



The SLAC Comparator for the Calibration of Digital Leveling Equipment

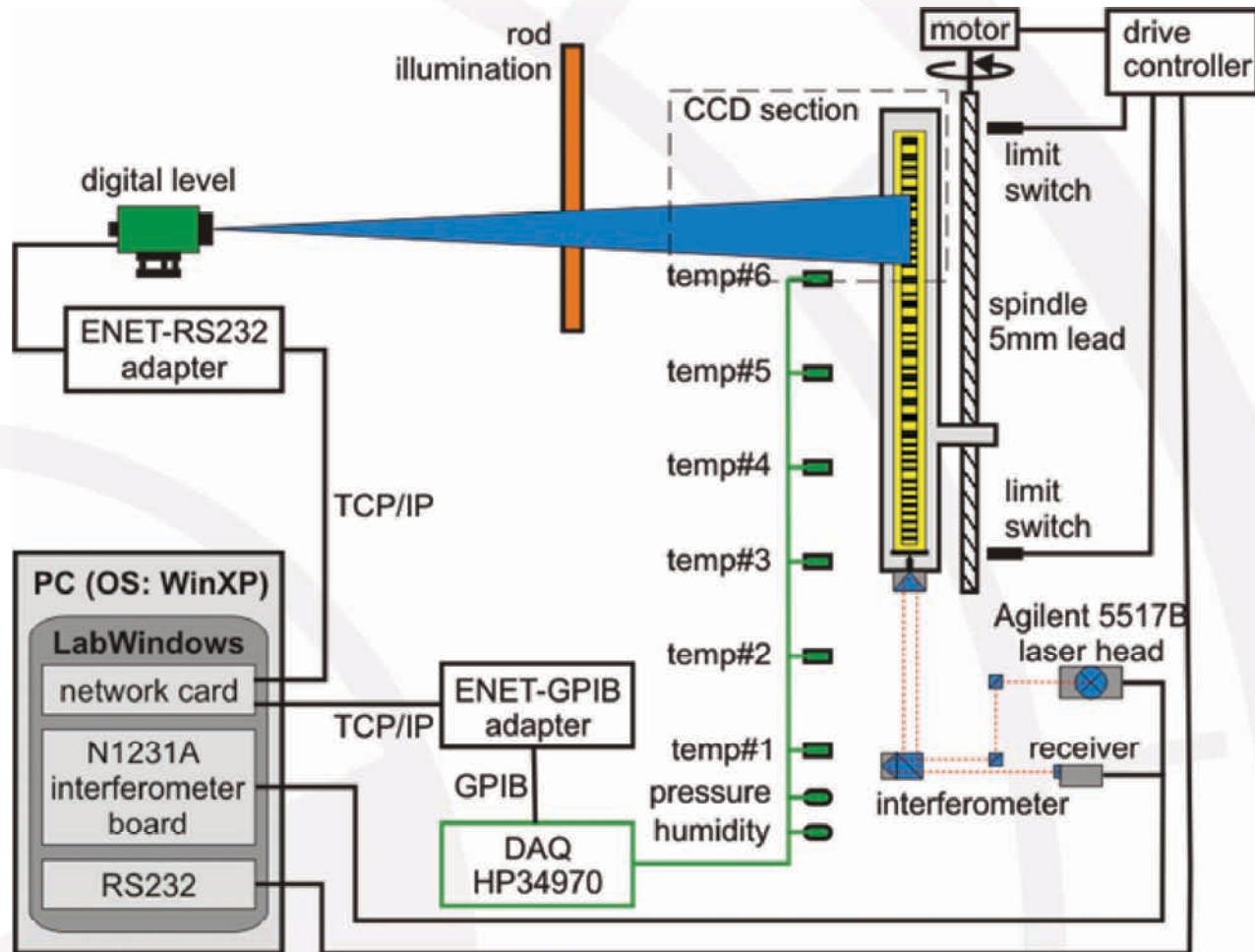
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Stanford, CA, USA



Overview

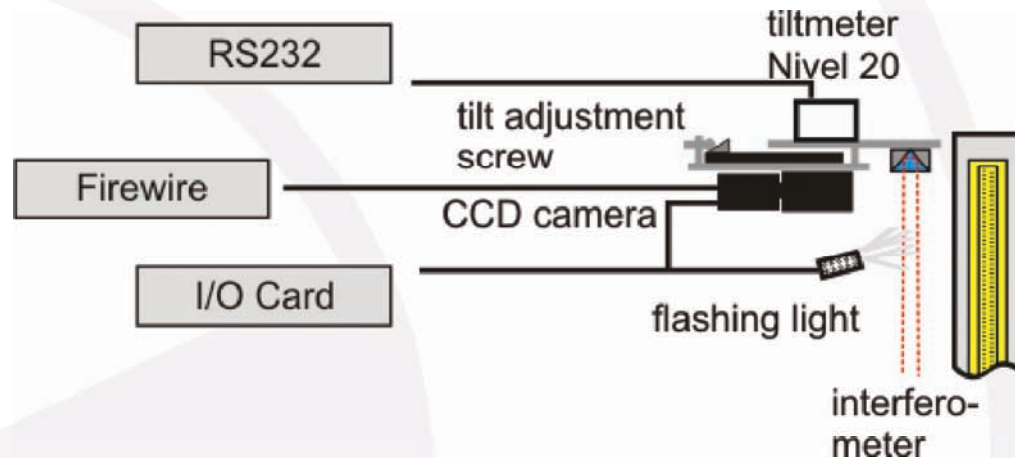
- System Calibration
- Rod Calibration
- Factors influencing the accuracy:
 - Scale factor
 - Critical distances and focusing
 - End section of the staff
 - Illumination
- Equipment tested:
 - Leica DNA03
 - Trimble (formerly Zeiss) DiNi 12
 - NEDO precision invar rods
 - NEDO self illuminating rod

System Calibration



Rod Calibration

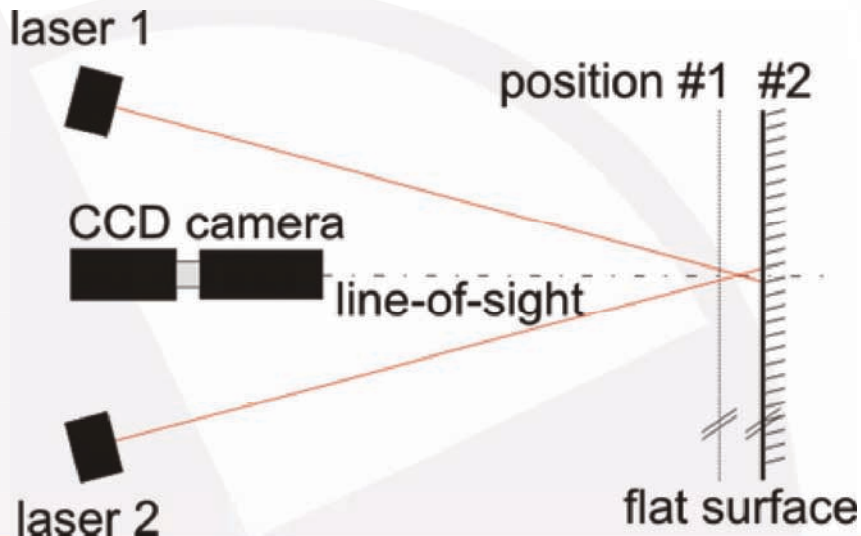
- Camera System
 - CCD camera (Sony XCD-SX900)
 - Telephoto lens (Schneider Kreuznach Componon S 5.6/100, $f=128\text{mm}$)
 - Inclinometer (Leica Nivel 20)
 - Interferometer (Agilent 5517B)



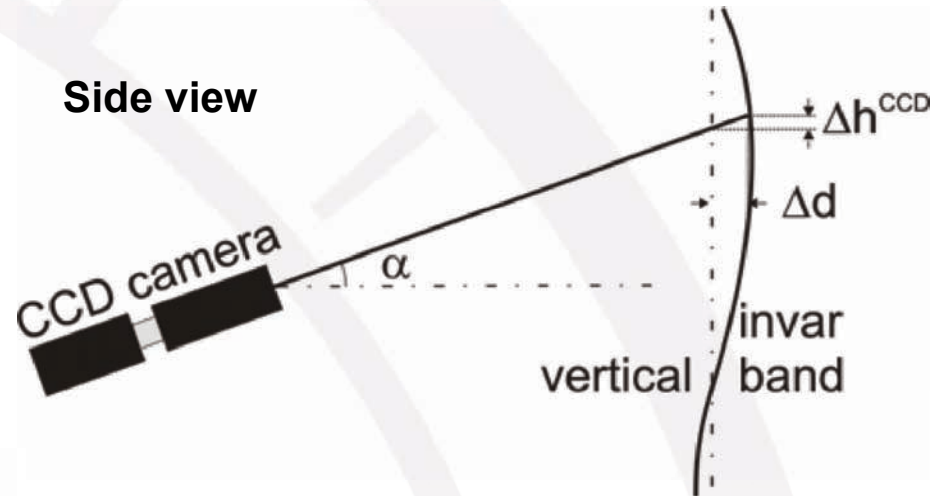
Camera Setup

- Camera Tilt
 - Invar band not 2D
 - $\Delta d < 1\text{mm}$; $\Delta h^{\text{CCD}} = 0.15\mu\text{m}$

Top view



Side view



- Camera Leveling
 - Leveled laser beams
 - Two different distances
 - Cross-correlation of the laser point position

Edge Detection

- Edge detection

Image 1

Interferometer: 0mm



Image 2

Interferometer: 2.5mm

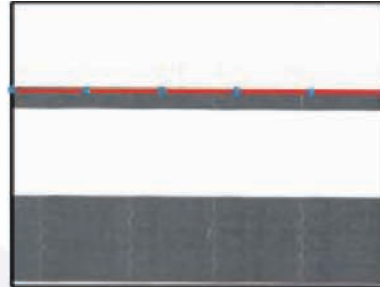


Image 3

Interferometer: 5mm

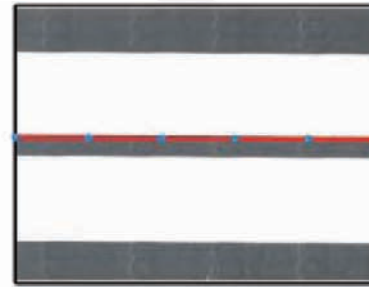
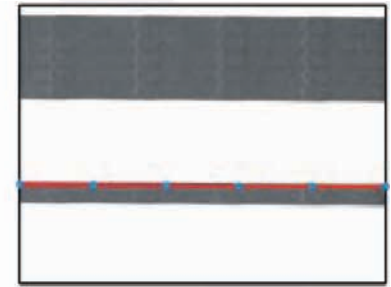


Image 4

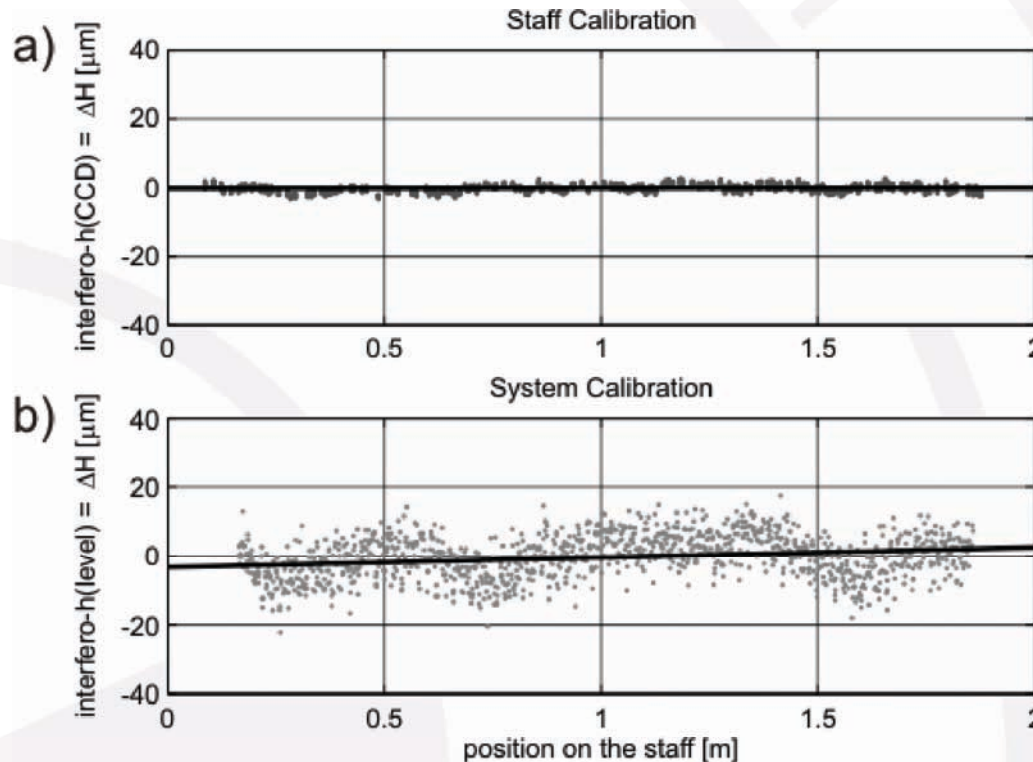
Interferometer: 7.5mm



- Postprocessing:
 - Least Squares Adjustment
 - Scale Factor of Image
 - Rotation of Image
 - Perspective Distortion
 - Position of the Edge

Comparison of System vs. Rod Calibration

Slightly different results. The system calibration includes a systematic pattern which is caused by the level (including its software)



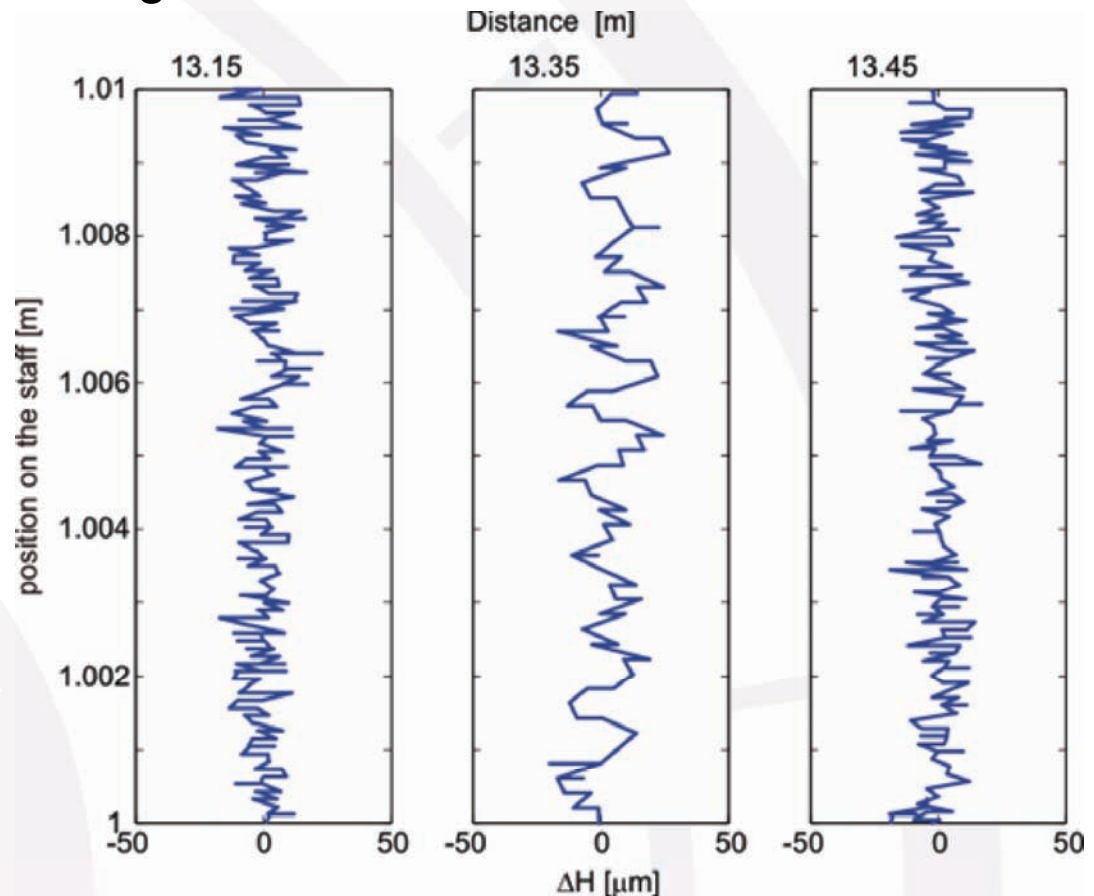
Scale factor:
0.1 ppm

Scale factor:
2.4 ppm

Critical Distances – Leica

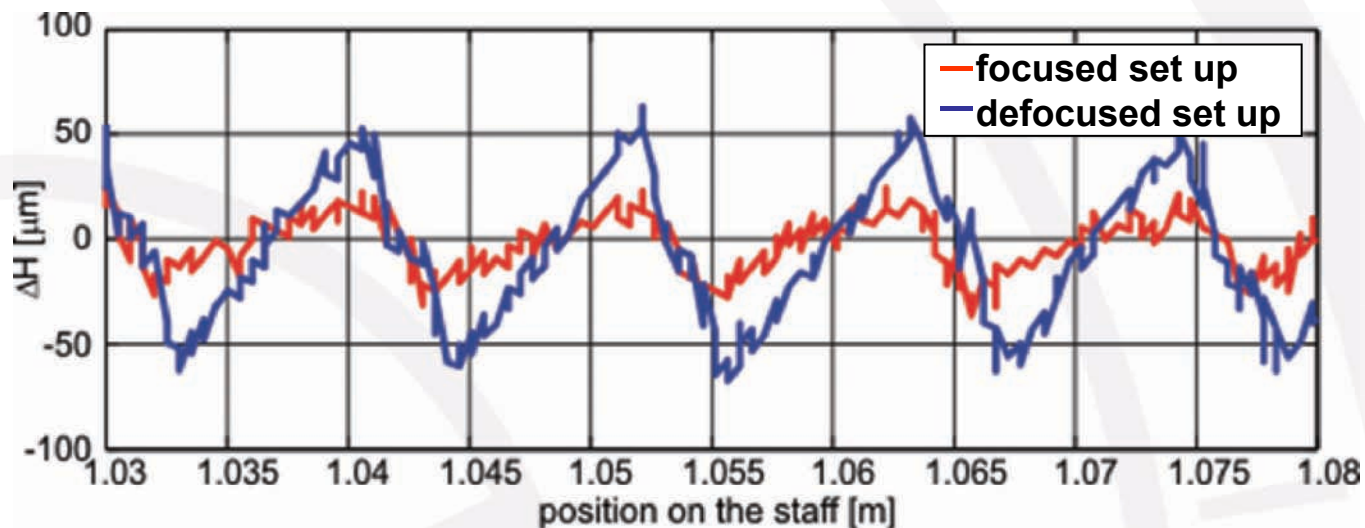
- 1 code element (Leica: 2.025mm) is projected onto exactly 1 pixel, or integer multiples
- Leica NA3000 critical distance at 14.92 m (causes up to 0.4 mm misreading)
- Leica DNA03 critical distance at 26.70 m
- Trimble Dini12: 251 critical distances between 1.5 m and 15 m

e. g. Leica: DNA03:



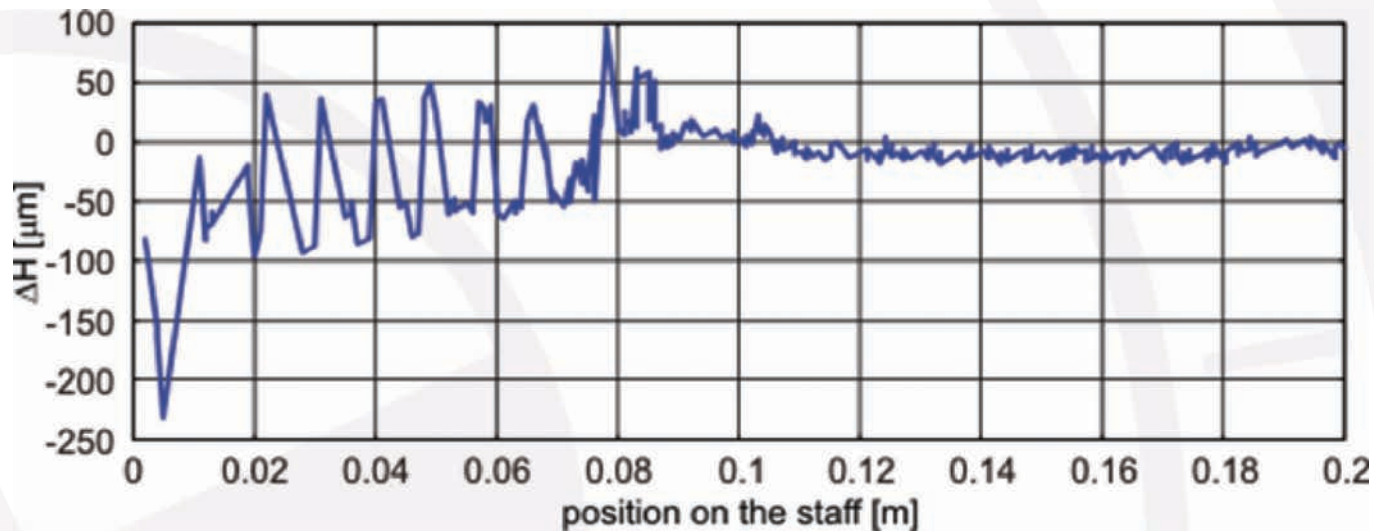
Defocused Measurements

- Leica DNA03 and Trimble DiNi12: critical distances do not cause deviations $> 30 \mu\text{m}$
- Defocused measurements increase these values



End Section of the Rod

- Measurements when only part of the rod is visible
 - Smaller section of the scale is available to compute the height in the digital level
 - Inaccurate measurements are the consequence



Illumination

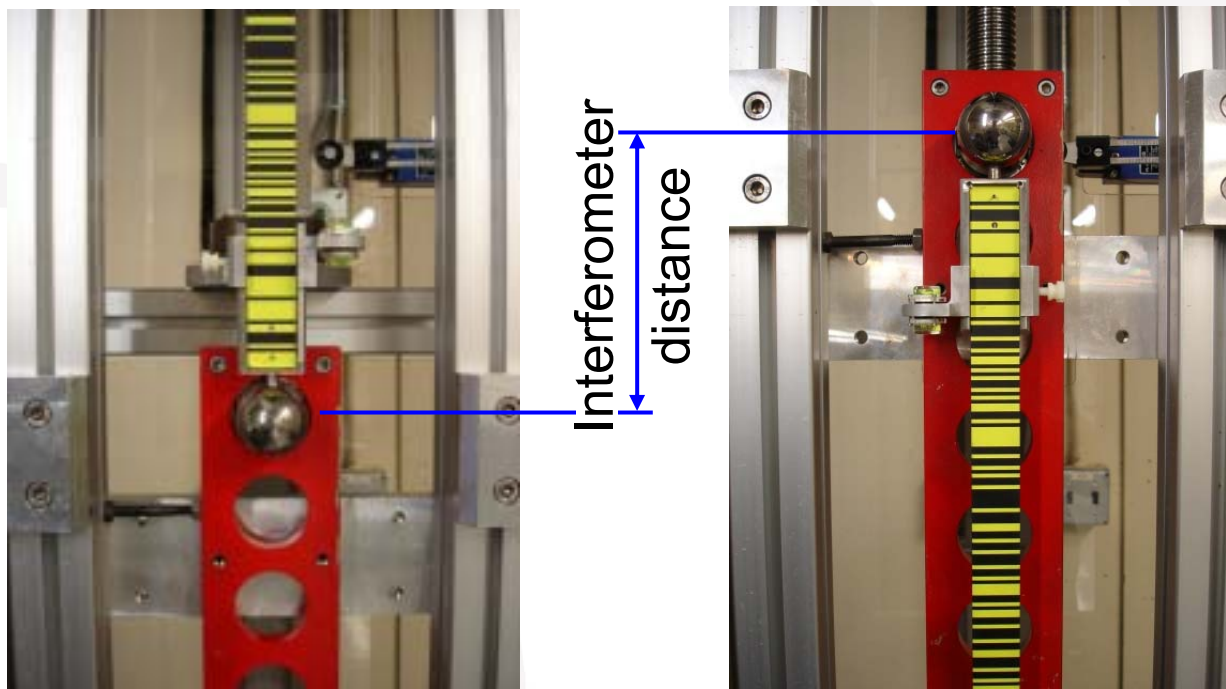
- Measurements in dimly lit environments require additional illumination
- Illumination at a steep angle causes biased measurements of up to $100\text{ }\mu\text{m}$ (only correct for the instruments tested)
- Prototype of a self illuminating rod



Offset Determination (1)

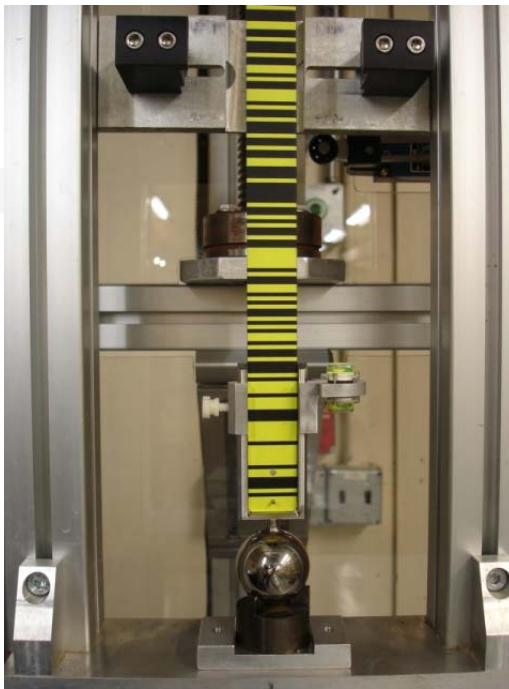
To link all height readings together the scale offset between the rods has to be determined.

Step 1: determination of 1 ½ in ball center



Offset Determination (2)

Step 2: transfer of short rod offset to regular rods with 1 ½ inch ball





Summary

- Both system and rod calibration performed at SLAC
- Regular calibration and testing of equipment
- Test of new equipment
- Test of field procedures
- Determination of rod offsets