INTRODUCTION

RECENT DEVELOPMENTS IN THE STANDARDIZATION AND TESTING OF LASER TRACKERS

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OVERVIEW

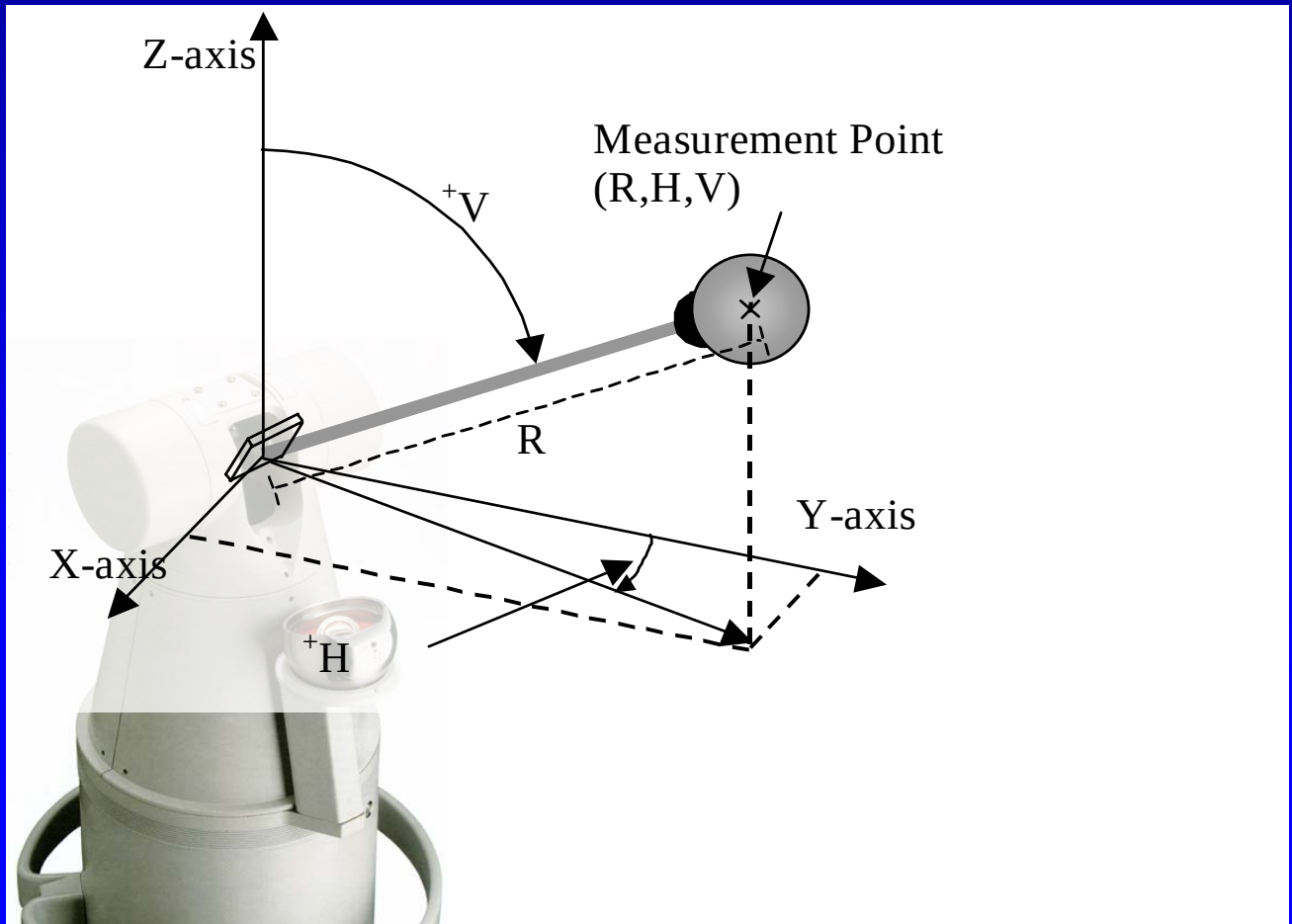
1. ASME B89.4.19 – instruments that may be tested according to this standard
2. Performance Tests
3. Performance Specifications
4. NIST Laser Tracker Calibration Facility
5. Questions?

Laser Tracker Performance Evaluation Standard: Status Report

- ***ASME B89.4.19 Performance Evaluation of Laser Based Spherical Coordinate Measuring Systems***
- **Should be available in the next few months**

Laser Tracker Performance Evaluation Standard: Status Report

Spherical coordinate measuring systems determine 3-D coordinates using a displacement or distance measuring device as well as two angle measuring encoders



Laser Tracker Performance Evaluation Standard

Instruments included in the Standard

- Laser trackers and total stations used as industrial 3-D measuring systems

Instruments that are excluded

- Multi-lateration systems (ranging system only trackers).
- Theodolites and other instruments used exclusively for land or geodetic surveying

Laser Tracker Performance Evaluation Standard

What is not tested

- Algorithms
  1. Bundle adjust algorithms
  2. Geometric fit algorithms
- Laser tracker part temperature compensation
- Retroreflector errors

Performance Tests

Primarily Length Measurement Tests

- System Tests - Measurement of known length (reference length) in various positions and orientation that are sensitive to error sources of the laser tracker
- Ranging tests evaluate the interferometer (IFM) and/or Absolute Distance Meter (ADM) measurement capability

Two-Face Measurements

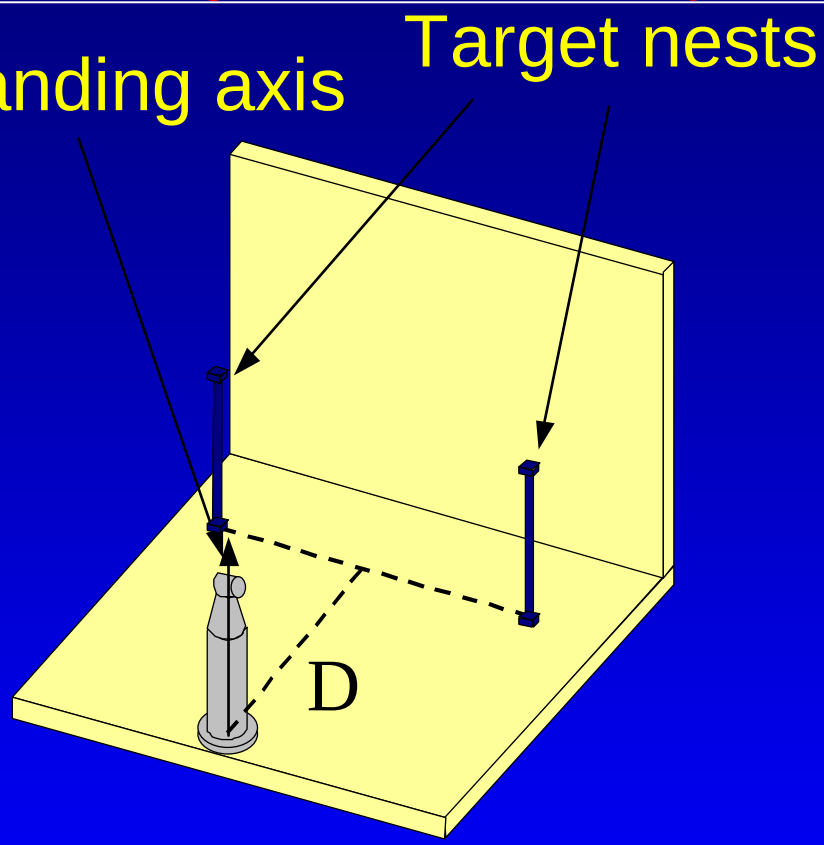
Performance Tests

Length Measurement Systems Tests – reference length (≈ 2.3 meters in length) measured in various orientation and at specified distances relative to the laser tracker.

- Horizontal length measurement system tests
- Vertical length measurement system tests
- Right diagonal length measurement system tests
- Left diagonal length measurement system tests
- Two users specified length measurements

Performance Tests

Horizontal length measurement system test

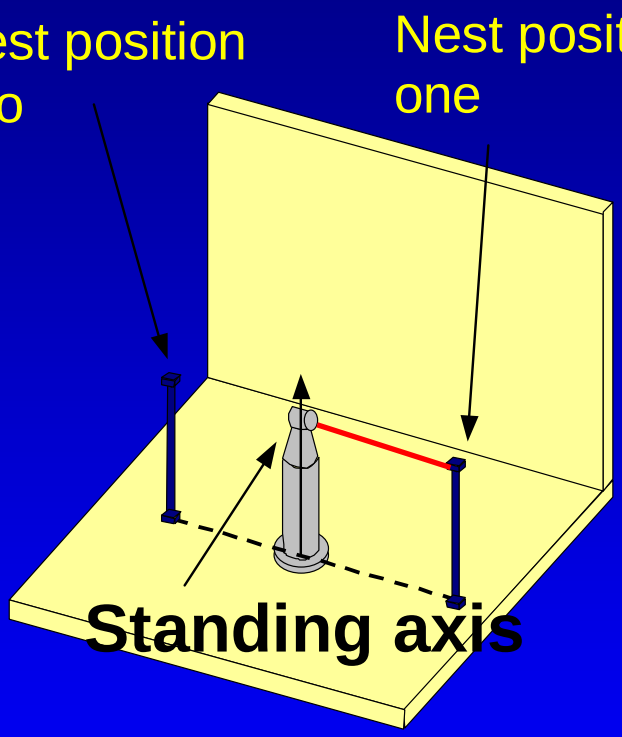


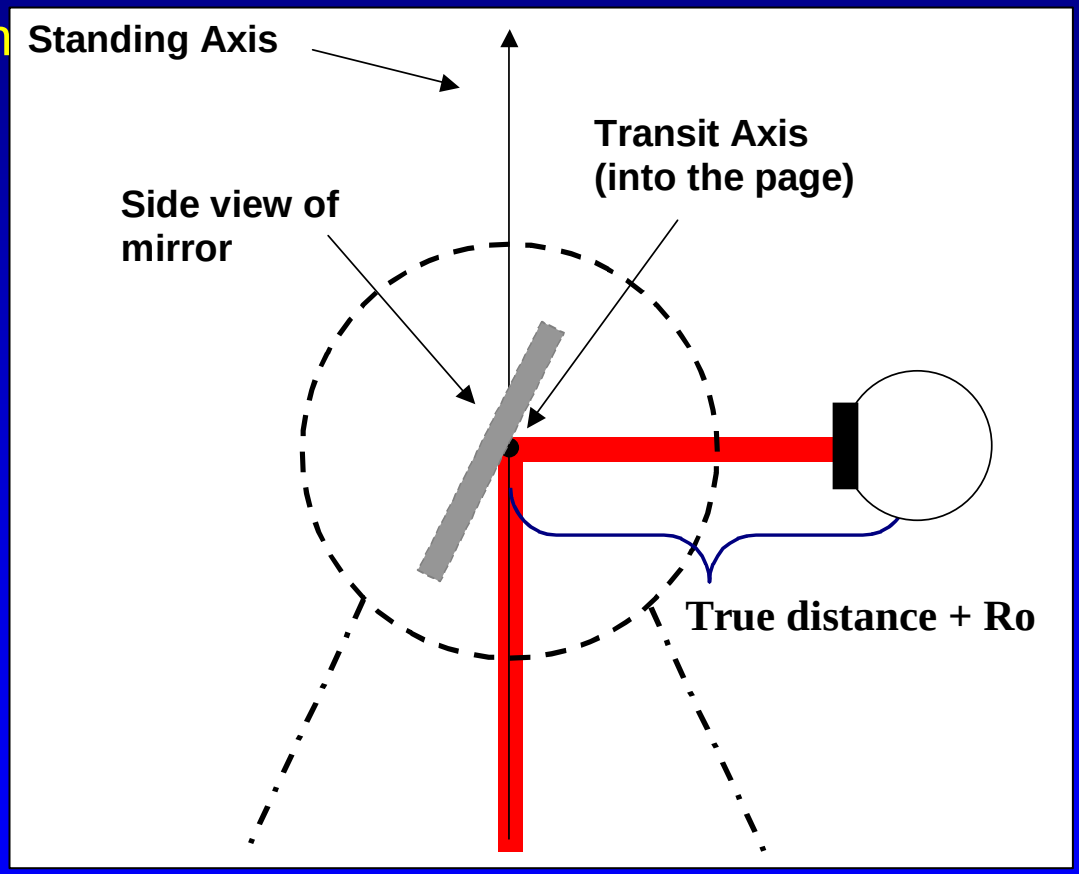
Reference length is measured in three positions a distance, D, from the tracker. In each position the tracker is rotated about the standing axis. The distance D is between 0.2 and 6.3 meters in length.

Test of horizontal angle measurement capability

Performance Tests

Horizontal length measurement system test

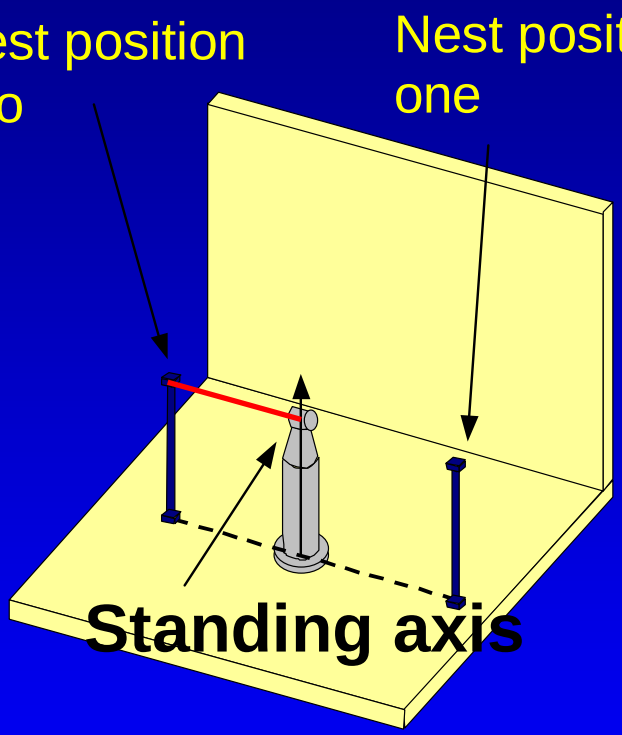


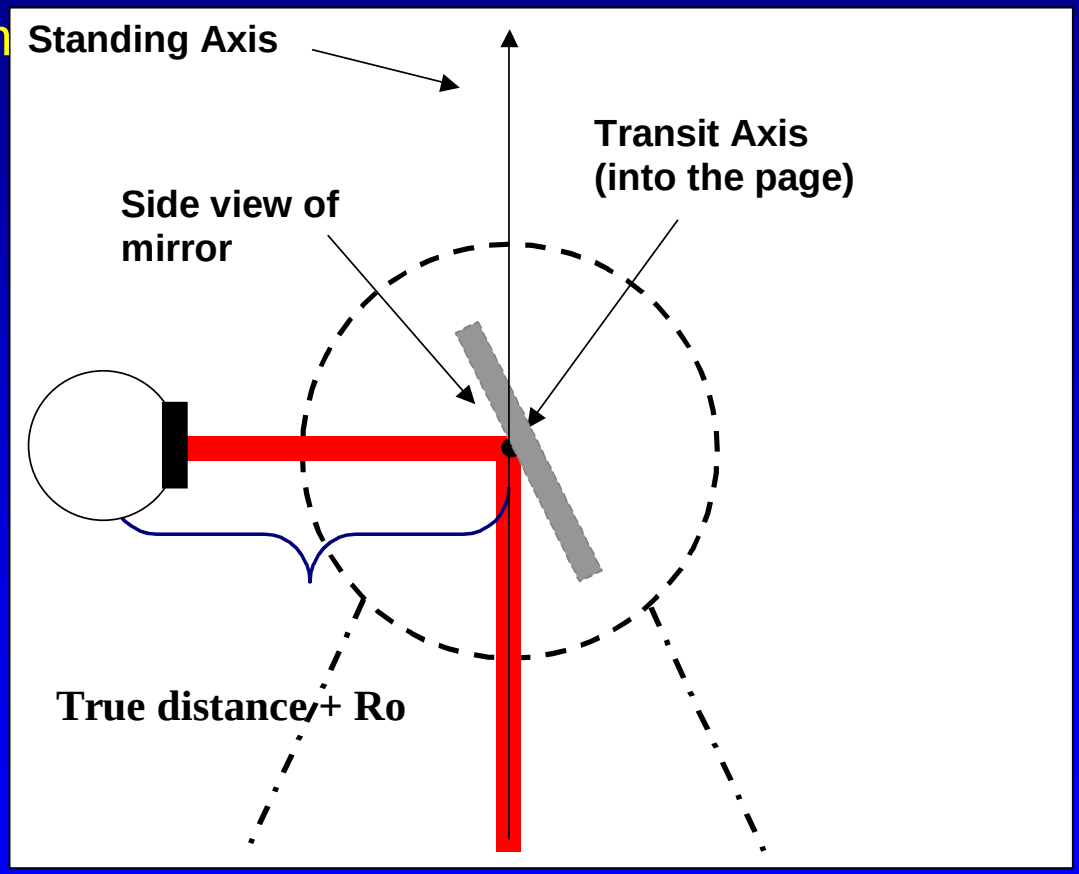


A small distance D, approximately 230 mm, is required to sample the R0 error.

Performance Tests

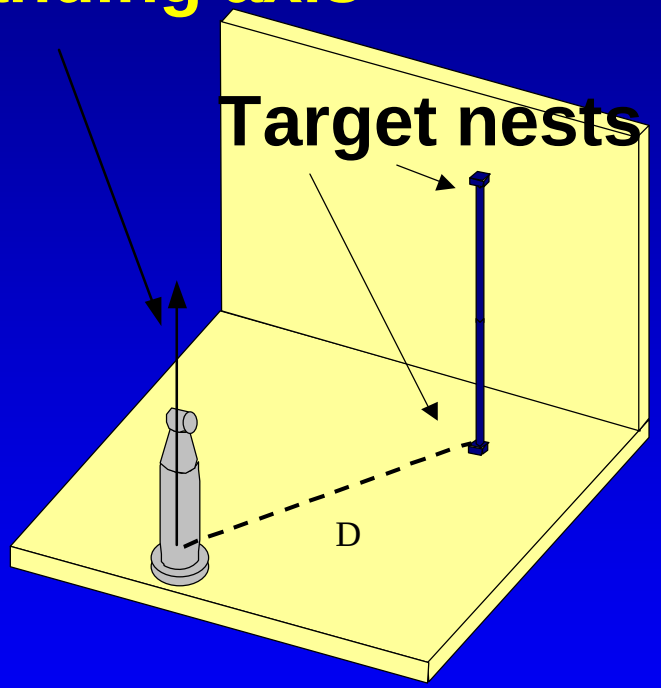
Horizontal length measurement system test





Performance Tests

Vertical length measurement system test

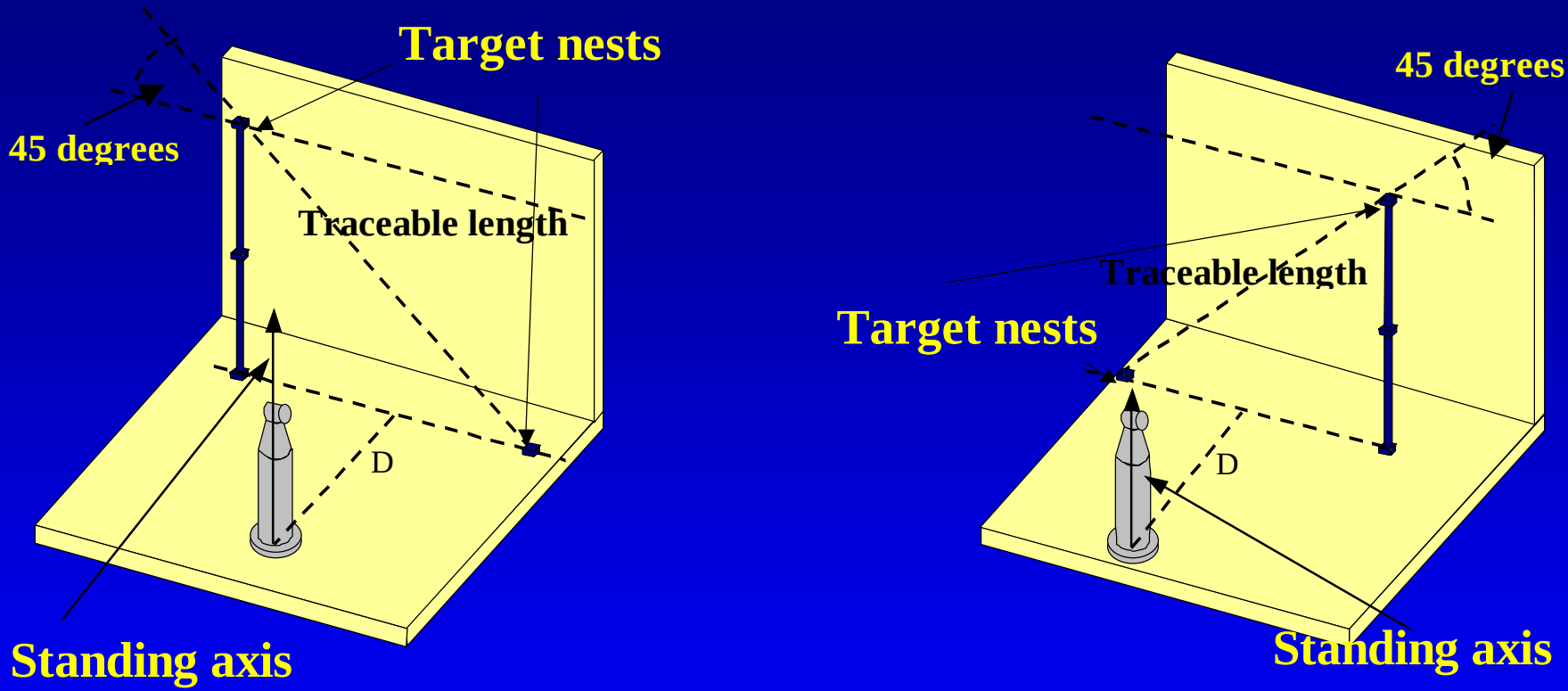


Reference length is measured in two positions a distance, D, from the tracker. In each position the tracker is rotated about the standing axis. D is between 2.3 and 6.3 meters in length.

Test of vertical angle measurement capability

Performance Tests

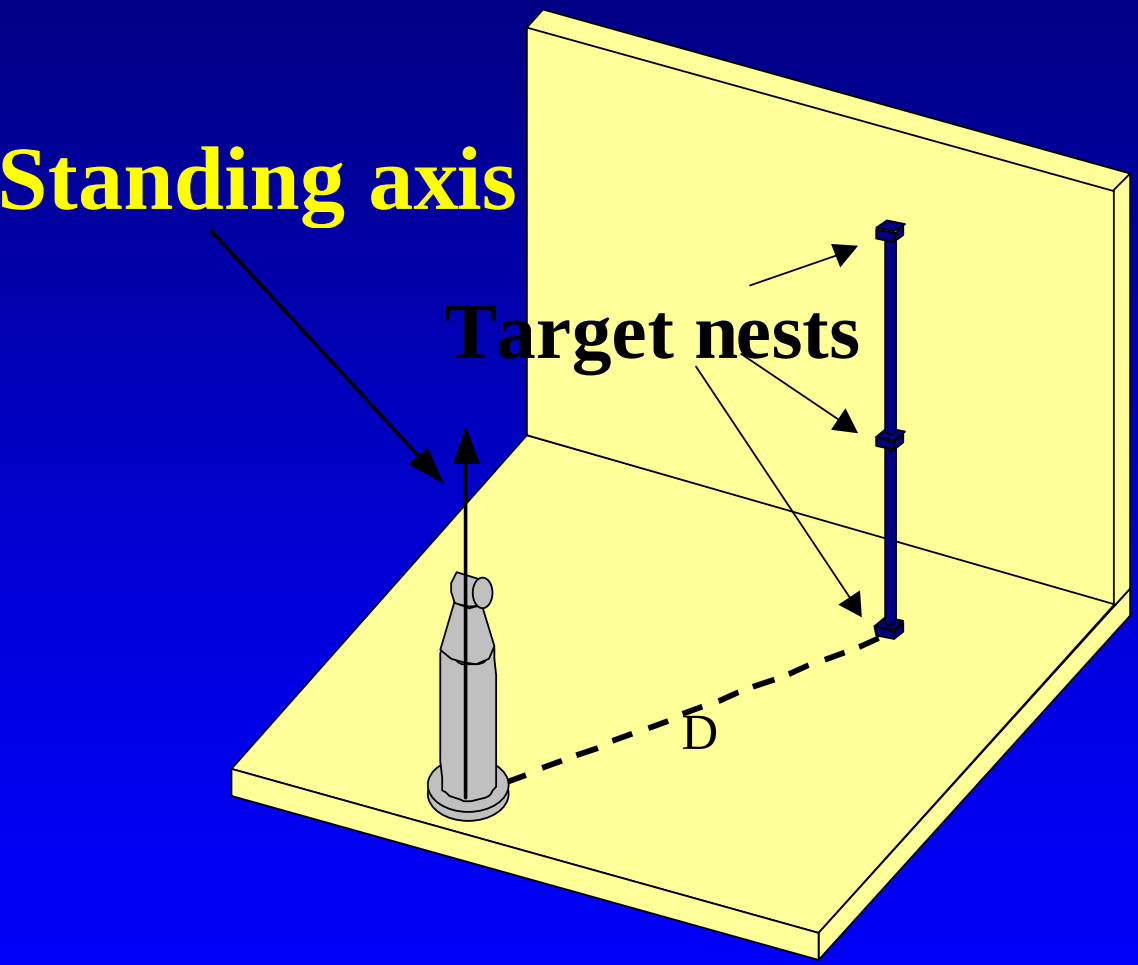
Right and left diagonal length measurement system tests



Test of combination of vertical and horizontal angle measurement capability

Performance Tests

Two-face system tests



Reference lengths are measured in three positions a distance, D, from the tracker. In each position the tracker is rotated about the standing axis. D is between 1.5 and 6.3 meters in length.

Performance Tests

Ranging Tests

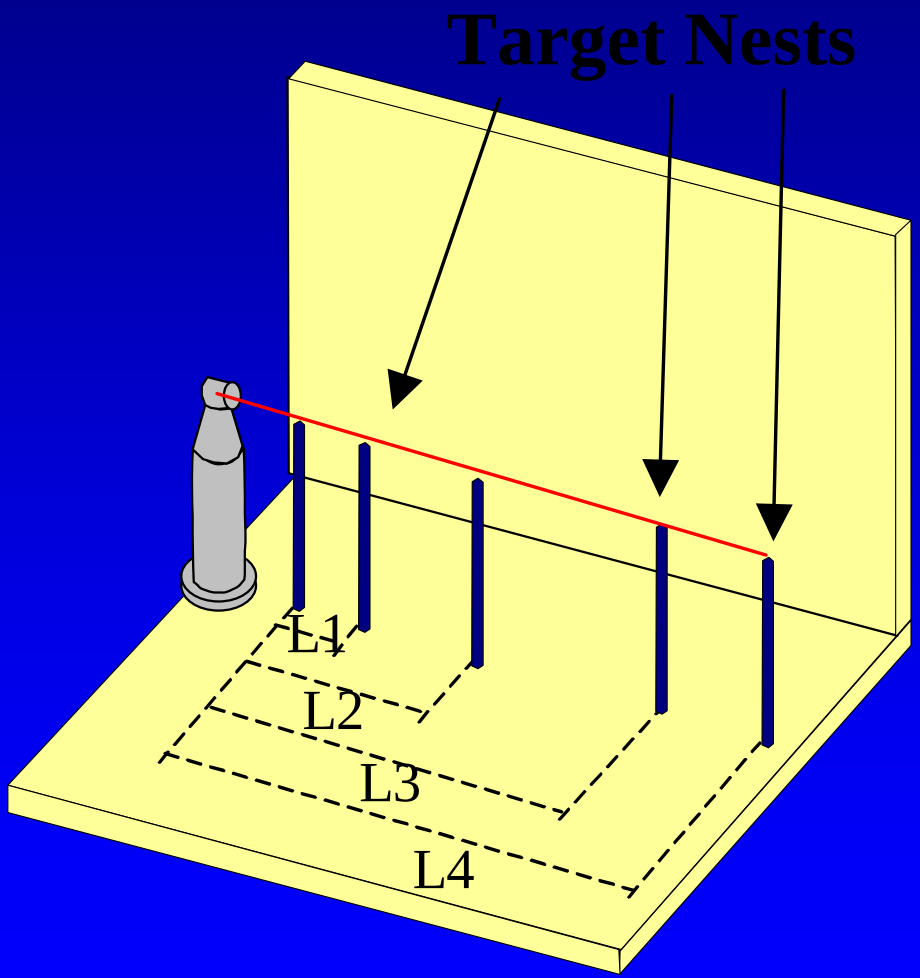
Tests of ranging systems

1. Measurement of a long lengths (longest ≈ 26 meters long)
2. Short length measurements
3. Calibration report for the IFM, tested in accordance with procedures described in the draft Standard ASME B89.1.8

Performance Tests

Ranging tests

ADM tests (long length measurements)



Four reference length measurements are required. Two additional user selected lengths shall be measured between the required maximum and minimum lengths (L1 ≈ 6 m and L4≈26 m)

Performance Tests

Ranging tests

IFM tests

- Long length (Same as ADM tests)
- Short length measurements for IFM

  IFM mature technology

  Errors primarily length dependent

  Need only a few points to project errors over long range

  Longest required length approximately 2.3 meters

Performance Tests

Ranging tests

IFM calibration procedure

- Uses offset and linear terms provided from the laser calibration report to determine conformance to specifications

Performance Specifications: Evaluation of Test Results

Errors ≤ Maximum Permissible Error (MPE)

- Decision rules are specified
- Formula for calculating MPE for any point-to-point length inside the laser tracker measuring envelope must be provided

Performance Specifications: Specification Sheets

AN AMERICAN NATIONAL STANDARD

Performance Evaluation of Laser Based Spherical Coordinate Measurement Systems

ASME B89.4.19-200X

DRAFT - WTE
Friday November 25, 2005

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THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

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Form 3.1 General Specifications and Rated Conditions

General Specifications and Rated Conditions

RATED CONDITIONS

Measurement envelope
Distance — Min. _____ meters Max. _____ meters
Range of horizontal angles _____ degrees
Range of vertical angles _____ degrees

a. Temperature Range
Operating — Min. ____ °C Max. _____ °C
Thermal Gradient Limits — Max. ____ °C/meter Max. _____ °C/hr max.

b. Humidity Range
Operating — Min. ____ %RH Max. _____ %RH

c. Barometric Pressure Range
Operating — Min. _____ mm Hg Max. _____ mm Hg

d. Ambient light - The manufacturer shall identify conditions, if any, under which ambient light degrades specifications.

e. Electrical - The electrical power supplied to a machine can affect its ability to perform accurate and repeatable measurements. This is particularly true when a machine uses some form of computer for any control or readout function.
Voltage _____ V Current _____ A
Frequency _____ Hz Surge/Sag _____ V
Max Transient Voltages and duration: _____ V _____ s

f. Probe Type - The probe diameter and reflector type (e.g., cube corner, glass prism) used during performance testing shall be specified.
Diameter _____mm reflector type: _____

g. Sampling Strategy - The manufacturer shall state the measurement acquisition time (averaging time) and sampling frequency (points per second) to meet specification.
Acquisition time: _____ s Frequency: _____ points/s

LIMITING CONDITIONS

h. Temperature Range
Min. ____ °C Max. _____ °C

i. Humidity Range
Min. _____ %RH Max. _____ %RH

k. Barometric Pressure Range
Min. _____ mm Hg Max. _____ mm Hg

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Form 3.2 MPE Specifications and Test Results

Manufacturer's Performance Specifications & Test Results

	IFM Specifications and Test Results			ADM Specifications and Test Results		
Test (positions)	MPE_{IFM}	δ_{max} or Δ_{max} *	Pass	MPE_{ADM}	δ_{max} or Δ_{max} *	Pass
Horizontal (1)						
Horizontal (2,3,4,5)						
Horizontal (6,7,8,9)						
Vertical (1,2,3,4)						
Vertical (5,6,7,8)						
Right Diagonal (1,2,3,4)						
Right Diagonal (5,6,7,8)						
Left Diagonal (1,2,3,4)						
Left Diagonal (5,6,7,8)						
User Selected (1)						
User Selected (2)						
Two Face (1,2,3,4)		†			†	
Two Face (5,6,7,8)		†			†	
Two Face (9,10,11,12)		†			†	
IFM Ranging Ref *L* (1) =		‡				
IFM Ranging Ref *L* (2) =		‡				
IFM Ranging Ref *L* (3) =		‡				
IFM Ranging Ref *L* (4) =		‡				
ADM Ranging Ref *L* (1) =						
ADM Ranging Ref *L* (2) =						
ADM Ranging Ref *L* (3) =						
ADM Ranging Ref *L* (4) =						
ADM Ranging Ref *L* User (1) =						
ADM Ranging Ref *L* User (2) =						
Formula for calculating the *MPE* or attach *MPE* specification sheet						

Test Performed by: _____ Date _____ Instrument Serial Number: _____
C_{IFM} for IFM System tests: _____; C_{IR} for IFM Ranging tests: _____ IF $1 \le C_{IFM} < 2$ Check ☐ "Low C_{IFM}"
C_{ADM} for ADM System tests: _____; C_{IR} for ADM Ranging tests: _____ IF $1 \le C_{IR} < 2$ Check ☐ "Low C_{IR}"
Final Test Results (Pass/Fail): _____
Notes: The IFM columns must contain specifications and results for laser trackers with IFM only, the ADM columns must contain specifications and results for instruments with ADM only, and both pairs of columns must contain specifications and results for instruments with both an IFM and an ADM.

* δ for length system results, Δ for Two-Face results; see sections 7.1 and 7.2
† Two-Face Tests may be performed with either an IFM or an ADM
‡ These results can be: results from long reference lengths, or computed from short reference lengths (see Section 7.3.1), or computed from the laser interferometer calibration certificate (see Section 7.3.1)

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Form 3.1 General Specifications and Rated Conditions

General Specifications and Rated Conditions

RATED CONDITIONS

Measurement envelope

Distance	Min. _____ meters	Max.	_____	meters
Range of horizontal angles			_____	degrees
Range of vertical angles			_____	degrees

a. Temperature Range

Operating	Min.	____ °C	Max.	_____ °C
Thermal Gradient Limits	Max.	____ °C/meter	Max.	_____ °C/hr max.

b. Humidity Range

Operating	Min.	____ %RH	Max.	_____ %RH

c. Barometric Pressure Range

Operating	Min. _____ mm Hg		Max.	_____ mm Hg

d. Ambient light - The manufacturer shall identify conditions, if any, under which ambient light degrades specifications.

e. Electrical - The electrical power supplied to a machine can affect its ability to perform accurate and repeatable measurements. This is particularly true when a machine uses some form of computer for any control or readout function.

Voltage	_____ V	Current	_____ A
Frequency	_____ Hz	Surge/Sag	_____ V
Max Transient Voltages and duration:	_____ V		_____ s

f. Probe Type - The probe diameter and reflector type (e.g., cube corner, glass prism) used during performance testing shall be specified.

Diameter _____mm reflector type: _____

g. Sampling Strategy - The manufacturer shall state the measurement acquisition time (averaging time) and sampling frequency (points per second) to meet specification.

Acquisition time: _____ s Frequency: _____ points/s

LIMITING CONDITIONS

h. Temperature Range

Min. ____ °C Max. _____ °C

i. Humidity Range

Min. _____ %RH Max. _____ %RH

k. Barometric Pressure Range

Min. _____ mm Hg Max. _____ mm Hg

Form 3.2 MPE Specifications and Test Results

Manufacturer's Performance Specifications & Test Results						
	IFM Specifications and Test Results			ADM Specifications and Test Results		
Test (positions)	MPE_{IFM}	δ_{max} or Δ_{max}*	Pass	MPE_{ADM}	δ_{max} or Δ_{max}*	Pass
Horizontal (1)						
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ADM Ranging Ref *L* (4) =						
ADM Ranging Ref *L* User (1) =						
ADM Ranging Ref *L* User (2) =						
Formula for calculating the *MPE* or attach *MPE* specification sheet						

Test Performed by: _____ Date _____ Instrument Serial Number: _____

C_{IFM} for IFM System tests: _____; C_{IR} for IFM Ranging tests: _____ IF $1 \le C_{IFM} < 2$ Check ☐ "Low_C_{IFM}"

C_{ADM} for ADM System tests: _____; C_{IR} for ADM Ranging tests: _____ IF $1 \le C_{IR} < 2$ Check ☐ "Low_C_{IR}"

Final Test Results (Pass/Fail): _____

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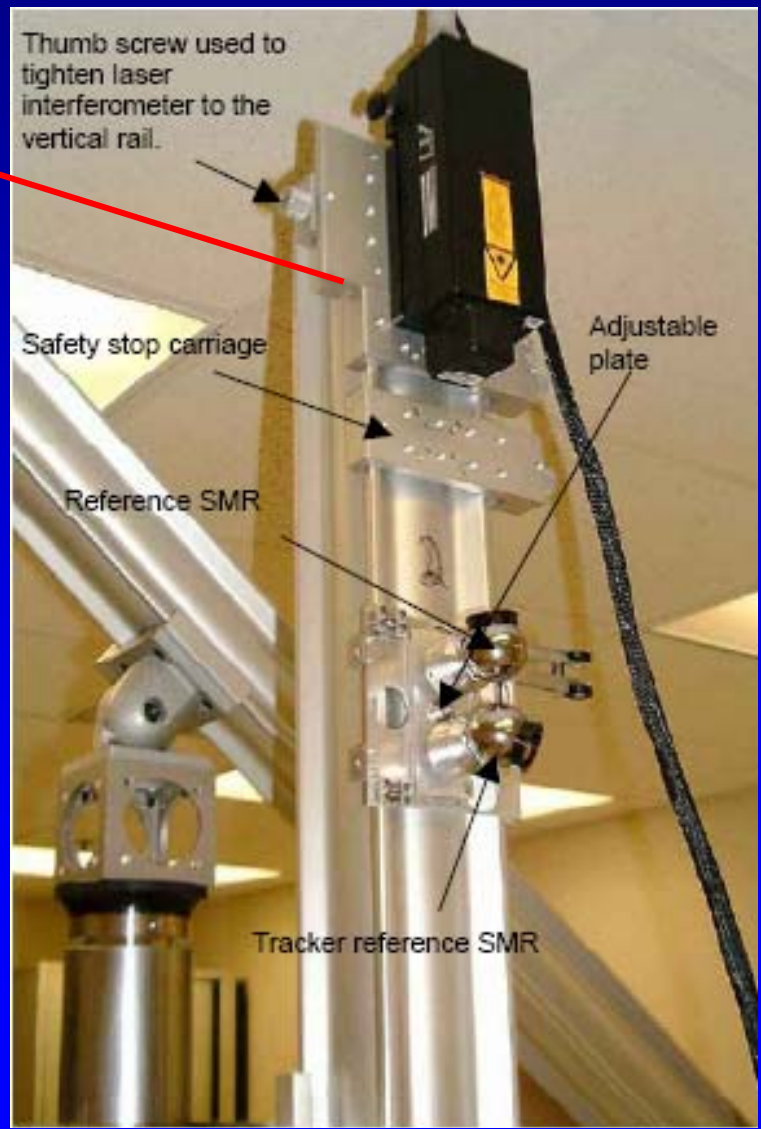
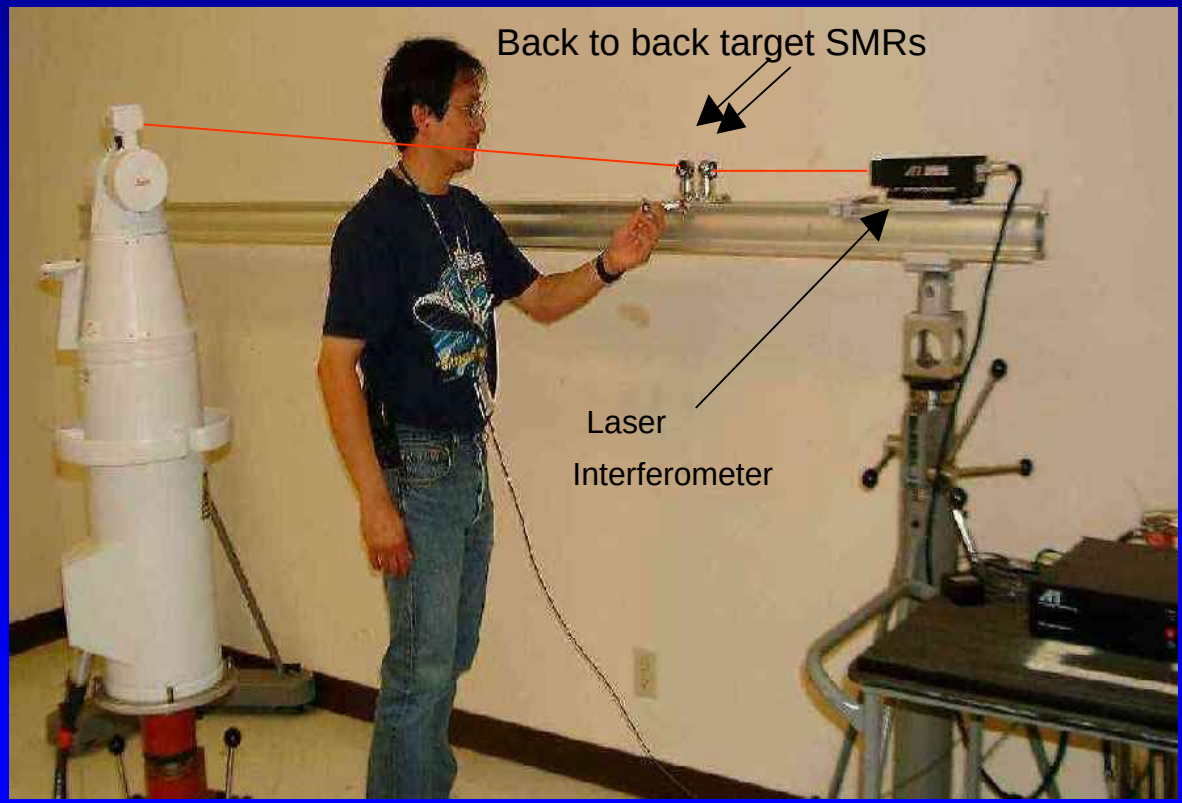
NIST Laser Tracker Calibration Facility

System Tests



NIST Laser Tracker Calibration Facility

System Tests



NIST Laser Tracker Calibration Facility

System Tests

A Laser Tracker Calibration System

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Abstract - We describe a laser tracker calibration system developed for frameless coordinate metrology systems. The system employs a laser rail to provide an *in-situ* calibrated length standard that is used to test a tracker in several different configurations. The system is in service at the National Institute of Standards and Technology (NIST) and at the Naval Surface Warfare Center, Corona Division (NSWC, Corona Division). The system description, calibration procedure, and uncertainty budget are presented.

Introduction

Laser trackers are becoming the tool of choice for large scale coordinate measuring needs. The requirement to rapidly validate the performance of these instruments to ensure the integrity of their measurement results is increasingly critical. The task is complicated by the fact that the measuring envelope of these instruments is quite large (> 35 meters). Such large measurement volumes often require the use of large length standards, e.g., greater than two meters, to characterize the instrument. Physical standards such as large calibrated artifacts, commonly referred to as scale bars, may suffer the problems of being unwieldy to use, difficult to construct and quite often costly to maintain.

This paper describes the design of the NIST Laser Rail Calibration System (Larcs) which is deployed at the NSWC, Corona Division. The system was developed to provide users with an easy to use and easy to maintain tool for performing length measurement tests for characterizing the

Commercial equipment and materials are identified in order to adequately specify certain procedures. In no case does such identification imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

Uncertainty source detailed in paper presented at the Measurement Science Conference (a copy available upon request)

NIST Laser Tracker Calibration Facility

System Tests

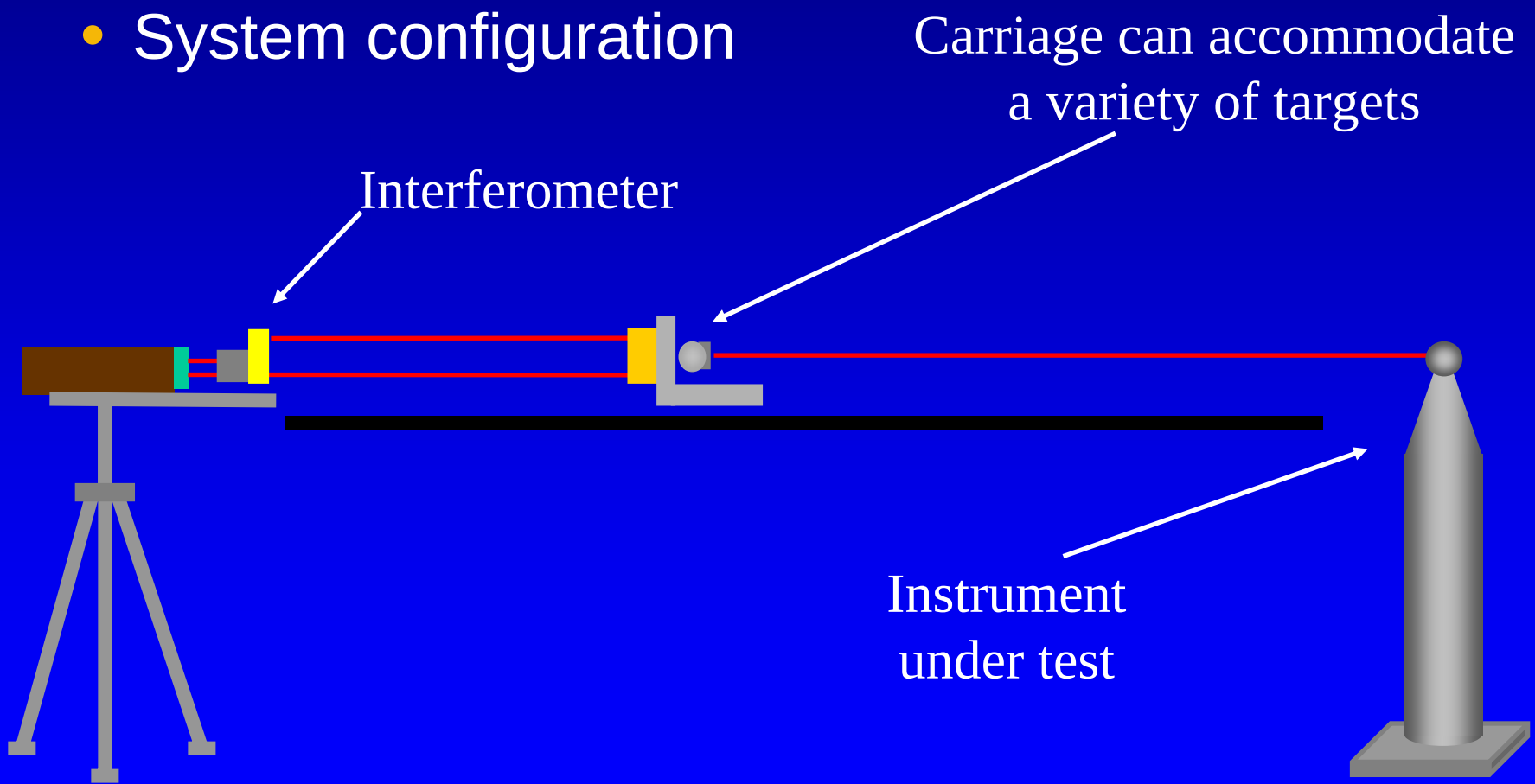
System Test Uncertainty per B89.4.19:

- $U(k=2) = 3\ \mu m + 0.5 \times 10^{-6}\ L\ \mu m$
- **For 2.3 m length $U(k=2) = 4.2\ \mu m$**

NIST Calibration Available

NIST Laser Tracker Calibration Facility
Ranging Tests

- System configuration



NIST Laser Tracker Calibration Facility
Ranging Tests

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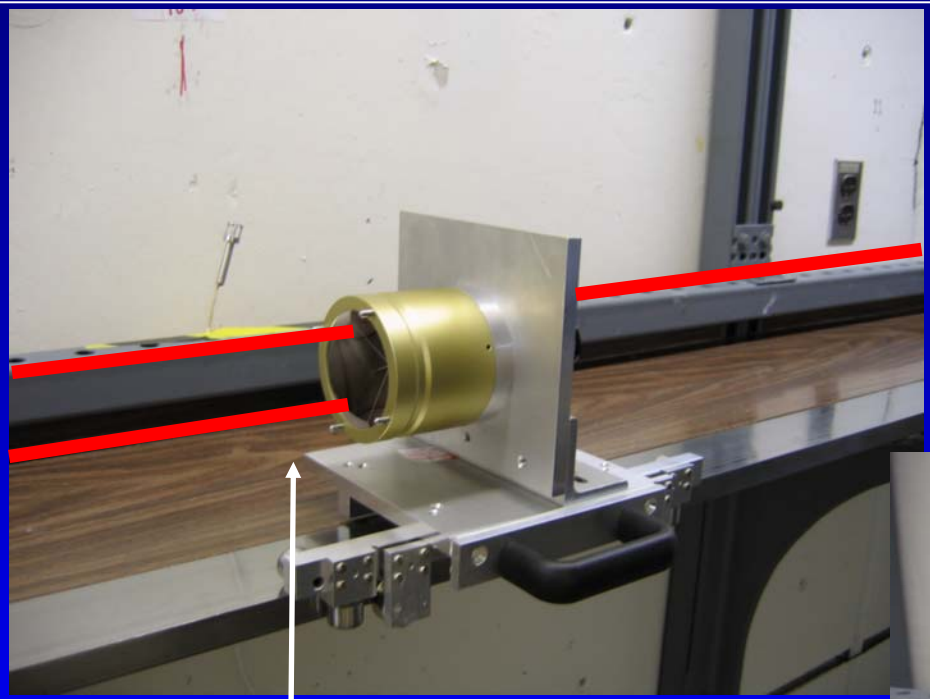
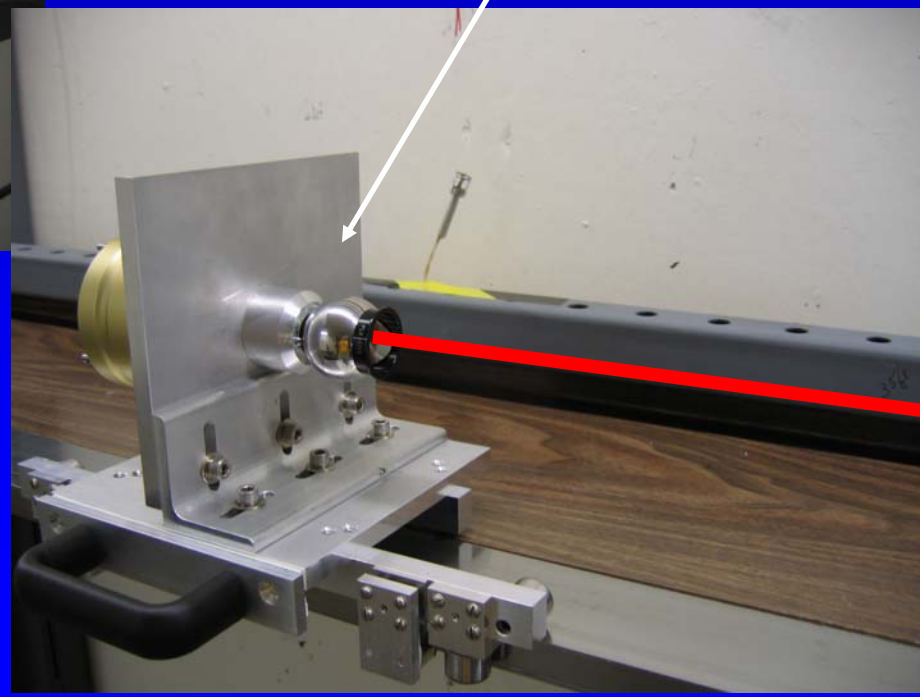
Ranging Tests

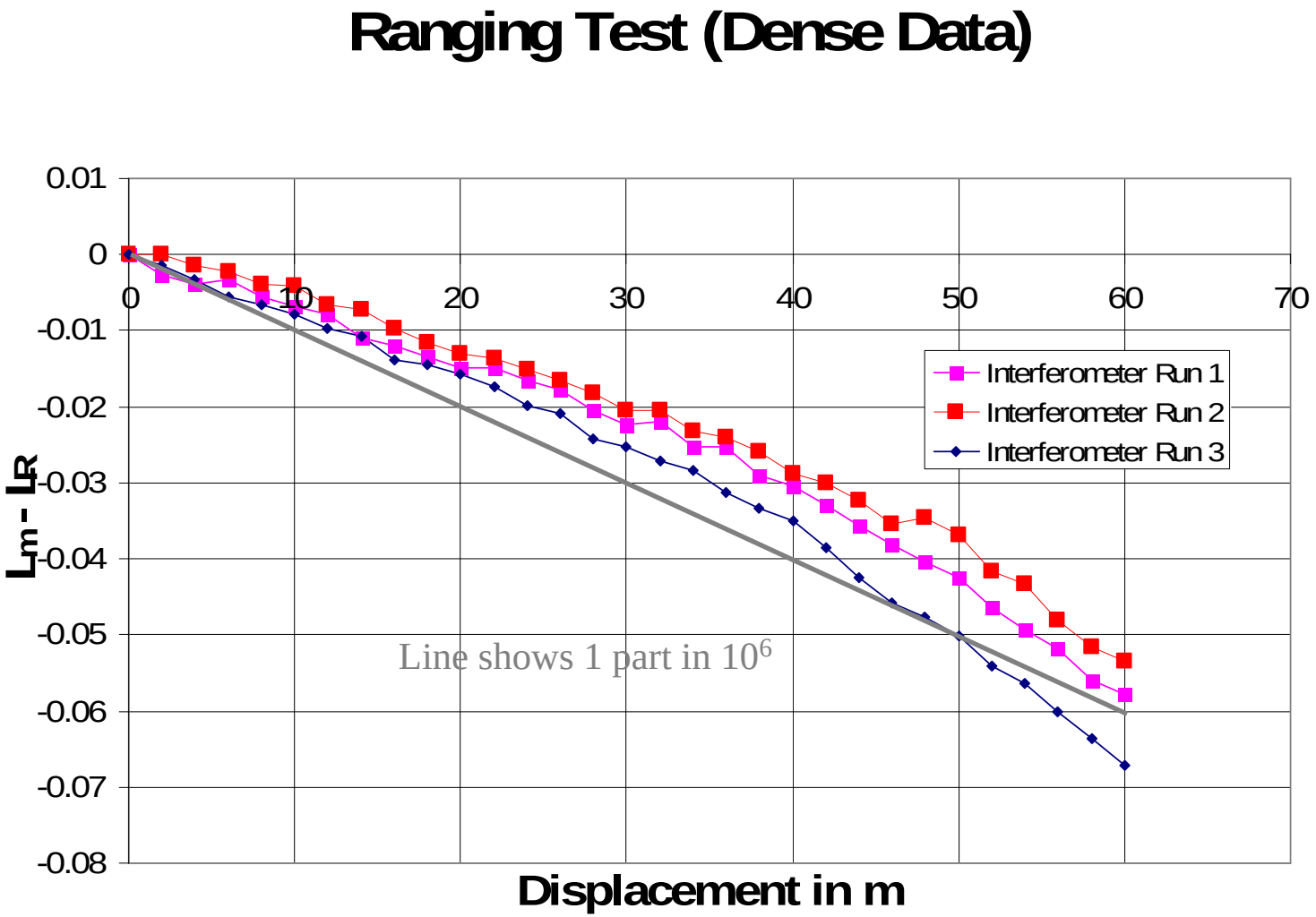


Reference retroreflector

Target retroreflector



NIST Laser Tracker Calibration Facility
Ranging Tests



NIST Laser Tracker Calibration Facility
Ranging Tests

Ranging Test Uncertainty per B89.4.19

$U(k=2) = 3\ \mu m + 0.1 \times 10^{-6}\ L\ \mu m$

For 30 m length $U(k=2) = 6\ \mu m$

NIST Calibration Available

Questions?

NIST 1-D Range Calibration Facility