rules for proving conformance, and

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

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

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

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

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
laser tracker
coordinate measuring system in which a cooperative target is followed with a laser beam and its location determined in terms of a distance (range) and two angles

Note 1 to entry: The two angles are referred to as azimuth, θ (rotation about a vertical axis – the standing axis of the laser tracker) and elevation, φ (angle above a horizontal plane – perpendicular to the standing axis).

3.2
interferometric measurement mode
IFM mode
measurement method that uses a laser displacement interferometer integrated in a *laser tracker* (3.1) to determine distance (range) to a target

Note 1 to entry: Displacement interferometers can only determine differences in distance, and therefore require a reference distance (e.g. home position).

3.3
absolute distance measurement mode
ADM mode
measurement method that uses time of flight instrumentation integrated in a *laser tracker* (3.1) to determine the distance (range) to a target

Note 1 to entry: Time of flight instrumentation may include a variety of modulation methods to calculate the distance to the target.

3.4
retroreflector
passive device designed to reflect light back parallel to the incident direction over a range of incident angles

Note 1 to entry: Typical retroreflectors are the cat's-eye, the cube corner, and spheres of special material.

Note 2 to entry: Retroreflectors are cooperative targets.

Note 3 to entry: For certain systems, e.g. laser radar, the retroreflector might be a cooperative target such as a polished sphere.

3.5
spherically mounted retroreflector
SMR
retroreflector (3.4) that is mounted in a spherical housing

Note 1 to entry: In the case of an open-air cube corner, the vertex is typically adjusted to be coincident with the sphere centre.

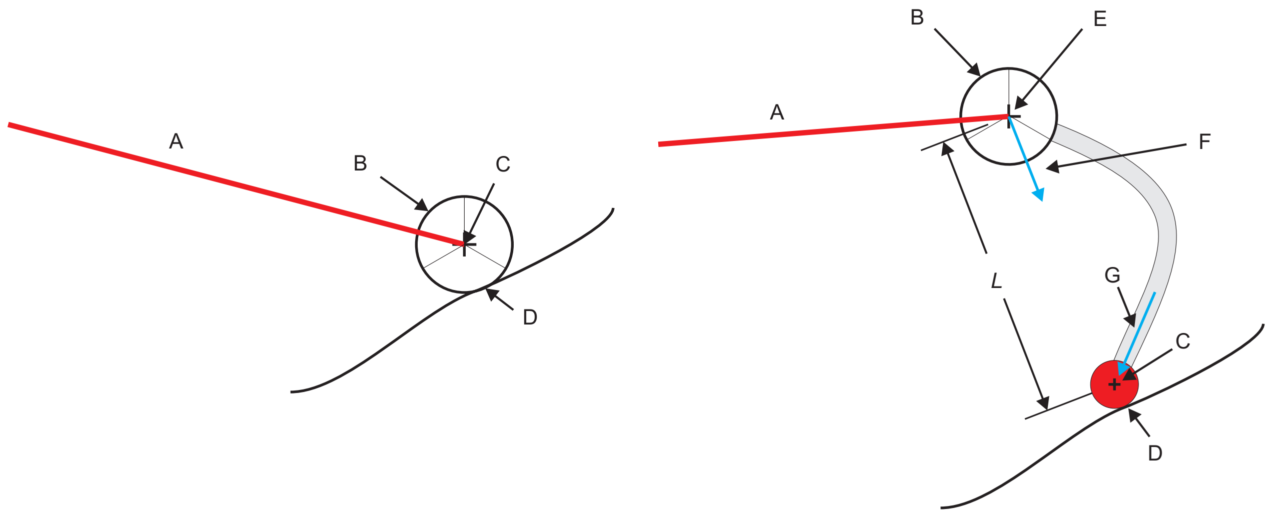
Note 2 to entry: The tests in this part of ISO 10360 are typically executed with a spherically mounted retroreflector.

Note 3 to entry: See Figure 1.

3.6
stylus and retroreflector combination
SRC
probing system that determines the measurement point utilizing a probe stylus to contact the workpiece, a *retroreflector* (3.4) to determine the base location of the probe, and other means to find the stylus orientation unit vector

Note 1 to entry: The datum for the stylus tip offset (L) is the centre of the retroreflector.

Note 2 to entry: See Figure 1.



a) SMR

b) SRC

Key

A laser beam
B retroreflector
C measurement point
D contact point
E base location
F stylus orientation unit vector
G normal probing direction vector
L stylus tip offset

Figure 1 — Representation of SMR vs. SRC

3.7
optical distance sensor and retroreflector combination
ODR
probing system that determines the measurement point utilizing an optical distance sensor to measure the workpiece, a *retroreflector* (3.4) to determine the base location of the optical distance sensor, and other means to find the orientation of the optical distance sensor

3.8
target nest
nest
device designed to repeatably locate an SMR

3.9
length measurement error
$E_{\mathrm{Uni:L:LT}}$
$E_{\mathrm{Bi:L:LT}}$
error of indication when performing a unidirectional ($E_{\mathrm{Uni:L:LT}}$) or bidirectional ($E_{\mathrm{Bi:L:LT}}$) point-to-point distance measurement of a calibrated test length using a laser tracker with a stylus tip offset of L

Note 1 to entry: $E_{\mathrm{Uni:0:LT}}$ and $E_{\mathrm{Bi:0:LT}}$ (used frequently in this part of ISO 10360) correspond to the common case of no stylus tip offset, as the retroreflector optical centre coincides with the physical centre of the probing system for spherically mounted retroreflectors.

3.10
normal CTE material
material with a coefficient of thermal expansion (CTE) between $8 \times 10^{-6}/\ °C$ and $13 \times 10^{-6}/\ °C$

[SOURCE: ISO 10360-2:2009]

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

3.11
probing form error
$P_{\text{Form.Sph.1x25::SMR.LT}}$
error of indication within which the range of Gaussian radial distances can be determined by a least-squares fit of 25 points measured by a *laser tracker* (3.1) on a spherical material standard of size

Note 1 to entry: Only one least-squares fit is performed, and each point is evaluated for its distance (radius) from this fitted centre.

3.12
probing size error
$P_{\text{Size.Sph.1x25::SMR.LT}}$
error of indication of the diameter of a spherical material standard of size as determined by a least-squares fit of 25 points measured with a *laser tracker* (3.1)

3.13
location error
two-face error
plunge and reverse error

$L_{\text{Dia.2x1:P\&R:LT}}$
the distance, perpendicular to the beam path, between two measurements of a stationary *retroreflector* (3.4), where the second measurement is taken with the *laser tracker* (3.1) azimuth axis at approximately 180° from the first measurement and the laser tracker elevation angle is approximately the same

Note 1 to entry: This combination of axis rotations is known as a *two face*, or *plunge and reverse*, test.

Note 2 to entry: The laser tracker base is fixed during this test.

3.14
maximum permissible error of length measurement
$E_{\text{Uni:L:LT,MPE}}$
$E_{\text{Bi:L:LT,MPE}}$
extreme value of the length measurement error, $E_{\text{Bi:L:LT}}$ or $E_{\text{Uni:L:LT}}$, permitted by specifications

Note 1 to entry: $E_{\text{Bi:0:LT,MPE}}$ and $E_{\text{Uni:0:LT,MPE}}$ are used throughout this part of ISO 10360.

3.15
maximum permissible error of probing form
$P_{\text{Form.Sph.1x25::SMR.LT,MPE}}$
extreme value of the *probing form error* (3.11), $P_{\text{Form.Sph.1x25::SMR.LT}}$, permitted by specifications

3.16
maximum permissible error of probing size
$P_{\text{Size.Sph.1x25::SMR.LT,MPE}}$
extreme value of the *probing size error* (3.12), $P_{\text{Size.Sph.1x25::SMR.LT}}$, permitted by specifications

3.17
maximum permissible error of location
$L_{\text{Dia.2x1:P\&R:LT,MPE}}$
extreme value of the location error, $L_{\text{Dia.2x1:P\&R:LT}}$, permitted by specifications

3.18
rated operating condition
operating condition that must be fulfilled, according to specification, during measurement in order that a measuring instrument or measuring system performs as designed

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

Note 2 to entry: Within this part of ISO 10360, the term “as designed” in the definition means “as specified by MPEs”.

Note 3 to entry: When the rated operating conditions are not met in a test according to this part of ISO 10360, neither conformance nor non-conformance to specifications can be determined.

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

4 Symbols

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

Table 1 — Symbols of specification quantities

Symbol	Meaning
$E_{\text{Uni:L:LT}}$ $E_{\text{Bi:L:LT}}$	Length measurement error (Uni- or Bi-directional lengths) where L is the stylus tip offset
$P_{\text{Form.Sph.1×25::SMR.LT}}$ $P_{\text{Form.Sph.1×25::SRC.LT}}$ $P_{\text{Form.Sph.1×25::ODR.LT}}$	Probing form error for SMR, SRC or ODR operation mode
$P_{\text{Size.Sph.1×25::SMR.LT}}$ $P_{\text{Size.Sph.1×25::SRC.LT}}$ $P_{\text{Size.Sph.1×25::ODR.LT}}$	Probing size error for SMR, SRC or ODR operation mode
$L_{\text{Dia.2×1:P\&R:LT}}$	Location error (from two face tests)
$E_{\text{Uni:L:LT,MPE}}$ $E_{\text{Bi:L:LT,MPE}}$	Maximum permissible error of length measurement where L is the stylus tip offset
$P_{\text{Form.Sph.1×25::SMR.LT,MPE}}$	Maximum permissible error of probing form
$P_{\text{Size.Sph.1×25::SMR.LT,MPE}}$	Maximum permissible error of probing size
$L_{\text{Dia.2×1:P\&R:LT,MPE}}$	Maximum permissible error of location (from two face tests)
	Accessory sensor testing – SRC
Symbol	**Meaning**
$P_{\text{Form.Sph.1×25::SRC.LT}}$	Probing form error for SRC
$P_{\text{Size.Sph.1×25::SRC.LT}}$	Probing size error for SRC
$P_{\text{Dia.15×1::SRC.LT}}$	Orientation error for SRC
$P_{\text{Form.Sph.1×25::SRC.LT,MPE}}$	Maximum permissible error of probing form for SRC
$P_{\text{Size.Sph.1×25::SRC.LT,MPE}}$	Maximum permissible error of probing size for SRC
$P_{\text{Dia.15×1::SRC.LT,MPE}}$	Maximum permissible error of orientation for SRC
	Accessory sensor testing – ODR
Symbol	**Meaning**
$P_{\text{Form.Sph.1×25::ODR.LT}}$	Probing form error for ODR (25 points)
$P_{\text{Form.Sph.D95\%::ODR.LT}}$	Probing form error for ODR (95 % of the points)
$P_{\text{Size.Sph.1×25::ODR.LT}}$	Probing size error for ODR (25 points)

Table 1 *(continued)*

Symbol	Meaning
$P_{\text{Size.Sph.All::ODR.LT}}$	Probing size error for ODR (all points)
$E_{\text{Form.Pla.D95\%::ODR.LT}}$	Flat form error of measurement with ODR (95 % of the points)
$P_{\text{Form.Sph.1×25::ODR.LT,MPE}}$	Maximum permissible error of probing form for ODR (25 points)
$P_{\text{Form.Sph.D95\%::ODR.LT,MPE}}$	Maximum permissible error of probing form for ODR (95 % of the points)
$P_{\text{Size.Sph.1×25::ODR.LT,MPE}}$	Maximum permissible error of probing size for ODR (25 points)
$P_{\text{Size.Sph.All::ODR.LT,MPE}}$	Maximum permissible error of probing size for ODR (all points)
$E_{\text{Form.Pla.D95\%::ODR.LT,MPE}}$	Maximum permissible error of flat form measurement with ODR (95 % of the points)
	Multiple sensor testing
Symbol	**Meaning**
$P_{\text{Form.Sph.}n\text{×25::MPS.LT}}$	Multiple probing system form error
$P_{\text{Size.Sph.}n\text{×25::MPS.LT}}$	Multiple probing system size error
$L_{\text{Dia.}n\text{×25::MPS.LT}}$	Multiple probing system location error
$P_{\text{Form.Sph.}n\text{×25::MPS.LT,MPE}}$	Maximum permissible multiple probing system form error
$P_{\text{Size.Sph.}n\text{×25::MPS.LT,MPE}}$	Maximum permissible multiple probing system size error
$L_{\text{Dia.}n\text{×25::MPS.LT,MPE}}$	Maximum permissible multiple probing system location error

NOTE 1 For the common case of length testing with an SMR, L will be equal to 0 (e.g. $E_{\text{Bi:0:LT}}$).

NOTE 2 The specific combinations of sensors for the multiple probing system errors depend on the sensors provided with the laser tracker system. The combination could be explicitly captured in the symbol, such as $P_{\text{Size.Sph.2x25:ODS,SMR:MPS.LT}}$ where the symbols indicating sensors are listed alphabetically.

NOTE 3 In the Multiple Sensor Testing entries, n (in n×25) is the number of sensors being involved (n≥2).

5 Rated operating conditions

5.1 Environmental conditions

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

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

— the user, in the case of reverification tests.

In both cases, the user is free to choose the environmental conditions under which the testing will be performed within the specified limits (Form 1 in Annex A is the recommended method for specifying these conditions).

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

5.2 Operating conditions

The conditions required by the manufacturer in order to meet the MPE specification shall be specified (as given, e.g. in a specification sheet).

In addition, the laser tracker shall be operated using the procedures given in the manufacturer's operating manual when conducting the tests given in Clause 6. Specific areas in the manufacturer's manual to be adhered to are, for example

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

b) machine compensation procedures,

c) cleaning procedures for retroreflector and nests,

d) SMR or SRC qualification,

e) location, type, and number of environmental sensors (i.e. "the weather station"), and

f) location, type, number of thermal workpiece sensors.

6 Acceptance tests and reverification tests

6.1 General

In the following

— acceptance tests are executed according to the manufacturer's specifications and procedures that are in compliance with this part of ISO 10360, and

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

If specifications permit, the laser tracker may be tested in an orientation other than the normal upright, vertical orientation. In every case, the azimuth and elevation angles will be oriented with respect to the laser tracker. The position and orientation of the test lengths with respect to the laser tracker shall be clearly defined before the tests begin. In general, the test lengths will not rotate with the laser tracker. However, the locations for probing and two-face tests will maintain a fixed relationship with respect to the laser tracker's standing axis (i.e. they will rotate with the laser tracker). For example, if the laser tracker is mounted with its standing axis horizontal, the "above" and "below" directions described in Table 2 and Table 3 will be parallel to the standing axis.

Where least-squares (Gaussian) fitting is used in the derivation of test results, this shall be an unconstrained fit to the data, unless constraints to the fitting are explicitly stated.

6.2 Probing size and form errors

6.2.1 Principle

The principle of this test procedure is to measure the size and form of a test sphere using 25 points probed with the SMR, SRC, or ODR. This subclause gives the specific testing procedure for using an SMR to collect the points. Refer to Annex G or Annex H for additional information about testing with the SRC or ODR sensors, respectively. A least-squares sphere fit of the 25 points is examined for the errors of indication for form and size. This analysis yields the form error, $P_{\text{Form.Sph.1x25::SMR.LT}}$, and the size error, $P_{\text{Size.Sph.1x25::SMR.LT}}$.

NOTE 1 Probing errors $P_{\text{Form.Sph.1x25::SMR.LT}}$ and $P_{\text{Size.Sph.1x25::SMR.LT}}$ do not apply to laser radar systems.

NOTE 2 These are tests of the laser tracker system's ability to locate individual points in space. These tests are not intended to check any of the specifications supplied by an SMR manufacturer, although errors in the SMR will influence the test results.

NOTE 3 When performing this test with a spherically mounted retroreflector (SMR), three types of errors in the SMR may influence the results of this test. If the sphere, within which the retroreflector is mounted, is out-of-round, this will influence the test result. Also, if the mirrored surfaces which comprise the retroreflector are not mutually orthogonal, or if their point of intersection is not coincident with the sphere centre, the test result will be affected.

6.2.2 Measuring equipment

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

NOTE It may be difficult to make measurements on smaller test spheres due to interference with the sphere mount.

6.2.3 Procedure

Mount the test sphere so that a full hemisphere may be probed. When a spherically mounted retroreflector is used for probing, the test sphere support should be oriented away from the laser tracker. For an SRC, the support should be located away from the normal probing direction.

The test sphere should be mounted rigidly to minimize errors due to bending.

NOTE 1 The normal probing direction for the SRC is along the stylus shaft of the SRC.

Measure and record 25 points. The points shall be approximately evenly distributed over at least a hemisphere of the test sphere. Their position 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 of the test sphere;

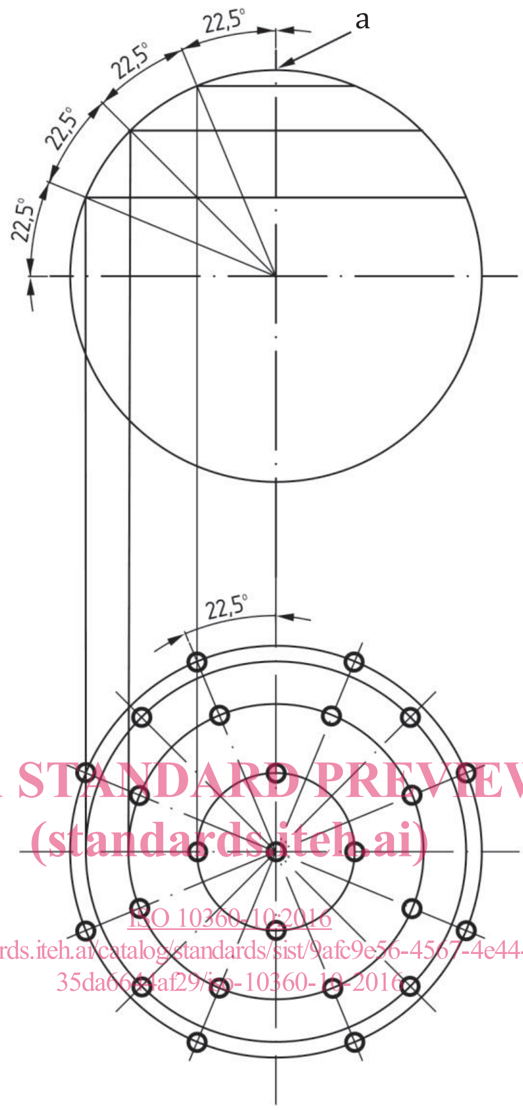
— four points (equally spaced) 22,5° below the pole;

— 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.

NOTE 2 Due to the manual nature of point measurement with laser trackers, it is recognized that the exact points recommended might not be measured.



a Pole – point on sphere opposite the support.

Figure 2 — Location of probing points

The results of these tests may be highly dependent on the distance of the retroreflector from the laser tracker, especially for the SRC and ODR sensors. Therefore, the test shall be performed at the required distances from the laser tracker, as indicated in Table 2.

Table 2 — Probe testing locations

Distance from the laser tracker	Required for these sensors	Height relative to the laser tracker centre of rotation
<2 m[a]	SMR, SRC, ODR	approximately same height
approximately 10 m	SRC, ODR	more than 1 m above or below

[a] Where a manufacturer's specifications explicitly state that an SRC or ODR sensor only performs at a distance greater than 2 m from the laser tracker, the test shall be performed at the minimum stated distance.

NOTE 3 The probe testing locations will have the same location and orientation relative to the laser tracker's standing axis if the laser tracker is not oriented vertically.

