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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
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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.

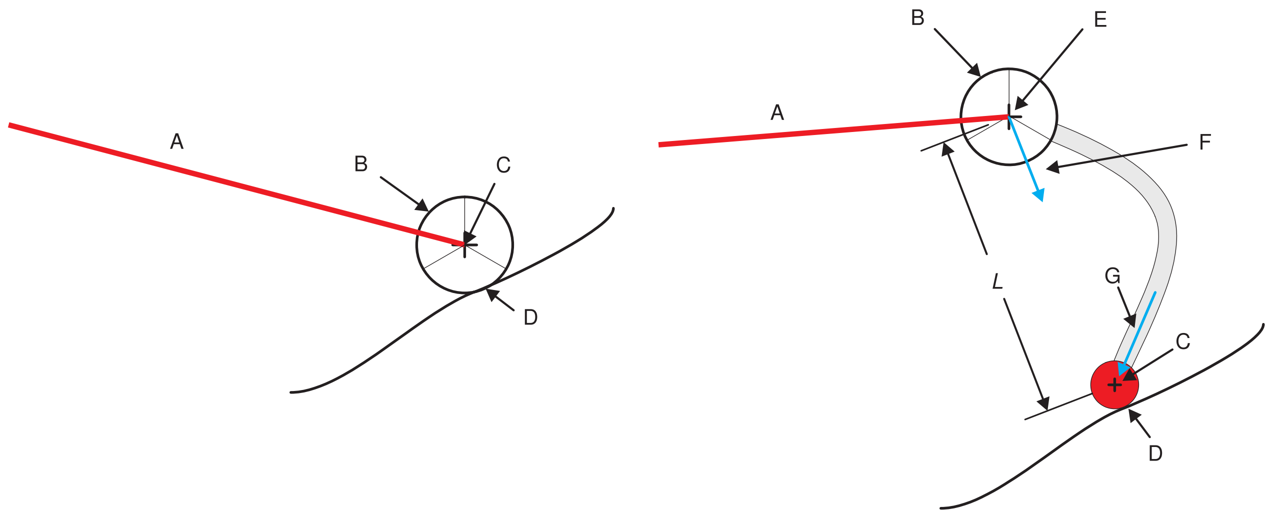
Note 2 to entry: The tests in this part of ISO 10360 are typically executed with a spherically mounted retroreflector.

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
$E_{\text{Uni:L:LT}}$
$E_{\text{Bi:L:LT}}$
error of indication when performing a unidirectional ($E_{\text{Uni:L:LT}}$) or bidirectional ($E_{\text{Bi:L:LT}}$) 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: $E_{\text{Uni:0:LT}}$ and $E_{\text{Bi:0:LT}}$ (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 × 10^{-6}/ °C and 13 × 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;

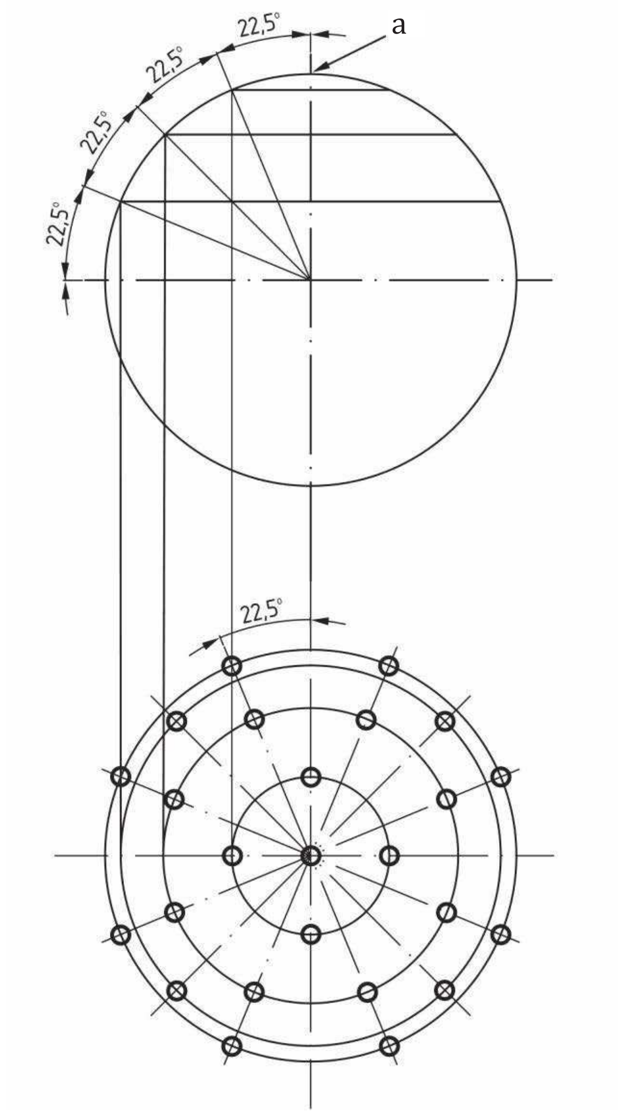
— four points (equally spaced) 22,5° below the pole;

— 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.

6.2.4 Derivation of test results

6.2.4.1 Size errors

Using all 25 measurements, compute the Gaussian associated sphere. Record the diameter of this sphere. The signed difference of this (measured) diameter from the calibrated (reference) diameter of the test sphere, i.e. $D_{\text{MEAS}} - D_{\text{REF}}$, is the probing size error, $P_{\text{Size.Sph.1x25::SMR.LT}}$ (for an SMR).

6.2.4.2 Form errors

For each of the 25 measurements, calculate the Gaussian radial distance, R, as the distance from the centre of the least-squares sphere to the measurement point. Record the range of these values, i.e. $R_{\text{max}} - R_{\text{min}}$, as the probing form error, $P_{\text{Form.Sph.1x25::SMR.LT}}$ (for an SMR).

6.3 Location errors (two-face tests)

6.3.1 Principle

The principle of this test procedure is to detect geometric errors of the laser tracker by measuring the location of a stationary retroreflector twice in different laser tracker configurations. These configurations are obtained by a) measuring in normal mode, then b) rotating the azimuth axis by approximately 180° and moving the elevation angle through the vertical to reacquire the retroreflector. The apparent distance, perpendicular to the laser beam, between the two measurements of the retroreflector yields the test result, $L_{\text{Dia.2x1:P\&R:LT}}$.

As these tests can be performed quickly, and will immediately reveal problems with the laser tracker geometry and its correction, it is recommended that these tests be performed first.

6.3.2 Measuring equipment

The equipment for this test is a target nest that is mounted rigidly at the positions required in Table 3.

6.3.3 Procedure

Mount the target nest so that the nest and its support will not interfere with measurement of the retroreflector.

Place the SMR in the nest, and measure the location of the SMR using the two angles and the range. Rotate both angular axes of the laser tracker by the appropriate angles and re-acquire the retroreflector. Measure this location of the retroreflector in the angles only, using the range value from the first measurement.

The target nest should be mounted rigidly to minimize uncertainty in the measurements.

The results of these tests may be highly dependent on the distance of the test sphere from the laser tracker, and influenced by the laser tracker's angular orientation. Therefore, these tests shall be performed at two distances from the laser tracker and at three different orientations, as indicated in Table 3. The distance from the laser tracker is the horizontal distance between the laser tracker and the retroreflector position, and the orientation angle is the nominal azimuth angle of the laser tracker when it is pointing at the retroreflector.

Table 3 — Two-face measurement positions

Position number	Distance from the laser tracker[a]	Description of the retroreflector position	Azimuth angle(s) with respect to the laser tracker in degrees[a]
1–3	1,5 m	Two-face test, retroreflector at least 1 m below the height of the laser tracker centre of rotation	0, 120, 240
4–6	1,5 m	Two-face test, retroreflector at height of the laser tracker centre of rotation	0, 120, 240
7–9	1,5 m	Two-face test, retroreflector at least 1 m above height of the laser tracker centre of rotation	0, 120, 240
10–12	6 m	Two-face test, retroreflector at least 1 m below height of the laser tracker centre of rotation	0, 120, 240
13–15	6 m	Two-face test, retroreflector at height of the laser tracker centre of rotation	0, 120, 240
16–18	6 m	Two-face test, retroreflector at least 1 m above height of the laser tracker centre of rotation	0, 120, 240

[a] The distance from the laser tracker should be within 10 % of the nominal distance, and azimuth angle within 5°.

NOTE The 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.

6.3.4 Derivation of test results

Calculate the location error relating the two measured locations. This distance between the two locations is the location error, $L_{\text{Dia.2x1:P\&R:LT}}$.

If the two measured locations correspond to (θ_1, φ_1, R_1) and (θ_2, φ_2, R_2) in spherical coordinates, the calculated location error relating the two locations is calculated as

$$L_{\text{Dia.2x1:P\&R:LT}} = R_1 \sqrt{(\varphi_1 - \varphi_2)^2 + \left[\left(\left| \theta_1 - \theta_2 \right| - \pi \right) \cos\varphi_1 \right]^2} \tag{1}$$

where θ and φ are the azimuth and elevation angles in radians, respectively. φ_1 and φ_2 are approximately equal, and θ_1 and θ_2 are approximately π radians (180 degrees) apart. Only the first range value, R_1, is used in the calculation of the location error, as this test is not intended to capture differences in the range values. Instruments using ADM range measurement will report the second range, R_2, while instruments using IFM range measurement will not.

NOTE 1 For this document, the elevation angle φ is zero at the horizontal.

NOTE 2 Although φ_1 and φ_2 are approximately equal, the instrument may report them as significantly different values (0,1 rad, and π – 0,1 rad) as they occur at different locations on the laser tracker's encoder.

NOTE 3 The subscript "Dia" in the symbol $L_{\text{Dia.2x1.P\&R.:LT}}$ refers to the diameter of the minimum circumscribing sphere containing the two reported locations. For two locations, this diameter is the distance between the locations.

6.4 Length errors

6.4.1 General

The tests of length measurement errors are comprised of 105 length measurements. Of these, 41 test length positions are mandatory and described in Table 4. The user is free to choose the remaining 64 test length positions. To assist the user in choosing these positions, two non-mandatory alternatives are provided.

NOTE Laser tracker usage may guide the user's choice as well (e.g. if the laser tracker is specified over a prismatic volume, alternative 2 described in 6.4.4.3 may be appropriate).

One or more formulae shall be specified by the manufacturer so that the MPE can be uniquely determined for any point-to-point measurement in the measuring volume. If more than one formula is specified, a rule shall be unambiguously stated so that it is always clear which formula is to be used. The form of the formulae is the choice of manufacturer. The manufacturer shall have a means of specifying the MPEs for the prescribed calibrated test lengths measured in the positions described in Table 4 of this part of ISO 10360.

For the purposes of comparing specifications, the MPEs for positions 1 to 35 and 41 shall be explicitly stated in a table such as shown in Annex A at the standoff distances indicated in Table 4 and a test length of 2,75 m, except for lengths 30 to 35 which shall be a length of 9 m. Where the standoff distance is "as close as practical," a distance of 0,5 m shall be used in computing the MPE.

For the purposes of testing, the calibrated test lengths may be within the ranges of length (i.e. 2,25 m to 2,75 m and 7 m to 9 m) stated in Table 4, and the MPEs used to determine conformance of the laser tracker will be recalculated based on the actual length of the test length used in the test.

The MPEs for positions 36 to 40 shall be stated as a formula in $A + (B/K)L$ form.

6.4.2 Principle

The length measurement errors describe the three-dimensional deviation behaviour of the laser tracker in the specified measuring volume. This deviation behaviour is caused by the superposition of different individual deviations such as uncorrected systematic deviations of the length measuring system and the angle encoders, random measuring deviations, geometric imperfections in the rotary axes and/or of the probing system. As the deviation behaviour depends, among other things, on the mode of operation, different values of the characteristics may result for different modes of operation (interferometric or absolute distance measurement, vertical or horizontal installation of the laser tracker, and the use of an SMR, SRC, or ODR). If a specific mode of operation is not indicated in the manufacturer's specification, this specification shall apply to all modes of operation available to the user. It is recommended, if multiple sensors are available, that the length tests be performed with the SMR to determine length measurement errors. The performance of the other sensors shall then be determined in accordance with the procedures in Annex G and Annex H.

NOTE Lines f and g of the specification sheet (Annex A) are examples of where modes of operation might be specified by the manufacturer.

In most cases, length testing is performed with an SMR only. Additional tests for accessory probing systems are given in Annex G and Annex H. If both IFM and ADM are specified, perform a subset of two complete tests according to 6.4.4.4.

6.4.3 Measuring equipment

A calibrated test length may be realized in a number of ways, including scale bars, target nests mounted on walls or freestanding structures, use of a rail-and-carriage system, gauge blocks, ball bars, etc. Annex B provides the details of test lengths.

A laser tracker uses one linear axis and two rotary axes to determine the location of a retroreflector. The normative locations in Table 4 include tests that span at least 66 % of the manufacturer specified measuring ranges of the linear and the two angular axes, respectively. Positions 1 and 2 accomplish this for each rotary axis separately, while positions 36 to 40 accomplish this for the ranging (linear) axis. The angular range of a measurement is determined by both the test length to be measured and its distance from the laser tracker. It is therefore possible to obtain a variety of angular measurements using a single calibrated test length. For this reason, the test lengths in positions 1 to 29 of Table 4 shall be between 2,25 m and 2,75 m.

The manufacturer shall state the upper, and optionally lower, limits of the CTE of the calibrated test length. The manufacturer may calibrate the CTE of a calibrated test length. The manufacturer shall specify the maximum permitted (k = 2) uncertainty of the CTE of the calibrated test length. In the case where the calibrated test length is composed of a uni-directional length and other information as described in Annex B, the CTE shall be considered to be that of the uni-directional length. The default for a calibrated test length is a normal CTE material unless the manufacturer's specifications explicitly state otherwise.

A reference laser interferometer may be used to establish calibrated test lengths. A laser interferometer that is corrected for the index of refraction of air has a zero CTE ($\alpha = 0$). Hence, if it is used to produce a calibrated test length, this test length is considered a low CTE material. Additionally, if the reference laser has a workpiece (material) temperature sensor, then the workpiece CTE in the laser's software shall be set to 0. If a temperature compensated laser tracker is being tested, the workpiece CTE in the laser tracker software shall be set to 0 when measuring these test lengths.

If the calibrated test length is not a normal CTE material, then the corresponding $E_{\mathrm{Uni:0:LT,MPE}}$ or $E_{\mathrm{Bi:0:LT,MPE}}$ values are designated with an asterisk (*) and an explanatory note shall be provided describing the CTE of the calibrated test length.

EXAMPLE $E_{\mathrm{Uni:0:LT,MPE}}{}^*$ or $E_{\mathrm{Bi:0:LT,MPE}}{}^*$

* Test length is carbon fibre with a CTE no greater than $0,5 \times 10^{-6}$/ °C and with an expanded uncertainty (k = 2) U(CTE) no greater than $0,3 \times 10^{-6}$/ °C.

For the case where the manufacturer's specification for $E_{\mathrm{Uni:0:LT,MPE}}$ or $E_{\mathrm{Bi:0:LT,MPE}}$ requires a CTE less than 2×10^{-6}/ °C (thus being a non-normal CTE), an additional "synthetic length test" shall be performed, as described in Annex C.

NOTE 1 Due to the large size of test lengths required for testing laser trackers, it is common for this low CTE option to be included in the laser tracker specifications.

NOTE 2 Because of the difficulty in establishing long test lengths, especially in real environments, the test value uncertainty is very important in determining conformance to specifications.

6.4.4 Procedure

6.4.4.1 Required test length positions

Place the calibrated test length(s) at each location and orientation relative to the laser tracker described in Table 4 and shown in Figure 3. If, in the case of IFM measurements, a beam break occurs during a length measurement, the measurement during which the beam was broken shall be restarted. In the case of ADM measurements, the beam shall be broken before each reflector measurement (at either end of each length measurement), forcing the laser tracker to re-establish the distance to the reflector as part of the ADM measurement process. Each entry in Table 4 shall have a manufacturer specified MPE that is applicable to that particular calibrated test length in the orientation and location specified.

In Table 4, the laser tracker origin is at the intersection of the two rotary axes, and the azimuth angle has clockwise sense about the vertical standing axis of the laser tracker, with 0° azimuth set by the non-rotating laser tracker base. The distance of the test length from the laser tracker origin is shown by distance d in Figure 3.

NOTE 1 In many instances, it may be easier to move or re-orient the laser tracker than to move the test length.

Table 4 — Measurement positions

Position number (Basic positions)	Distance from laser tracker origin	Description of test length position (shown in Figure 3)	Azimuth angle(s)
1	As close as practical	Horizontal, centred (i.e. the ends of the test length are equidistant from the laser tracker), and at laser tracker height.[a]	at any azimuth
2	As close as practical	Vertical, centre of the length at laser tracker height (ends of the test length equidistant from the laser tracker).[b]	at any azimuth
3–6	3 m	Horizontal, centred (i.e. the ends of the test length are equidistant from the laser tracker), and at laser tracker height.	0, 90, 180, 270
7	3 m	Vertical, centre of the length at laser tracker height (ends of the test length equidistant from the laser tracker).	at any azimuth
8–11	3 m	Right diagonal, centred (i.e. the ends of the test length are equidistant from the laser tracker), and the centre of the length is at laser tracker height.	0, 90, 180, 270
12–15	3 m	Left diagonal, centred (i.e. the ends of the test length are equidistant from the laser tracker), and the centre of the length is at laser tracker height.	0, 90, 180, 270
16–19	6 m	Horizontal, centred (i.e. the ends of the test length are equidistant from the laser tracker), and at laser tracker height.	0, 90, 180, 270
20–23	As close as practical	Horizontal, not-centred (i.e. the laser tracker is directly in front of one end of the length), and at laser tracker height.	0, 90, 180, 270
24	As close as practical	Vertical, not-centred (i.e. the laser tracker is directly in front of one end of the length).	at any azimuth
25–28	As close as practical	Diagonal, one end below or above the point directly in front of the laser tracker, the other end to the right or left of the point directly in front of the laser tracker. The range to the two ends of the length are equal.	0, 90, 180, 270
29	As close as practical	Horizontal, centred directly above (as much as that is possible) the laser tracker itself.	at any azimuth
30–35	Long [c)]	Horizontal, centred (i.e. the ends of the test length are equidistant from the laser tracker), at laser tracker height.	0, 30, 60, 90, 120, 150
36–40	5 Ranging test distances	These test distances cover 66 % of the linear axis (IFM or ADM) of the laser tracker.[d,e]	at any azimuth
41	Synthetic length test	Follow requirements of Annex C (only required for low CTE test length case)	at any azimuth

[a] This test covers 66 % of the horizontal angle measurement range of the laser tracker, if the maximum angle is considered to be 180° for a single point-to-point measurement.

[b] This test covers 66 % of the vertical angle measurement axis of the laser tracker.

[c] In the special “long“ case, a longer test length is measured at a longer distance from the laser tracker. It is recommended to measure a test length of 7 m to 9 m at a distance of 7 m to 9 m.

[d] The distance between the two measured points used to evaluate the longest test length shall be at least 66 % of the manufacturer specified maximum measurement range of the laser tracker unless there is mutual agreement otherwise between manufacturer and the user.

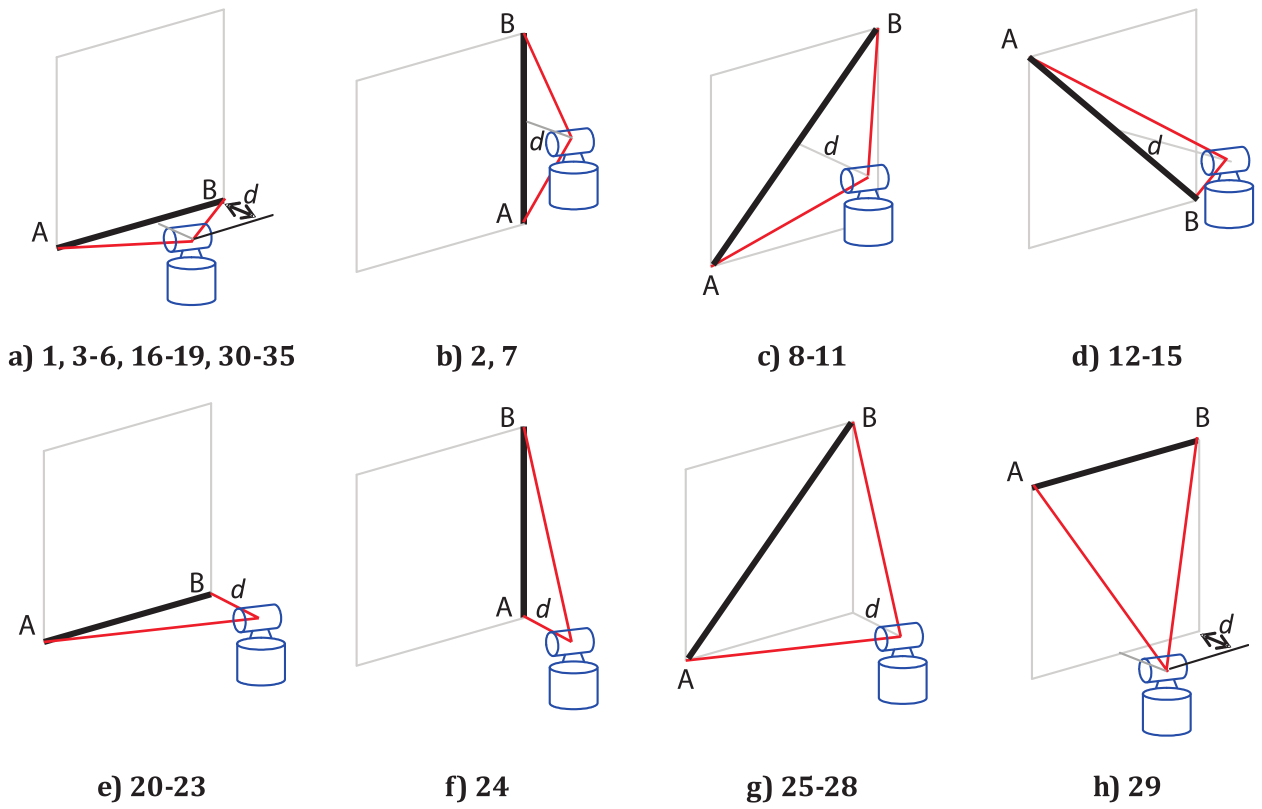
[e] For users that do not intend to use the full measurement range of the laser tracker, the user may choose lengths 36 to 40 that span a shorter range than 66 % of the maximum specified range and shall note the new maximum range on the test report. This does not influence any of the other specifications in this part of ISO 10360.

NOTE 2 The lengths in Table 4 are supplemented with additional measurements (see 6.4.3) for a total of 105 length measurements.

In the ranging tests (lengths 36 to 40), each of the five test lengths are defined as a two point distance. However, it is permitted to measure a first point close to the laser tracker (e.g. less than 1,5 m from the laser tracker) and then the five successive points at increasing distances, where the five test lengths are all calculated from the common first point. In explanation, if the points are labelled A (closest) to F (farthest), a sequence of measurements such as (AB, AC, AD, AE, AF) are the specified test lengths to which the MPE applies. However, a measurement sequence such as ABCDEF is permitted to evaluate the ranging capability of the laser tracker, because the repeatability of re-measuring nest A is expected to be small compared to the errors observed in the long lengths measured in the ranging tests. The user may, however, require that the full formal test procedure be conducted at each test length; this re-measures the A location five times as in (AB, AC, AD, AE, AF) or (AB, CA, AD, EA, AF). The distribution of the test lengths shall be approximately evenly spaced, with the longest length (AF) spanning at least 66 % of the manufacturer specified maximum measuring range of the instrument.

In some cases, test lengths may not be available that are sufficiently long to span 66 % of the instrument's measuring range. In this case, both parties may agree to use other means to generate a calibrated test length. These might include length standards that are "stitched" together (i.e. overlapped end-to-end) to form a longer test length, or laser-based test lengths, such as those consisting of a line of nests whose nest-to-nest distances are calibrated with a reference interferometer or using multilateration. In such cases, the procedure shall be documented and the uncertainties associated with these techniques shall be considered carefully, as they contribute to the test value uncertainty.

The tester should use extreme care to be certain that the environment and the test length end points are stable for the measurement of test lengths 36 to 40. It is common that these lengths are established using a reference interferometer in air, and variability in the environment or the nests can contribute to uncertainty in the test length, which contributes to the test value uncertainty of the length measurement error value.



Key

A and B ends of the test length

d shortest distance from the laser tracker origin to a vertical line containing the length

NOTE *d* is perpendicular to the vertical plane containing the test length. Where the test length is vertical, the plane is also perpendicular to a horizontal line from the laser tracker origin to a line containing the test length.

Figure 3 — Positions for test lengths (positions 1 – 29)

6.4.4.2 User-defined positions: alternative 1

In order to obtain 105 test lengths (consistent with other parts of ISO 10360), an additional 64 test length positions are added to the 41 test length positions in 6.4.4.1. To assist the user in choosing these measurement positions, two alternative sets of supplemental positions are described. Alternative 1 is described in Table 5.

Table 5 — Supplemental measurement positions – Alternative 1

Position number (Supplemental, Alternative 1)	**Distance from the laser tracker origin**	**Description of test length position**	**Azimuth angle(s)**
42–44	3 m	Position 7 at different angles - Vertical, centred (i.e. the ends of the test length are equidistant from the laser tracker), and the centre of the length is at laser tracker height.	90, 180, 270 (relative to the angle used in position 7)
45–48	6 m	Vertical, centre of the length at laser tracker height (ends of the test length equidistant from the laser tracker).	0, 90, 180, 270
49–52	6 m	Right diagonal, centred (i.e. the ends of the test length are equidistant from the laser tracker), and the centre of the length is at laser tracker height.	0, 90, 180, 270
53–56	6 m	Left diagonal, centred (i.e. the ends of the test length are equidistant from the laser tracker), and the centre of the length is at laser tracker height.	0, 90, 180, 270
57–59	As close as practical	Position 24 at different angles - Vertical, not-centred (i.e. the laser tracker is directly in front of one end of the length)	90, 180, 270 (relative to the angle used in position 24).
60–63	As close as practical	Horizontal, not-centred (i.e. the laser tracker is directly in front of one end of the length), and at laser tracker height. This is the mirror position corresponding to positions 20–23 in Table 4 (If the laser tracker were previously directly in front of end B of the test length as in Figure 3 e), then, the laser tracker must now be positioned directly in front of end A of the test length)	0, 90, 180, 270
64–67	As close as practical	Diagonal, one end below or above the point directly in front of the laser tracker, the other end to the right or left of the point directly in front of the laser tracker. The range to the two ends of the length are equal. This is the complementary position corresponding to positions 25–28 in Table 4 [e.g. if the laser tracker were previously directly in front of and below target B with laser tracker and target A at the same height, as in Figure 3 g), then the laser tracker should now be directly in front of and above end A of the test length with the laser tracker and end B of the test length at the same height].	0, 90, 180, 270
68–71	As close as practical	Diagonal, one end below or above the point directly in front of the laser tracker, the other end to the right or left of the point directly in front of the laser tracker. The range to the two ends of the length are equal. This is the mirror position corresponding to positions 64–67 above. (If the test length was in a right diagonal position for positions 64–67, then the test length should be oriented in a "left diagonal" position for positions 68–71.)	0, 90, 180, 270
72–74	As close as practical	Horizontal, centred directly above (as much as is possible) the laser tracker itself.	90, 180, 270 (relative to the angle used in position 29)
75–78	6 m	Body diagonal of a cube	0, 90, 180, 270
79–82	As close as practical	Diagonal, centred (i.e. the ends of the test length are equidistant from the laser tracker), and the centre of the length is at laser tracker height.	0, 90, 180, 270
Repeatability measurements:			

Table 5 *(continued)*

Position number (Supplemental, Alternative 1)	Distance from the laser tracker origin	Description of test length position	Azimuth angle(s)
83–86	Distance approximately equal to half the test length	Horizontal, centred (i.e. the ends of the test length are equidistant from the laser tracker), and at laser tracker height. Repeat the measurement four times. This tests the repeatability of the horizontal angle measurement capability.	at any azimuth
87–90	Distance approximately equal to twice the test length	Horizontal, centred (i.e. the ends of the test length are equidistant from the laser tracker), and at laser tracker height. Repeat the measurement four times. This tests the repeatability of the horizontal angle measurement capability.	at any azimuth
91–94	Distance approximately equal to half the test length	Vertical, centre of the length at laser tracker height (ends of the test length equidistant from the laser tracker). Repeat the measurement four times. This tests the repeatability of the vertical angle measurement capability.	at any azimuth
95–98	Distance approximately equal to twice the test length	Vertical, centre of the length at laser tracker height (ends of the test length equidistant from the laser tracker). Repeat the measurement four times. This tests the repeatability of the vertical angle measurement capability.	at any azimuth
99–102	3 m	In any radial direction, where the near end of the length is 3 m away from the laser tracker. Repeat the measurement four times. This tests the repeatability of the range measurement capability.	at any azimuth
103–105	6 m	In any radial direction, where the near end of the length is 6 m away from the laser tracker. Repeat the measurement three times. This tests the repeatability of the range measurement capability.	at any azimuth

6.4.4.3 User defined positions: alternative 2

In order to obtain 105 test lengths (consistent with other parts of ISO 10360), an additional 64 test length positions are added to the 41 test length positions in6.4.4.1. To assist the user in choosing these measurement positions, two alternative sets of supplemental positions are described. Alternative 2 is described in Figure 4.

In this alternative, the laser tracker is centred in front of the longest side of the measuring volume at a distance of 1,5 m in such a way that the measuring head is approximately equidistant from the upper and lower edge of the measuring volume. The test length positions are determined by eight different measurement lines. Figure 4 shows a possible arrangement of these eight measurement lines. Other arrangements are also permitted.

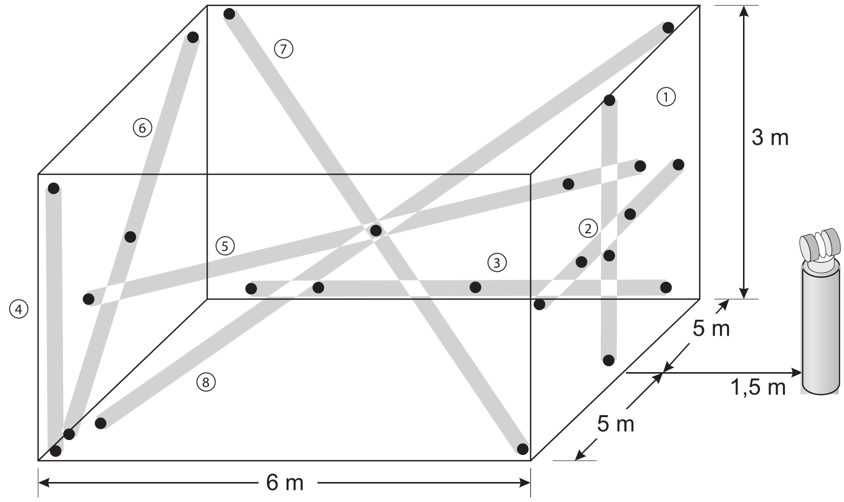


Figure 4 — Example showing the arrangement of the measurement lines for the test of the length measurement error

The 64 test length positions in this alternative of the acceptance test are described relative to a measuring volume of 10 m × 6 m × 3 m (length × width × height). If the laser tracker is primarily used to measure small parts, a measuring volume of 5 m × 3 m × 2 m is then recommended. Other measuring volumes are, however, permitted. The setup shown in Figure 4 consists of 33 individual distances. All in all, 64 test lengths should be measured along the eight measurement lines. Along every measurement line at least three different test lengths must be measured. The measurements along each measurement line shall be repeated at different orientations: in order to cover the complete azimuth range, the laser tracker shall be rotated by approximately 120° about its vertical axis before the repeated measurement of a line. In addition, some test length measurements should be repeated along each measuring line.

EXAMPLE

Consider three lengths on a measuring line, L_1, L_2, and L_3. One process meeting the description in 6.4.4.3 would be to set the laser tracker a 0° azimuth and measure L_1, L_2, and L_3. Then rotate the laser tracker by 120° and measure L_1 and L_2. Finally, rotate the laser tracker an additional 120° and measure L_3. Many combinations of measurements are possible, and the user is free to choose positions within the constraints of this subclause.

The shortest test length should amount to at least 1/10 of the shortest side of the specified measuring volume. In each measurement line, the largest test length has to be chosen in such a way that it is not shorter than 2/3 of the length which is maximally possible in the measurement line within the measuring volume.

Annex D indicates how targets on a wall can be used, along with carefully adjusting the laser tracker position, to achieve the effect of the measuring volume above in Figure 4.

6.4.4.4 Testing of laser trackers with both IFM and ADM modes specified

A laser tracker may have both IFM and ADM modes specified by the manufacturer. It is common that the major difference in the specifications for these two modes is in the MPEs of the ranging lengths (lengths 36 to 40 from Table 4). In the case where the MPEs are the same for the two modes, it is permissible to test all of the lengths in ADM mode, with the exception of lengths 1, 2, and 36 to 40 in Table 4, which shall be tested in both modes.

NOTE If the MPEs given by the specifications for IFM measurements are smaller in absolute value than those of the ADM measurements, it is also permissible to test in ADM mode only, with the exception of those test lengths noted above (1,2, and 36–40).

6.4.5 Derivation of test results

For all 105 measurements, determine each length measurement error, $E_{\mathrm{Uni:0:LT}}$ or $E_{\mathrm{Bi:0:LT}}$, by obtaining the difference between the indicated value and the calibrated value of each test length (where the calibrated value is taken as the conventional true value of the length). The indicated value of a particular measurement of a calibrated test length may be corrected by the laser tracker to account for systematic errors, or thermally induced errors (including thermal expansion) if the laser tracker has accessory devices for this purpose. Manual correction of the results obtained from the computer output to account for temperature or other corrections shall not be allowed when the environmental conditions satisfy the conditions of 5.1.

For each of the 105 length measurement errors ($E_{\mathrm{Uni:0:LT}}$ or $E_{\mathrm{Bi:0:LT}}$ values), calculate a corresponding MPE value ($E_{\mathrm{Uni:0:LT,MPE}}$ or $E_{\mathrm{Bi:0:LT,MPE}}$ value) based on the manufacturer's MPE specification.

NOTE The manufacturer's MPE specification will, in general, be a formula.

7 Compliance with specification

7.1 Acceptance tests

The probing performance of the laser tracker is verified if

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

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

Report the measured probing form error, and the measured probing size error (with its respective sign). If any of the probing tests fails, repeat the measurement at that position three times, attempting to replicate the 25 measurement points used in the failed test. All three of these repeated probing tests must be successful. The largest (absolute value) error of the three is reported for that test (with respective sign in the case of the probing size test.

The two-face (location error) performance of the laser tracker is verified if

— the location error, $L_{\text{Dia.2x1:P\&R:LT}}$, is not greater than the relevant maximum permissible location error, $L_{\text{Dia.2x1:P\&R:LT,MPE}}$, as specified by the manufacturer and taking into account the test value uncertainty.

Report the location errors obtained. If one of the two-face tests fails, repeat the measurement at that position three times. The largest (absolute value) error of the three is reported for that test.

The length measuring performance of the laser tracker is verified if

— the length measurement errors (values of $E_{\text{Uni:0:LT}}$ or $E_{\text{Bi:0:LT}}$), are within the maximum permissible error of length measurement, $E_{\text{Uni:0:LT,MPE}}$ or $E_{\text{Bi:0:LT,MPE}}$, as specified by the manufacturer, taking into account the test value uncertainty.

Report the length measurement errors. No more than five of the 105 test lengths may be outside of specification. Any length measuring outside of specification must be remeasured three times, and each of these measurements must each be within the specification.

7.2 Reverification tests

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

8 Applications

8.1 Acceptance test

In a contractual situation between a manufacturer and a user such as that described in a

— purchasing contract,

— maintenance contract,

— repair contract,

— renovation contract, or

— upgrading contract etc.,

the acceptance test specified in this part of ISO 10360 may be used as a test for verifying the performance of the laser tracker used for measuring linear dimensions in accordance with the specification for the stated maximum permissible errors, $E_{\text{Uni:0:LT,MPE}}$ or $E_{\text{Bi:0:LT,MPE}}$, $P_{\text{Form.Sph.1x25::SMR.LT,MPE}}$ $P_{\text{Size.Sph.1x25::SMR.LT,MPE}}$, and $L_{\text{Dia.2x1:P\&R:LT,MPE}}$, as agreed upon by the manufacturer and the user.

The manufacturer is permitted to specify detailed limitations applicable for $E_{\text{Uni:0:LT,MPE}}$ or $E_{\text{Bi:0:LT,MPE}}$, $P_{\text{Size.Sph.1x25::SMR.LT,MPE}}$ and $L_{\text{Dia.2x1:P\&R:LT,MPE}}$. If no such specification is given, $E_{\text{Uni:0:LT,MPE}}$ or $E_{\text{Bi:0:LT,MPE}}$, $P_{\text{Form.Sph.1x25::SMR.LT,MPE}}$, $P_{\text{Size.Sph.1x25::SMR.LT,MPE}}$, and $L_{\text{Dia.2x1:P\&R:LT,MPE}}$ apply for any location and orientation of the test length in the measuring volume of the laser tracker.

A graphical presentation of the test results compared with the appropriate MPE values may be helpful.

8.2 Reverification test

In an organization's internal quality assurance system, the performance verification described in this part of ISO 10360 can be used as a reverification test to verify the performance of the laser tracker used for measuring linear dimensions in accordance with the specification for the maximum permissible errors, $E_{\text{Uni:0:LT,MPE}}$ or $E_{\text{Bi:0:LT,MPE}}$, $P_{\text{Form.Sph.1x25::SMR.LT,MPE}}$, $P_{\text{Size.Sph.1x25::SMR.LT,MPE}}$, and $L_{\text{Dia.2x1:P\&R:LT,MPE}}$, as stated by the user. The user is permitted to state the values of, and to specify detailed limitation applicable to, $E_{\text{Uni:0:LT,MPE}}$ or $E_{\text{Bi:0:LT,MPE}}$, $P_{\text{Form.Sph.1x25::SMR.LT,MPE}}$, $P_{\text{Size.Sph.1x25::SMR.LT,MPE}}$, and $L_{\text{Dia.2x1:P\&R:LT,MPE}}$.

If the user wishes to reduce the number of test lengths for reverification, it is recommended that the 41 test lengths from Table 4 be used in addition to five test lengths representative of customary measurements. The lengths in Table 4 are a minimal set chosen to reveal the geometric errors of the laser tracker (see Reference [2]).

NOTE 1 The laser tester accounts for the test value uncertainty according to ISO 14253-1; accordingly, a reverification test (where typically the tester is the user) may have a different acceptance zone than in an acceptance test.

NOTE 2 In acceptance testing, the acceptance zone is obtained from the manufacturer's specifications. In reverification testing, the reverification limits may be derived from the user's metrological needs.

A graphical presentation of the test results compared with the appropriate MPE values may be helpful.

8.3 Interim check

In an organization's internal quality assurance system, a reduced performance verification may be used periodically to provide confidence through sample measurements that the laser tracker conforms with specified requirements regarding the maximum permissible errors, $E_{\text{Uni:0:LT,MPE}}$ or $E_{\text{Bi:0:LT,MPE}}$, $P_{\text{Form.Sph.1x25::SMR.LT,MPE}}$, $P_{\text{Size.Sph.1x25::SMR.LT,MPE}}$, and $L_{\text{Dia.2x1:P\&R:LT,MPE}}$. The extent of the performance verification as described in this part of ISO 10360 may be reduced by using fewer measurements and positions, as described in Annex F.

A graphical presentation of the test results compared with the appropriate MPE values may be helpful.

9 Indication in product documentation and data sheets

The symbols of Clause 4 are not well suited for use in product documentation, drawings, data sheets, etc. Table 5 gives the corresponding indications which are also allowed.

Table 6 — Symbols and corresponding indications in product documentation, drawings, data sheets, etc.

Symbol used in this document	Corresponding indication
$E_{\text{Uni:0:LT}}$ $E_{\text{Bi:0:LT}}$	E[Uni:0:LT] E[Bi:0:LT]
$P_{\text{Form.Sph.1x25::SMR.LT}}$	P[Form.Sph.1x25::SMR.LT]
$P_{\text{Form.Sph.1x25::SRC.LT}}$	P[Form.Sph.1x25::SRC.LT]
$P_{\text{Form.Sph.1x25::ODR.LT}}$	P[Form.Sph.1x25::ODR.LT]
$P_{\text{Size.Sph.1x25::SMR.LT}}$	P[Size.Sph.1x25::SMR.LT]
$P_{\text{Size.Sph.1x25::SRC.LT}}$	P[Size.Sph.1x25::SRC.LT]
$P_{\text{Size.Sph.1x25::ODR.LT}}$	P[Size.Sph.1x25::ODR.LT]
$L_{\text{Dia.2x1:P\&R:LT}}$	L[Dia.2x1:P&R.LT]
$P_{\text{Dia.15x1::SRC.LT}}$	P[Dia.15x1: :SRC.LT]
$P_{\text{Form.Sph.1x25::SRC.LT}}$	P[Form.Sph.1x25::SRC.LT]

Table 6 *(continued)*

Symbol used in this document	Corresponding indication
$P_{\text{Size.Sph.1x25::SRC.LT}}$	P[Size.Sph.1x25: SRC.LT]
$P_{\text{Form.Sph.1 × 25::ODR.LT}}$	P[Form.Sph.1 × 25::ODR.LT]
$P_{\text{Form.Sph.D95\%::ODR.LT}}$	P[Form.Sph.D95 %::ODR.LT]
$P_{\text{Size.Sph.1×25::ODR.LT}}$	P[Size.Sph.1 × 25::ODR.LT]
$P_{\text{Size.Sph.All::ODR.LT}}$	P[Size.Sph.All::ODR.LT]
$E_{\text{Form.Pla.D95\%::ODR.LT}}$	E[Form.Pla.D95 %::ODR.LT]
$P_{\text{Form.Sph.}n\text{x25::MPS.LT}}$	P[Form.Sph.nx25::MPS.LT]
$P_{\text{Size.Sph.}n\text{x25::MPS.LT}}$	P[Size.Sph.nx25::MPS.LT]
$L_{\text{Dia.}n\text{×25::MPS.LT}}$	L[Dia.n × 25::MPS.LT]
$E_{\text{Uni:0:LT,MPE}}$ $E_{\text{Bi:0:LT,MPE}}$	MPE(E[Uni:0:LT]) MPE(E[Bi:0:LT])
$P_{\text{Form.Sph.1x25::SMR.LT,MPE}}$	MPE(P[Form.Sph.1x25::SMR.LT])
$P_{\text{Form.Sph.1x25::SRC.LT,MPE}}$	MPE(P[Form.Sph.1x25::SRC.LT])
$P_{\text{Form.Sph.1x25::ODR.LT,MPE}}$	MPE(P[Form.Sph.1x25::ODR.LT])
$P_{\text{Size.Sph.1x25::SMR.LT,MPE}}$	MPE(P[Size.Sph.1x25::SMR.LT])
$P_{\text{Size.Sph.1x25::SRC.LT,MPE}}$	MPE(P[Size.Sph.1x25::SRC.LT])
$P_{\text{Size.Sph.1x25::ODR.LT,MPE}}$	MPE(P[Size.Sph.1x25::ODR.LT])
$L_{\text{Dia.2x1:P\&R:LT,MPE}}$	MPE(L[Dia.2x1:P&R:LT])
$P_{\text{Dia.15x1::SRC.LT,MPE}}$	MPE(P[Dia.15x1::SRC.LT])
$P_{\text{Form.Sph.1x25::SRC.LT,MPE}}$	MPE(P[Form.Sph.1x25::SRC.LT])
$P_{\text{Size.Sph.1x25::SRC.LT,MPE}}$	MPE(P[Size.Sph.1x25::SRC.LT])
$P_{\text{Form.Sph.1×25::ODR.LT,MPE}}$	MPE(P[Form.Sph.1 × 25::ODR.LT])
$P_{\text{Form.Sph.D95\%::ODR.LT,MPE}}$	MPE(P[Form.Sph.D95 %::ODR.LT])
$P_{\text{Size.Sph.1×25::ODR.LT,MPE}}$	MPE(P[Size.Sph.1 × 25::ODR.LT])
$P_{\text{Size.Sph.All::ODR.LT,MPE}}$	MPE(P[Size.Sph.All::ODR.LT])
$E_{\text{Form.Pla.D95\%::ODR.LT,MPE}}$	MPE(E[Form.Pla.D95 %::ODR.LT])
$P_{\text{Form.Sph.}n\text{×25::MPS.LT,MPE}}$	MPE(P[Form.Sph.nx25::MPS.LT])
$P_{\text{Size.Sph.}n\text{×25::MPS.LT,MPE}}$	MPE(P[Size.Sph.nx25::MPS.LT])
$L_{\text{Dia.}n\text{×25::MPS.LT,MPE}}$	MPE(L[Dia.n × 25::MPS.LT])

Annex A
(informative)

Forms

Form 1: General Specifications and Rated Conditions			
RATED OPERATING CONDITIONS			
Measurement Envelope			
Distance (Range)		Min. _____ m	Max. _____ m
Horizontal Angle (Azimuth)		Min. _____ deg	Max. _____ deg
Vertical Angle (Elevation/Zenith)		Min. _____ deg	Max. _____ deg
or			
Length × width × height (Prismatic Volume)		_____ m *by* _____ m *by* _____ m	
a.	*Temperature Range*		
	Operating	Min._____ °C	Max._____ °C
	Thermal gradient limits	Min._____ °C/m	Max._____ °C/m
b.	*Humidity Range*		
	Operating	Min.____ %RH	Max._____ %RH
c.	*Barometric Pressure Range*		
	Operating	Min._____ Pa	Max._____ Pa
d.	*Ambient Light*: The manufacturer shall identify conditions, if any, under which ambient light degrades specimens.		
e.	*Electrical*	Voltage _____ V	Current _____ A
		Frequency _____ Hz	Surge/sag _____ V
		Transient max. _____ V	Transient duration _____s
f.	*Allowable orientations (vertical, horizontal, etc.)*	______________________	
g.	*Probe type*: The probe diameter and reflector type (e.g. in air SMR vs solid prism SMR, or cat's eye) used during performance testing shall be specified.	Diameter _____mm	Reflector type _________
h.	*Calibrated test length*		
	CTE	Min._____10^{-6}/°C	Max._____10^{-6}/°C
	CTE uncertainty		Max._____10^{-6}/°C
i.	*Sampling Strategy*: The manufacturer shall state the measurement acquisition time (averaging time) and sampling frequency (points per second) to meet specification.	Acq. time _____ s	Frequency _____ points/s
j.	*Warm up time*	___ minutes	
LIMITING CONDITIONS (exceeding these conditions may damage the instrument)			
k.	*Temperature Range*	Min._____ °C	Max._____ °C
l.	*Humidity Range*	Min._____ %RH	Max._____ %RH
m.	*Barometric Pressure Range*	Min._____Pa	Max. _____ Pa

Form 2: Manufacturer's Performance Specifications and Test Results (all units µm)	
As different MPEs are permitted for different tests, this table may be extended to accommodate the complete specification.	
Length errors	$E_{Uni:0:LT,MPE}$ or $E_{Bi:0:LT,MPE}$
	$E_{Uni:0:LT}$ or $E_{Bi:0:LT}$
	Test Value Uncertainty
	Pass/Fail
Thermal comp. errors	$E_{Uni:0:LT,MPE}$
	E_{therm}
	Test Value Uncertainty
	Pass/Fail
Probing size and form errors	$P_{Size.Sph.1x25::SMR.LT,MPE}$
	$P_{Size.Sph.1x25::SMR.LT}$
	Test Value Uncertainty
	Pass/Fail
	$P_{Form.Sph.1x25::SMR.LT,MPE}$
	$P_{Form.Sph.1x25::SMR.LT}$
	Test Value Uncertainty
	Pass/Fail
Location errors	$L_{Dia.2x1:P\&R:LT,MPE}$
	$L_{Dia.2x1:P\&R:LT}$
	Test Value Uncertainty
	Pass/Fail
Test performed by	
Date	
Serial number	
Final test results (Pass/Fail)	

☐ Check here if test lengths are bi-directional ($E_{Bi:0:LT}$)

☐ Check here if test lengths are uni-directional ($E_{Uni:0:LT}$)

☐ Check here if the specification corresponds to the laser tracker mounted in other than vertical orientation of the standing axis

6.4 requires that the MPEs for test lengths 1-41 be explicitly stated in a table. An example of such a table is shown below.

For lengths required by this part of ISO 10360 to be in the range 2,25 m to 2,75 m, give the MPE for 2,75 m.

For lengths required by this part of ISO 10360 to be in the range 7 m to 9 m, give the MPE for 9 m.

Formula for MPEs 1-35 & 41		Any format	
Formula for Ranging MPEs (positions 36-40)		$A + (B/K)L$ format	
Additional MPE formulas (if any)		Any format	
Additional MPE formulas (if any)		Any format	
Test length position	**MPE**	**Test length position**	**MPE**
1		22	
2		23	
:		:	
:		41	
21			

☐ Check here if test lengths are bi-directional ($E_{Bi:0:LT}$)

☐ Check here if test lengths are uni-directional ($E_{Uni:0:LT}$)

☐ Check here if the specification corresponds to the laser tracker mounted in other than vertical orientation of the standing axis

Length 41 is the workpiece thermal compensation test. It is performed over a length of 15 m, and should meet the MPE generated by the formula for lengths 1 to 35.

Annex B
(normative)

Calibrated test lengths

B.1 General

The measurand of interest (in the error of length measurement test) is a point-to-point distance in space. The realization of this measurand is accomplished using calibrated test lengths, where the distance between two physical points is traceable to the SI unit of length. The distinction between uni- and bi-directional lengths is discussed in B.6. Table B.1 provides graphical guidance for realizations of uni- and bidirectional test lengths.

B.2 Calibrated test lengths

Gauge blocks, step gauges, and ball bars

These may be the same as in ISO 10360-2. Ball bars and step gauges may either be uni- or bi-directional in nature. Gauge blocks are always measured in a bi-directional manner.

B.3 Scale bars

Centre-to-centre distance of spheres in the nests is calibrated

These are uni-directional test lengths. Care should be used when the nests result in the sphere centres being off of the neutral axis of the test length.

B.4 Rigid nests

Centre-to-centre distance determined from traceable measurement.

These are uni-directional measurements taken on nests mounted on permanent or semi-permanent monuments or structural members (e.g. walls, pillars) of a building in which testing occurs.

The calibration of nest to nest distances is often done with an independently calibrated interferometer. It is permitted to use a tracking interferometer for this purpose.

B.5 Rail or carriage system

Location of different instances of a sphere, nest, or gauge block. Traceable to the reference measurement system.

These measurements can either be uni- or bi-directional, depending on the probing strategy and the geometry of the moving object.

B.6 Uni- and bi-directional lengths

Tests for the error of length measurement for many coordinate measuring systems use bi-directional lengths for the determination of errors. As the realization of long bi-directional lengths can be both difficult and expensive, it is common to establish point-to-point distances as uni-directional lengths between nests.

If the manufacturer wishes to specify uni-directional tests, the notation $E_{\mathrm{Uni:0:LT}}$ shall be used.

An estimate of bi-directional length errors (e.g. when using the SMR sensor) may be calculated with Formula (B.1)

$$E_{\mathrm{Bi:0:LT}} \text{ approximately } E_{\mathrm{Uni:0:LT}} + P_{\mathrm{Size.Sph.1x25::SMR.LT}} \tag{B.1}$$

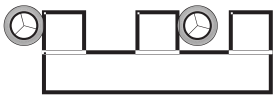
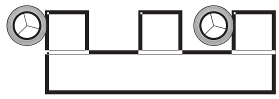
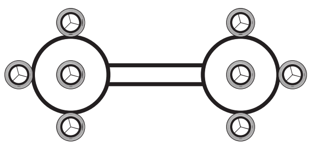
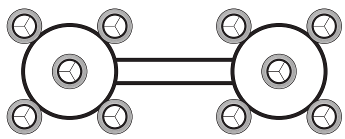
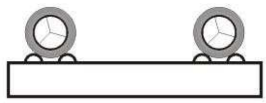
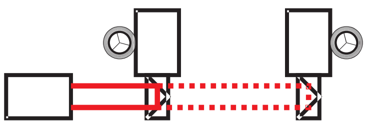
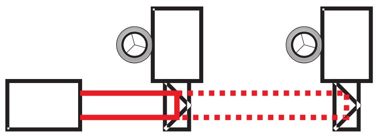
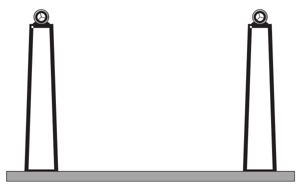
but this formula will give an over-estimate of the error. For this reason, the following inequalities can be used establishing conformance or non-conformance to bi-directional length measuring specifications.

— If $E_{\mathrm{Uni:0:LT}} + \mathrm{P}_{\mathrm{Size.Sph.1x25::SMR.LT}} \leq E_{\mathrm{Bi:0:LT,MPE}}$, then the specification is met.

— If $E_{\mathrm{Uni:0:LT}} > E_{\mathrm{Bi:0:LT,MPE}}$, then the specification is not met.

If the user is not satisfied with using these inequalities, a bi-directional test length should be obtained for testing.

Table B.1 — Realization of Bi- and Uni-directional test lengths

	Bi-directional lengths	Uni-directional lengths
Gauge Block		
Step Gauge		
Ball Bar		
Scale Bar		
Rail or carriage systems		
Rigid Nests		

Annex C
(normative)

Thermal compensation of workpieces

Because of the large size of many workpieces measured with laser trackers, the correct operation of the workpiece temperature measurement and compensation system is critical to accurate measurement.

For this purpose, a “synthetic“ test length is measured which is nominally 15 m long. With a calibrated reference interferometer, which is traceable and which may also be the calibrated interferometer of a second laser tracker, a test length between two target nests is established. Air temperature, air pressure, and air humidity are measured by the weather station of the reference interferometer and, thus, the refractive index of the air is determined and the refractive index of the test length compensated. The measurement result is the calibrated length, L, of the test length. The length, L, is now used to calculate a “synthetic” test length, L_S, equivalent to the length of a gauge block with the thermal expansion coefficient of exactly $\alpha_S = 11{,}5 \times 10^{-6}/\ °C$. The effect of this calculation is that the test length is being changed in such a way that it corresponds to a length with a thermal expansion coefficient of $11{,}5 \times 10^{-6}/\ °C$.

$$L_S = L[1 - \alpha_S\ (T - 20\ °C)] = L[1 - (11{,}5 \times 10^{-6})\ (T - 20\ °C)] \quad (C.1)$$

The test length temperature T required for the calculation is measured with a calibrated thermometer on a piece of steel (a specimen) and **not** with the aid of any temperature measuring system delivered with the laser tracker. The specimen shall be in thermal equilibrium with its environment, and the test must be performed when the temperature T is more than 1 °C away from 20 °C, i.e. $|\ T - 20\ °C\ | > 1\ °C$. After that, the “synthetic” test length between the two target nests is measured with the laser tracker to be tested. For this purpose, it is recommended to install the laser tracker at a short distance and directly aligned to the test length (i.e. the measurement is performed radially). A thermal expansion coefficient, $\alpha_S = 11{,}5 \times 10^{-6}/\ °C$ must be entered for the test length. For the laser tracker, the test length thus seems to be made of steel. To compensate the thermal expansion of the test length, the temperature of a specimen which has reached thermal equilibrium with its environment, is measured, as above, but this time with the laser tracker’s sensor, to obtain the test length temperature. If the laser tracker being tested in not equipped with a workpiece temperature sensor, no manual compensation of the measured length, L, is permitted. The measurement of the “synthetic” test length with the laser tracker is repeated three times with the result L.

The error $E_{therm} = (L - L_S)$ is calculated for each of the three measurements. None of these errors shall exceed $E_{Uni:0:LT,MPE}$ for the 15 m test length.

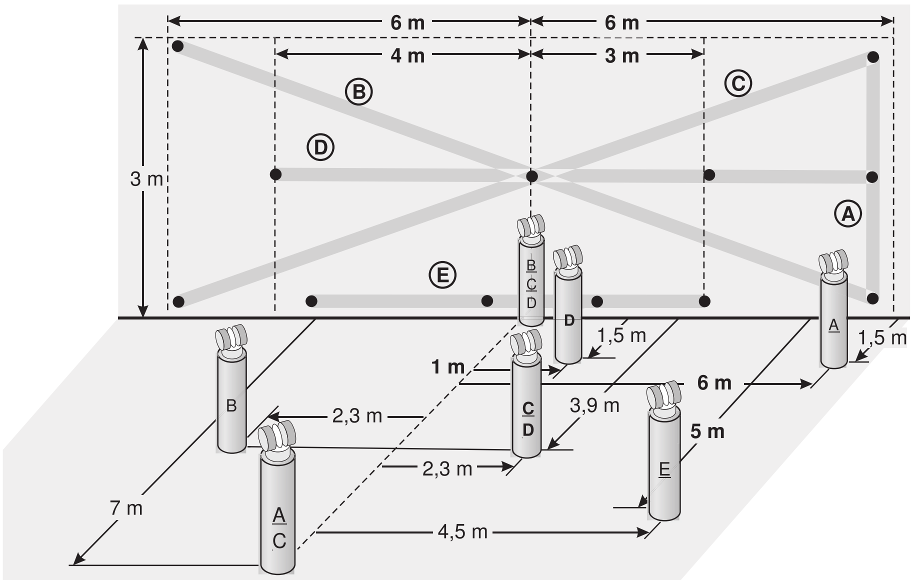
Where the manufacturer does not provide software with the laser tracker, he shall specify an $E_{Uni:0:LT,MPE}$ for those third-party software systems with which his instrument will be used with temperature compensation.

Annex D
(informative)

Achieving the alternative measuring volume

For testing of the length measurement error using the test lengths described in 6.4.4.3, it is possible to arrange all measuring lines in (approximately) a single plane and obtain the relationships between the test lengths and the laser tracker shown in Figure 4 by varying the position of the laser tracker. Figure D.1 shows, for the recommended measuring volume of 10 m × 6 m × 3 m, a possible planar arrangement of the measuring lines with varying positions of the laser tracker, equivalent to the measurement of test lengths from a single position of the laser tracker as shown in Figure 4. The letters shown on the laser tracker stand correspond to the measuring lines on the wall, as named by circled letters, to be measured from the present position. Underlined letters indicate mandatory positions of the laser tracker. In order to cover the complete azimuth range, the laser tracker is rotated by approximately 120° about its vertical axis in each position before the repeated measurements of the lines indicated by the letters on the stand.

A measuring and test arrangement as shown in Figure D.1 can be realized with the aid of stable tripods or by means of a stable wall. It is, for example, possible to mount magnetic nests for spherically mounted retroreflectors on one wall. The distances between the nests then represent the test lengths. If the distances have been calibrated before the laser tracker is tested, the distances have to be stable only for the duration of the test. It is recommended to calibrate the respective test lengths only immediately before a measuring line is measured and to determine them again for control immediately after the lengths have been measured with the laser tracker to be tested.



NOTE The laser tracker is standing on changing positions.

Figure D.1 — Example of a plane arrangement of the measuring lines for testing of the length measurement error

For the acceptance test, a measuring volume of 10 m × 6 m × 3 m (length × width × height) is recommended (see 6.4.4.3) in which 32 test lengths must be measured along eight measuring lines from a position outside the measuring volume, supplemented by three additional test lengths which must be measured “from the centre”. For the recommended arrangement of the measuring line (see Figure D.1), the following measures are obtained for the shortest and the longest length to be tested (see Table D.1).

Table D.1 — Shortest and longest test lengths along the measuring lines in Figure D.1

Measuring line	Shortest test length L_{min} (m)	Longest test length L_{max} (m)	Recommended longest test length (m)
A	$L_{min} \geq 0{,}3$	$2{,}0 \leq L_{max} \leq 3{,}0$	3,0
B	$L_{min} \geq 0{,}3$	$8{,}1 \leq L_{max} \leq 12{,}4$	12,0
C	$L_{min} \geq 0{,}3$	$8{,}1 \leq L_{max} \leq 12{,}4$	12,0
D	$L_{min} \geq 0{,}3$	$6{,}6 \leq L_{max} \leq 10{,}0$	9,0
E	$L_{min} \geq 0{,}3$	$4{,}0 \leq L_{max} \leq 6{,}0$	6,0

Annex E
(informative)

Specification of MPEs

E.1 General

The errors that are present in using laser trackers to measure point to point distances do not result in a simple linear relationship between the length measured and the error in determining that length. For this reason, it is permitted for the manufacturer to specify laser tracker performance using a more complex formula. The subsystem contributors and a resulting generic formula are given in this Annex.

E.2 Subsystem contributions

The notation for the manufacturer supplied performance specifications (of the sub-systems) for a laser tracker is given in Table E.1.

In Table E.1, the quantity, R, refers to the distance between the laser tracker and the point in space where a point coordinate is measured. The laser tracker manufacturer specifies the rated conditions (see Annex A) within which the MPE specifications hold. Accordingly, sub-system specifications, as shown in Table E.1, include the effects of measurement errors resulting from environmental conditions that are allowed by the rated conditions.

In some cases, the manufacturer may state additional sub-system specifications that could include environmental conditions as parameters in their MPE specification formula. The e_{IFM} and e_{ADM} specifications refer to the basic capability of the ranging system, while e_{R0} and e_T relate to the geometry of the laser tracker assembly and the quality of the rotary encoders.

Table E.1 — Quantities related to the laser tracker performance

Laser tracker subsystem	Symbol	Form of error contribution	Formula No.
Interferometer (IFM)	e_{IFM}	$e_{IFM} = A_{IFM} + B_{IFM} \cdot R$	(1)
Absolute distance meter (ADM)	e_{ADM}	$e_{ADM} = A_{ADM} + B_{ADM} \cdot R$	(2)
R0 parameter (R0)[a]	e_{R0}	$e_{R0} = B_{R0}$	(3)
Transverse[b]	e_T	$e_T = A_T + B_T \cdot R$	(4)

[a] The R0 error is the error in determining the distance from the laser tracker's geometric origin. This error is seen most clearly when comparing the measurement shown in Figure E.2 with a measurement obtained by placing the laser tracker directly between point 1 and point 2 in Figure E.2.

[b] Transverse error refers to the error resulting from incorrectly determining the angular components in determining the location of a measured point.

E.3 Development of generic formula

The geometrical arrangement of a laser tracker that measures the coordinates of points 1 and 2 for many of the positions described in Clause 6, Table 4 is shown in Figure E.1. See Figure E.2 for the case where the laser tracker is located on a line defined by the measured test length. From these coordinates, the test length, L, is determined.

The maximum permissible error (MPE) for this length measurement is specified by the manufacturer for performance verification tests. One method of expressing the MPE of measured test length, L, is using Formula (E.1). In this formula, the quantities that contain the subscripts 1 or 2 refer to the MPE specifications when evaluated at the pair of points 1 and 2 (respectively) for either the IFM or ADM specifications in Table E.1, depending on whether the IFM or ADM is used.

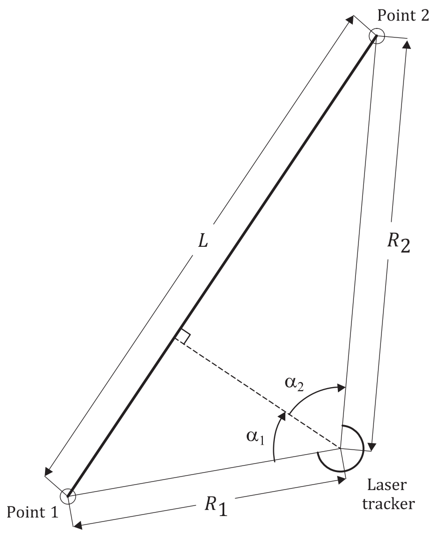


Figure E.1 — Laser tracker geometry

$$E_{\text{Uni:0:LT,MPE}} = \left(e_1^2 \sin^2\alpha_1 + e_2^2 \sin^2\alpha_2 + e_{\text{R0}}^2 \left(\sin\alpha_1 + \sin\alpha_2 \right)^2 + e_{\text{T1}}^2 \cos^2\alpha_1 + e_{\text{T2}}^2 \cos^2\alpha_2 \right)^{\frac{1}{2}} \quad \text{(E.1)}$$

The angles α_1 and α_2 are positive in the directions shown in Figure E.1 and negative in the opposite directions. The quantities e_1, e_2, e_{R0}, e_{T1}, and e_{T2} are calculated using Formula (1) to Formula (4) in Table E.1, where the quantity R in the $A + BR$ formula refers to the distance R_1 or R_2. The subscript 1 refers to path 1 and the subscript 2 refers to path 2. So, for example, $e_{\text{T1}} = A_{\text{T}}+R_1 \cdot B_{\text{T}}$ and e_1 is e_{IFM} or e_{ADM} for path 1.

Formula (E.1) shows the MPE having no environmental (e.g. temperature related) dependence. If the MPE's are specified in this way, then the MPE values apply to any environment satisfying the rated operating conditions (e.g. Clause 5 and Annex A) while employing reasonable, good practices for measurement (e.g. 5.2). The MPE formula could be expressed in a more complicated manner, showing specific temperature related dependence, but for testing, this would require the ability to measure the varying temperature along the beam path at the time of each measurement.

E.4 Note on range testing

A special case is when the laser tracker is aligned with the test length. That is, the case of a measurement in which the laser tracker is aligned with points 1 and 2 as shown in Figure E.2.

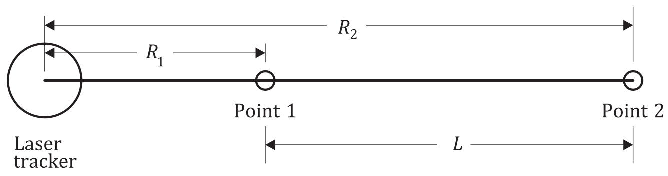


Figure E.2 — Laser tracker buck-in geometry

Point 1 establishes one end of the test length for the laser tracker measurement and point 2 the other end of the test length. Under these conditions, the two coordinate measurements are correlated, permitting Formula (E.2) to be rewritten (showing the ADM case) as

$$E_{\mathrm{Uni:0:LT,MPE}} = \left(A_{\mathrm{ADM}} + B_{\mathrm{ADM}} \cdot R_2\right) - \left(A_{\mathrm{ADM}} + B_{\mathrm{ADM}} \cdot R_1\right) = B_{\mathrm{ADM}} \cdot L \quad \text{(E.2)}$$

Here, the quantities A and B refer to either the ADM or IFM specifications in Table E.1. The length L is equal to the distance between the end points of the test length; in other words, $L = R_2 - R_1$.

E.5 Note on two-face measurement

Another special case is that of the two-face measurement. In this measurement, the coordinates of a point are first measured in the usual mode, referred to as front-sight mode, and then in the backsight mode. To put the laser tracker in backsight mode, the azimuth axis is rotated by 180° and then flipped about the elevation axis to point the laser beam back at the target. The transverse distance between the frontsight and backsight coordinates is the location error. The two-face test is a challenging test of the laser tracker performance because most of the laser tracker transverse errors are doubled. The two-face MPE (denoted $L_{\mathrm{Dia.2x1:P\&R:LT,MPE}}$) is equal to twice the value of e_{T1}.

Annex F
(informative)

Interim testing

F.1 General

Interim testing provides confidence that the laser tracker continues to perform according to specifications. The single most effective interim test of the laser tracker's correct operation and compensation is the two face test, described in 6.3. The performance of the tests in this subclause will provide confidence in the operation of the laser tracker.

Additional tests of known lengths, or reference locations to form a "network" of points in the user's facility, are also useful. With appropriate analysis, specifics regarding the geometric errors of the laser tracker can be determined using these methods.[1)]

Tests that incorporate the workpiece temperature sensor (and weather station) are also recommended.

Of course, records should be kept of interim test results so that anomalies or trends can be identified.

1) Specifics regarding the application of this technique can be found in Reference [1].

Annex G
(normative)

Testing of a stylus and retroreflector combination (SRC)

G.1 General

There are two metrological results that are important in providing confidence in measurements taking with a stylus and retroreflector combination. The first of these is a test of the system when this probing method is used, and the second is a test of the registration of this probing method to the default (SMR) probing system.

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

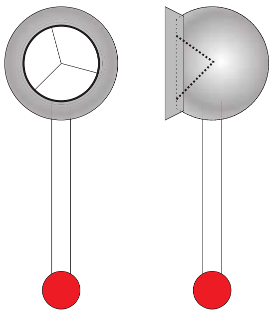


Figure G.1 — SRC (simplified)

A simplified arrangement, consisting only of the stylus and retroreflector of the SRC, is shown in Figure G.1.

G.2 Probing errors

The probe test for the SRC follows 6.2. Two tests are performed, at the locations described in Table 2. The values for $P_{\text{Form.Sph.1x25::SRC.LT}}$ and $P_{\text{Size.Sph.1x25::SRC.LT}}$ are found and compared to their respective MPEs.

G.3 Orientation-dependent errors

G.3.1 General

Different orientations of the SRC may result in the stylus having the same measurement point (C in Figure 1b). This allows the measurement of a single point with many different orientations of the SRC. Two tests are performed, at the locations described in Table 2.

NOTE Orientation of the SRC refers to the roll, pitch, and yaw of the SRC relative to the incoming beam from the laser tracker – these are not to be confused with the azimuth and elevation angles of the laser tracker.

G.3.2 Measuring equipment

A nest is used for this test that is of suitable size to accommodate the stylus used with the SRC. It is rigidly fixtured so that a range of SRC orientations will be measurable by the laser tracker.

G.3.3 Procedure

For each of the two locations for the nest, five measurement points are taken with the SRC as shown in Figure G.2 (roll of the SRC). An additional five points are taken with the SRC rotating toward and away from the laser tracker (pitch of the SRC), and five more rotating the SRC about the stylus orientation unit vector (yaw of the SRC). Thus, in total 15 measurements are performed at one location of the nest. The positions of the reflector should be widely spread over the access permitted by the nest for the roll tests, and also span at least 66 % of the stated acceptance angle for the retroreflector (and ancillary components, such as LEDs) in the pitch and yaw tests.

The manufacturer may specify the limits of roll for testing, but these shall be no less than ±45°.

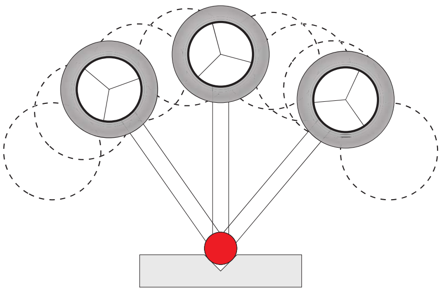


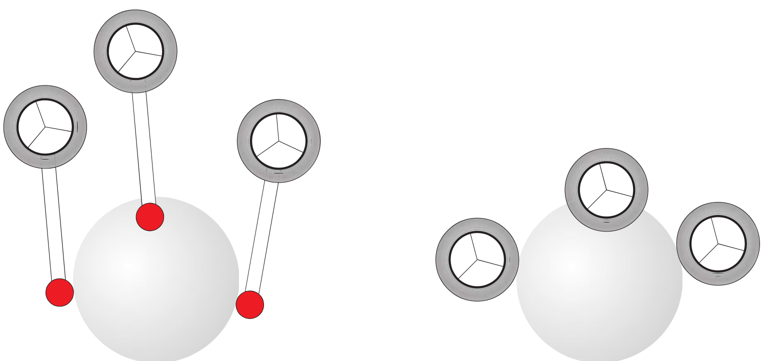
Figure G.2 — Orientation test for the SRC

G.3.4 Derivation of test results

The 15 measurement points are all of the same physical location. The ability of the instrument to locate all points in the same location is being tested. For this reason, the diameter of the minimum circumscribing sphere that contains all of the measured points is calculated. The diameter of this sphere is labelled $P_{\text{Dia.15x1::SRC.LT}}$.

G.4 Registration errors

The registration of the SRC to the main SMR probe is accomplished in the method of ISO 10360-9. A test sphere is measured with both the SRC and the SMR as shown in Figure G.3. Quantities to be measured include multiple probing system form error, $P_{\text{Form.Sph.2x25::MPS.LT}}$, multiple probing system size error, $P_{\text{Size.Sph.2x25::MPS.LT}}$, and multiple probing system location value, $L_{\text{Dia.2x25::MPS.LT}}$. The measured values are compared to specifications provided by the manufacturer, $P_{\text{Form.Sph.2x25::MPS.LT,MPE}}$, $P_{\text{Size.Sph.2x25::MPS.LT,MPE}}$, and $L_{\text{Dia.2x25::MPS.LT,MPE}}$, respectively, to determine compliance, as described in ISO 10360-9:2013, 7.1.



NOTE Only a few of the required 25 probing locations are shown in Figure G.3

Figure G.3 — Multi-probe testing for SRC (left) and SMR (right)

NOTE The results may be expressed in the form $P_{\text{Size.Sph.2x25:SMR,SRC:MPS.LT}}$.

G.5 Symbols pertaining to this annex

Table G.1 — Quantities related to SRC tests

Symbol	Meaning
$P_{\text{Form.Sph.1x25::SRC.LT}}$	Probing form error for SRC
$P_{\text{Size.Sph.1x25::SRC.LT}}$	Probing size error for SRC
$P_{\text{Dia.15x1::SRC.LT}}$	Orientation error for SRC
$P_{\text{Form.Sph.1x25::SRC.LT,MPE}}$	Maximum permissible error of probing form for SRC
$P_{\text{Size.Sph.1x25::SRC.LT,MPE}}$	Maximum permissible error of probing size for SRC
$P_{\text{Dia.15x1::SRC.LT,MPE}}$	Maximum permissible error of orientation for SRC
$P_{\text{Form.Sph.}n\text{x25::MPS.LT}}$	Multiple probing system form error
$P_{\text{Size.Sph.}n\text{x25::MPS.LT}}$	Multiple probing system size error
$L_{\text{Dia.}n\times\text{25::MPS.LT}}$	Multiple probing system location error
$P_{\text{Form.Sph.}n\text{x25::MPS.LT,MPE}}$	Maximum permissible multiple probing system form error
$P_{\text{Size.Sph.}n\text{x25::MPS.LT,MPE}}$	Maximum permissible multiple probing system size error
$L_{\text{Dia.}n\times\text{25::MPS.LT,MPE}}$	Maximum permissible multiple probing system location error

Annex H
(normative)

Testing of an optical distance sensor and retroreflector combination (ODR)

H.1 General

Systems are available which collect points using an optical distance sensor (see Figure H.1), where the location and orientation of the optical distance sensor are determined using the laser tracker.

As in Annex G, there are two types of errors to be evaluated: probing errors and registration errors.

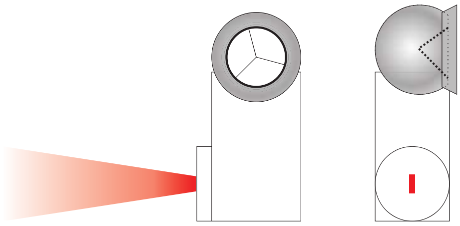


Figure H.1 — Simplified representation of the ODR

H.2 Probing errors

Measurements are performed according to ISO 10360-8:2013, 6.2. Quantities to be measured include probing form error, $P_{\text{Form.Sph.1×25::ODR.LT}}$, probing dispersion error, $P_{\text{Form.Sph.D95\%::ODR.LT}}$, probing size error, $P_{\text{Size.Sph.1×25::ODR.LT}}$, and probing size error All, $P_{\text{Size.Sph.All::ODR.LT}}$. The measured values are compared to specifications provided by the manufacturer, $P_{\text{Form.Sph.1×25::ODR.LT,MPE}}$, $P_{\text{Form.Sph.D95\%::ODR.LT,MPE}}$, $P_{\text{Size.Sph.1×25::ODR.LT,MPE}}$, and $P_{\text{Size.Sph.All::ODR.LT,MPE}}$, respectively, to determine compliance, as described in ISO 10360-8:2013, 7.1.

If multiple orientations of the ODR are permitted in normal operation, these orientations should be utilized in the measurement of the test sphere.

NOTE Orientation of the ODR refers to the roll, pitch, and yaw of the ODR relative to the incoming beam from the laser tracker, these are not to be confused with the azimuth and elevation angles of the laser tracker.

H.3 Registration errors

The registration of the ODR to the main SMR probe is accomplished in the method of ISO 10360-9. A test sphere is measured with both the ODR and the SMR as shown in Figure H.2. Quantities to be measured include multiple probing system form error, $P_{\text{Form.Sph.2x25::MPS.LT}}$, multiple probing system size error, $P_{\text{Size.Sph.2x25::MPS.LT}}$, and multiple probing system location value, $L_{\text{Dia.2x25::MPS.LT}}$. The measured values are compared to specifications provided by the manufacturer, $P_{\text{Form.Sph.2x25::MPS.LT,MPE}}$, $P_{\text{Size.Sph.2x25::MPS.LT,MPE}}$, and $L_{\text{Dia.2x25::MPS.LT,MPE}}$, respectively, to determine compliance, as described in ISO 10360-9:2013, 7.1.

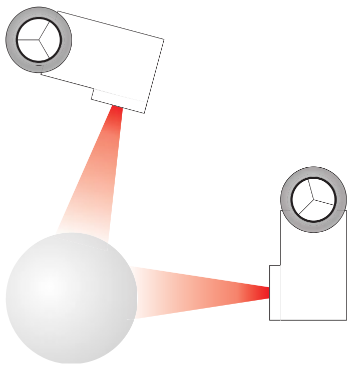


Figure H2 — Measurement of the test sphere using the ODR

H.4 Flat form measurement

The flat form measurement is performed in any one location of the measuring volume. Measurements are performed according to ISO 10360-8:2013, 6.4. If desired, position (2) of the flat may be obtained by leaving the flat in position (1) and changing the orientation of the scanner.

The quantity $E_{\text{Form.Pla.D95\%:ODR}}$ is measured and compared to the $E_{\text{Form.Pla.D95\%:ODR,MPE}}$ specifications provided by the manufacturer to determine compliance, as described in ISO 10360-8:2013, 7.1.

H.5 Symbols pertaining to this annex

Table H.1 — Quantities related to ODR tests

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)
$P_{\text{Size.Sph.All::ODR.LT}}$	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)
$P_{\text{Form.Sph.}n\text{x25::MPS.LT}}$	Multiple probing system form error
$P_{\text{Size.Sph.}n\text{x25::MPS.LT}}$	Multiple probing system size error
$L_{\text{Dia.}n \times \text{25::MPS.LT}}$	Multiple probing system location error
$P_{\text{Form.Sph.}n\text{x25::MPS.LT,MPE}}$	Maximum permissible multiple probing system form error
$P_{\text{Size.Sph.}n\text{x25::MPS.LT,MPE}}$	Maximum permissible multiple probing system size error
$L_{\text{Dia.}n\times\text{25::MPS.LT,MPE}}$	Maximum permissible multiple probing system location error

Annex I
(informative)

Relation to the GPS matrix model

I.1 General

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

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

This part of ISO 10360 specifies the acceptance test for verifying that the performance of a laser tracker used for measuring point-to-point distances is as stated by the manufacturer. It also specifies the reverification test that enables the user to periodically reverify the performance of a laser tracker used for measuring point-to-point distances.

I.3 Position in the GPS matrix model

This part of ISO 10360 is a general GPS standard, which influences chain link F of the chains of standards on size, distance, radius, angle, form, orientation, location, and run-out in the general GPS matrix, as graphically illustrated in Table I.1.

Table I.1 — ISO GPS Standards 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	Calibrations
Size						•	
Distance						•	
Form						•	
Orientation						•	
Location						•	
Run-out						•	
Profile surface texture							
Areal surface texture							
Surface imperfections							

I.4 Related International Standards

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

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[4] ISO 17450-1:2011, *Geometrical product specifications (GPS) — General concepts — Part 1: Model for geometrical specification and verification*

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

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

[7] ISO 10360-5, *Geometrical product specifications (GPS) — Acceptance and reverification tests for coordinate measuring machines (CMM) — Part 5: CMMs using single and multiple stylus contacting probing systems*

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