Current Developments of Laser Tracker Testing Standards
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Published Laser Tracker Standards

International Standard

- ISO 10360-10:2016 «Geometrical Product Specifications (GPS) – Acceptance and reverification tests for coordinate measuring systems (CMS) – Part 10: Laser Trackers for measuring point-to-point distances»

National Standards

- US: ASME B89.4.19-2006 «Performance Evaluation of Laser-Based Spherical Coordinate Measurement Systems»

- DE: VDI 2617 Blatt 10 «Accuracy of coordinate measuring machines - Characteristics and their checking - Acceptance and reverification tests of laser trackers"

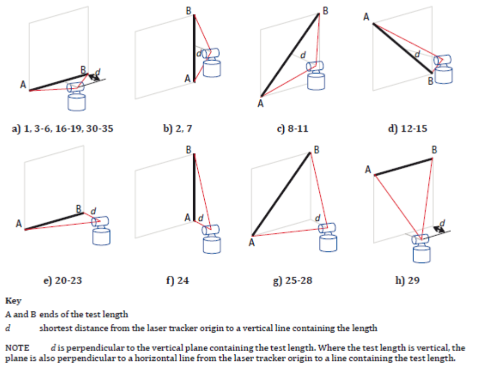

Figure 3 — Positions for test lengths (positions 1 - 29)

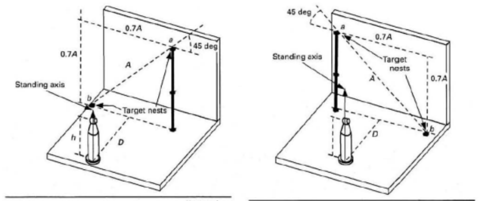

Table 4 Right Diagonal Length Measurement System Test

Position Number	Distance, D (Approximate)	Measured Horizontal Angle to Target Nest α, deg
1	1.2A	0
2	1.2A	90
3	1.2A	180
4	1.2A	270
5	2.7A	0
6	2.7A	90
7	2.7A	180
8	2.7A	270

GENERAL NOTE: The lengths and angles are approximate.

Table 5 Left Diagonal Length Measurement System Test

Position Number	Distance, D (Approximate)	Measured Horizontal Angle to Target Nest α, deg
1	1.2A	0
2	1.2A	90
3	1.2A	180
4	1.2A	270
5	2.7A	0
6	2.7A	90
7	2.7A	180
8	2.7A	270

GENERAL NOTE: The lengths and angles are approximate.

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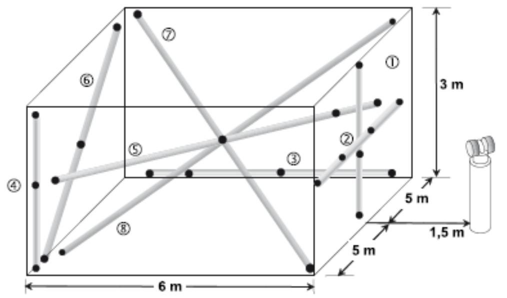

Bild 3. Beispiel zur Anordnung der Messlinien für die Prüfung der Längenmessabweichung (acht Messlinien)

Figure 3. Example of arranging the measuring lines for testing the error of indication for size measurement (eight measuring lines)

Under Review

Under Review

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ASME B89.4.19-2006 Revision

- Revision initiated November 2017
- Project lead by NIST, project leader Bala Muralikrishnan
- Main objectives of the revision of ASME B89.4.19-2006
  - Update Annex F to include a comprehensive interim test method
  - Provide clarification on ADM traceability to establish reference length for performance test
  - Small corrections of main body

- Non-goal: Changes to section 6 Performance Test method defined in main body
  - Despite of known weaknesses of test methods
    "There is considerable symmetry in the placement of the length that result in poor or no sensitivity in numerous geometric misalignment terms in trackers." see **[4]**

- Goal for publishing new revision: Q2-2019

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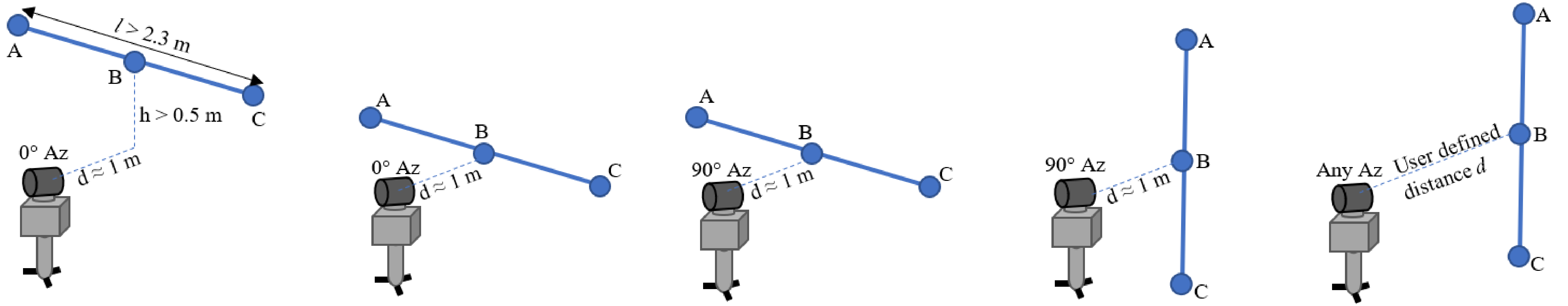
ASME B89.4.19 - Agreed Interim Test Method

- Interim test method based on NIST IR8016 **[1]** with small adaptations
- Interim test comprises the following parts
  - Two-Face Test
  - Length Measurements (symmetric and asymmetric positions)
  - Orient-to-Gravity Test

- Test Setup for two-face tests and length measurements (combined setup)

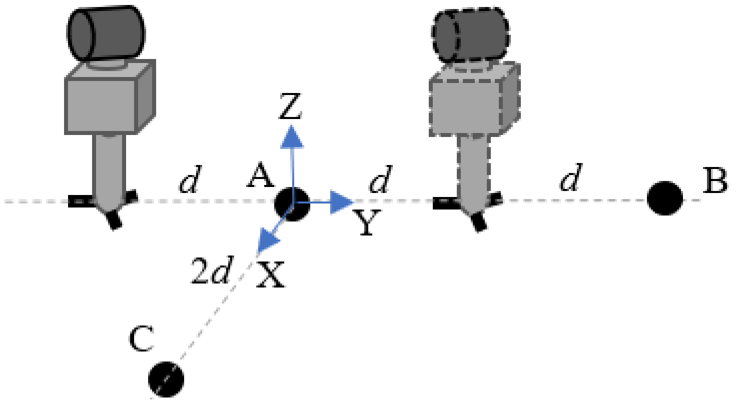


Position 1 Position 2 Position 3 Position 4 Position 5

ASME B89.4.19 - Agreed Interim Test Method ctd.

- Orient-to-Gravity Test
  - Method to detect inclinometer errors

- Test setup for Orient-to-Gravity test
  - Establish a level frame on position 1
  - Move origin to point A, clocking towards point B
  - Determine height differences A-B, A-C
  - Tilt Laser Tracker slightly and repeat steps above
  - Move Laser Tracker optionally to oosition 2 and repeat same measurements
  - Compare height differences between the three setups



Position 1 Position 2

ISO 10360-10 Revision

- Revision initiated in September 2017 at ISO/TC213 WG10 meeting in Tokyo
- Project leader, Prof. Ed Morse, UNCC Charlotte
- Main objective of revision
  - Reduction of effort required to perform acceptance and verification test defined in chapter 6 due to low user acceptance
  - Reduce number of length measurements significantly (currently 105 length measurements)
  - Add user defined two-face measurements
  - Add interim test (ideally same method as defined in ASME B89.4.19)
  - Adapt new approach to express length measurement error ($\mathbf{E_{Avg}}$ instead of $\mathbf{E_{Uni}}$ / $\mathbf{E_{Bi}}$)
  - Add repeatablility test in case of introduction of $\mathbf{E_{avg}}$

- Committee draft (CD) with reduced set of length measurements prepared for ISO member states for commenting
- NIST asked to do a sensitivity analysis if number of length measurement can be further reduced
- Time frame for republishing of ISO 10360-10: > 3 years

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ISO 10360-10 Revision, ctd.

- Current discussion to reduce number of spatial length measurement, based on dedicated investigations by NIST.
  - “*Core set of 41 length measurements was determined from a sensitivity analysis performed using mathematical error models for different tracker designs.*” **[4]**
    -> This set of length measurement tests is sufficient to detect all known geometrical misalignment parameters of a Laser Tracker.
    -> Requirement to do 105 measurement just for consistency with other 10360 series standards.
    -> ASME B89.4.19 does 35 length 3 times (repeatability) = 105 measurements
  - New approach is to reduce length measurements to 41 (or even below) and add a separate repeatability test with less effort the establish the measurement setup

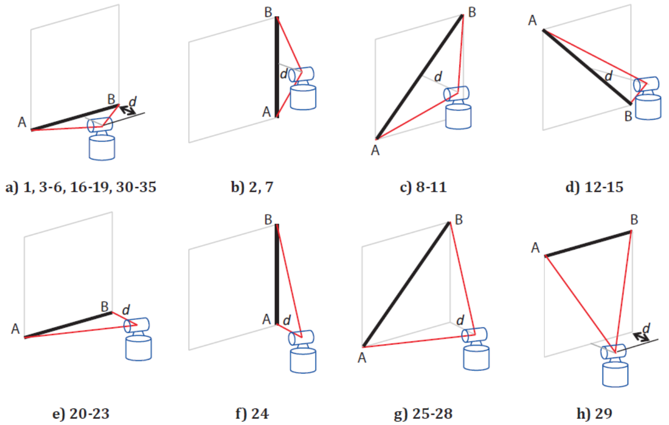

Table 4 — Measurement positions

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.

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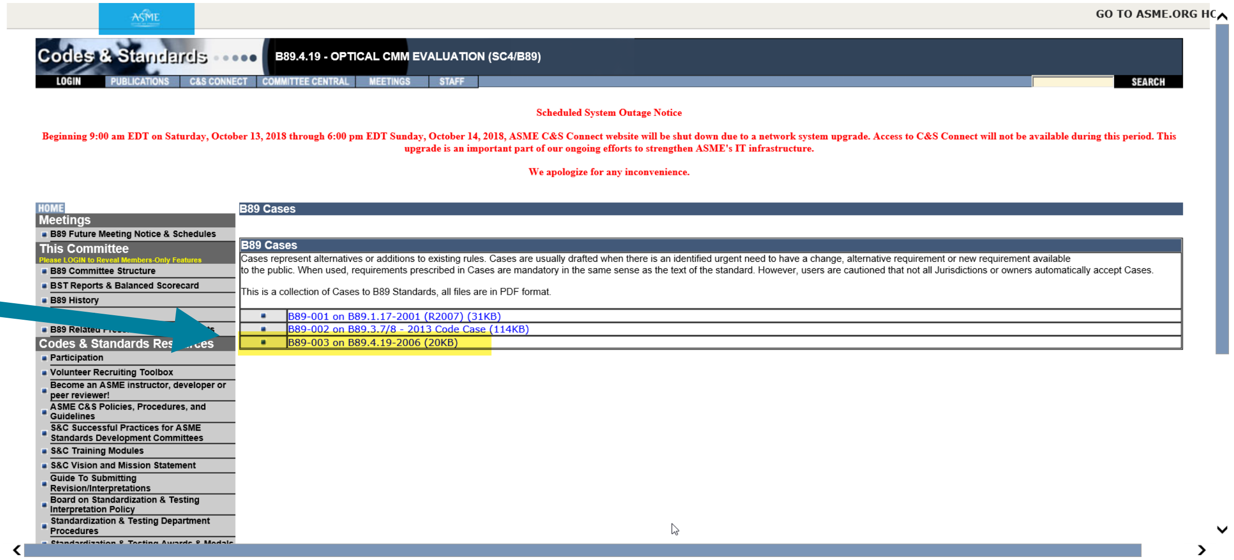
Summary

- ASME B89.4.19
  - New revision should be republished in 2019
  - Comprehensive interim test, based on modified NIST IR8016
  - Knows weaknesses of main test procedures remain unchanged
  - Traceable reference lengths can be established by ADM measurements too (measurement capability index Cm ≥ 4), Code Case recently published on ASME B89 website



- ISO 10360-10
  - New version should be published around 2021/2022
  - Potentially significant reduction of length measurements in acceptance test -> larger acceptance by users
  - Same or similar interim test as ASME B89.4.19 -> Test procedure and analysis can be implemented in standard metrology software packges

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References

[1] Vincent D. Lee, Christopher Blackburn, Bala Muralikrishnan, Daniel Sawyer, Mark Meuret, Aaron Hudlemeyer: *“A Proposed Interim Check for Field Testing a Laser Tracker’s 3-D Length Measurement Capability Using a Calibrated Scale Bar as a Reference Artifact”*, U.S. Department of Commerce,National Institute of Standards and Technology, September 2014, http://dx.doi.org/10.6028/NIST.IR.8016

[2] ASME B89.4.19-2006 *Performance Evaluation of Laser-Based Spherical Coordinate Measurement Machines*

[3] ISO 10360-10:2016(E), *“Geometrical Product Specifications (GPS) — Acceptance and reverification tests for coordinate measuring systems (CMS) — Part 10: Laser trackers for measuring point-to-point distances”*

[4] B. Muralikrishnan, D. Sawyer, C. Blackburn, S. Phillips, B. Borchardt, W.T. Estler, *ASME B89.4.19 Performance Evaluation Tests and Geometric Misalignments in Laser Trackers*, Journal of Research of the National Institute of Standards and Technology, Volume 114, Number 1, January-February 2009 [J. Res. Natl. Inst. Stand. Technol. 114, 21-35 (2009)]

[5] B. Muralikrishnan, D. Sawyer, C. Blackburn, S. Phillips, C. Shakarji, E. Morse, R. Bridges*, Choosing Test Positions for Laser Tracker Evaluation and Future Standards Development,* The Journal of the CMSC, Vol. 6, No. 1 Spring 2011

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THANK YOU!

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