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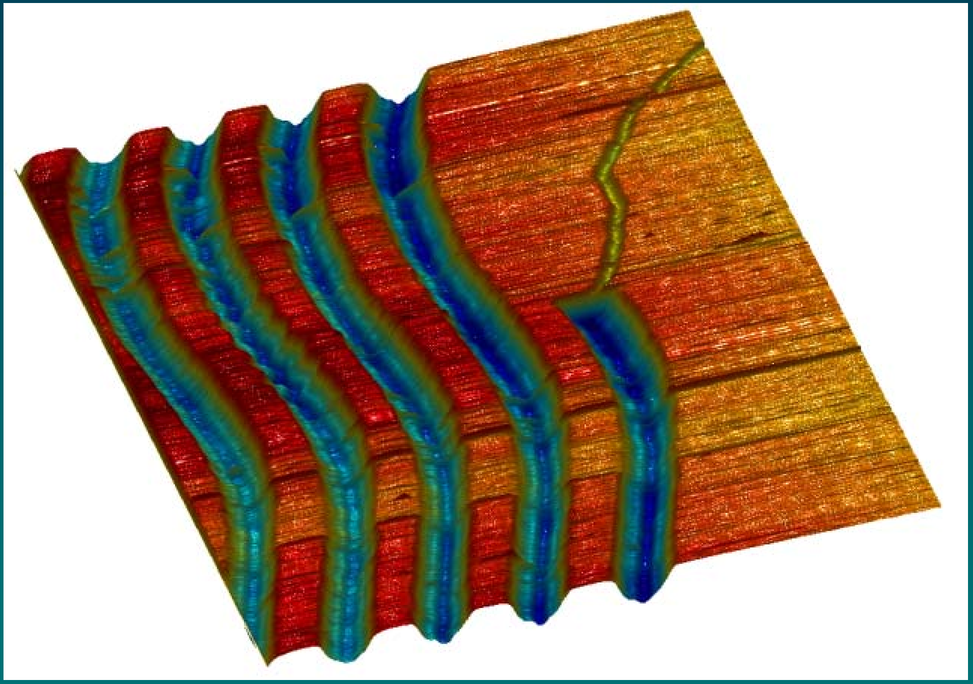
OPTICAL SENSING FOR THE HIGH PRECISION 3D SURFACE PROFILE MEASUREMENT OF GROOVED SURFACES

J.W. McBride,

Z. Zhao.



EUSPEN SiG February 2009

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Overview

- Review of UoS Activities in Free Form Surfaces
- Brief Introduction to Sound Archive Project, (see ASPE 2008) posted to UoS eprints.
- Con-focal Sensors
- New Research on Flat Disc Surfaces.
  - Sensor Limitations on inclined surfaces
  - Reference Surfaces
  - Solution for surfaces with >30 degree inclines

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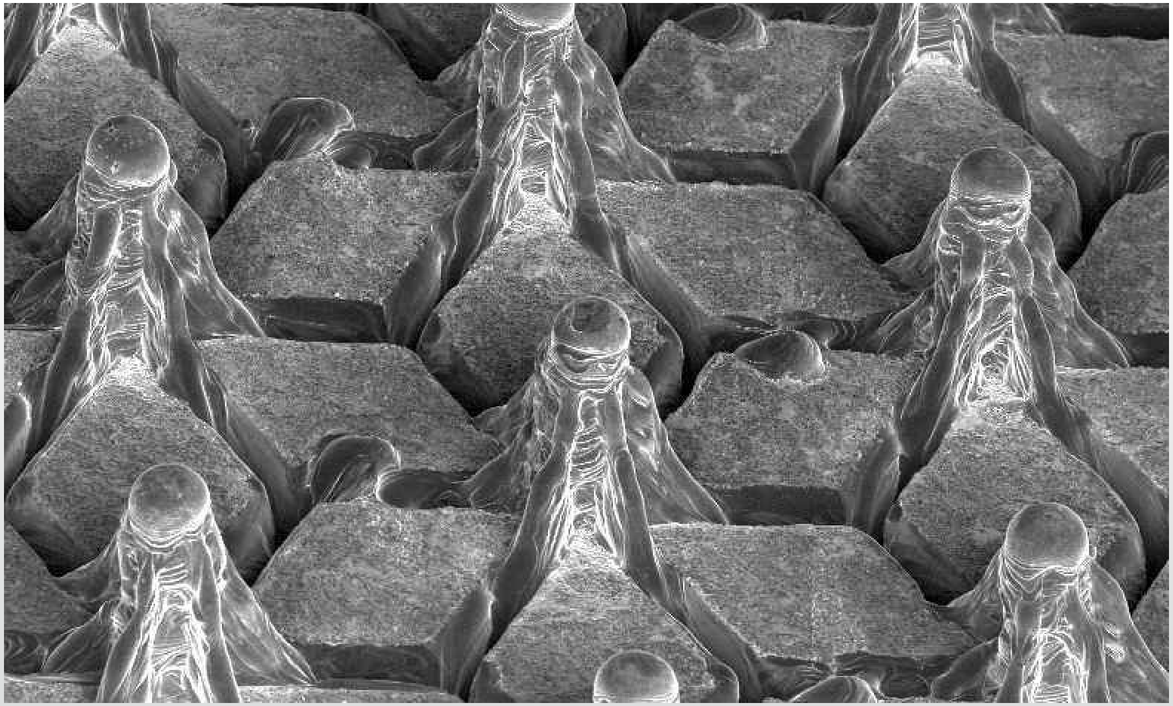
Free-Form Related Research at UoS.

- Assessment of Complex Electron Beam Textured Rough Surfaces. Jenny KC Ang, Prof. Robert Wood and Dr. Ling Wang national Centre for Advanced Tribology at Southampton



Project scope

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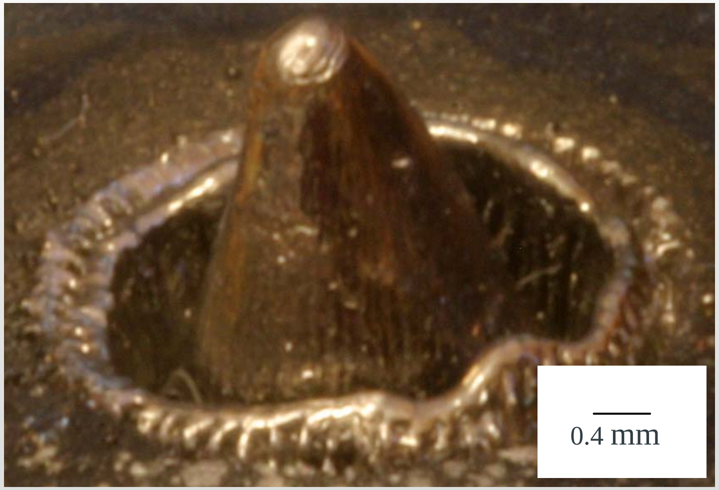
- 3D surface assessment of highly irregular surfaces (Complex Rough Surfaces, **CRS**)
- Characteristics of surfaces: feature sizes **50µm-10mm** in the x, y and z directions, overhangs/re-entrants, steep slopes and high aspect ratios. Tolerance ± 5% in spatial and ± 2°
- Screening of current metrology technologies shows **none** are readily suitable for this type of surface measurement
- Full surface characterisation is not required: **Form and waviness** (not roughness scale features)
- **Rapid** assessment of EB manufacturing process to detect splatter debris and loose material



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ASTIA - Advanced Surface Tailoring for Innovative Applications

- TSB and EPSRC funded research project
- TWI lead partner (Cambridge)
- **nCATS, University of Southampton (Southampton) – Development of assessment procedures for EB textured surfaces**
- Symmetry Medical (Sheffield)
- CVE (Cambridge)
- Thermacore (Ashington)
- Applications: ***heat exchangers, medical devices, electron beam equipment, QA assessment procedure, EB software***.

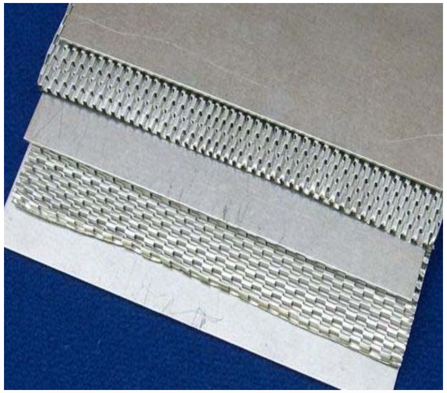
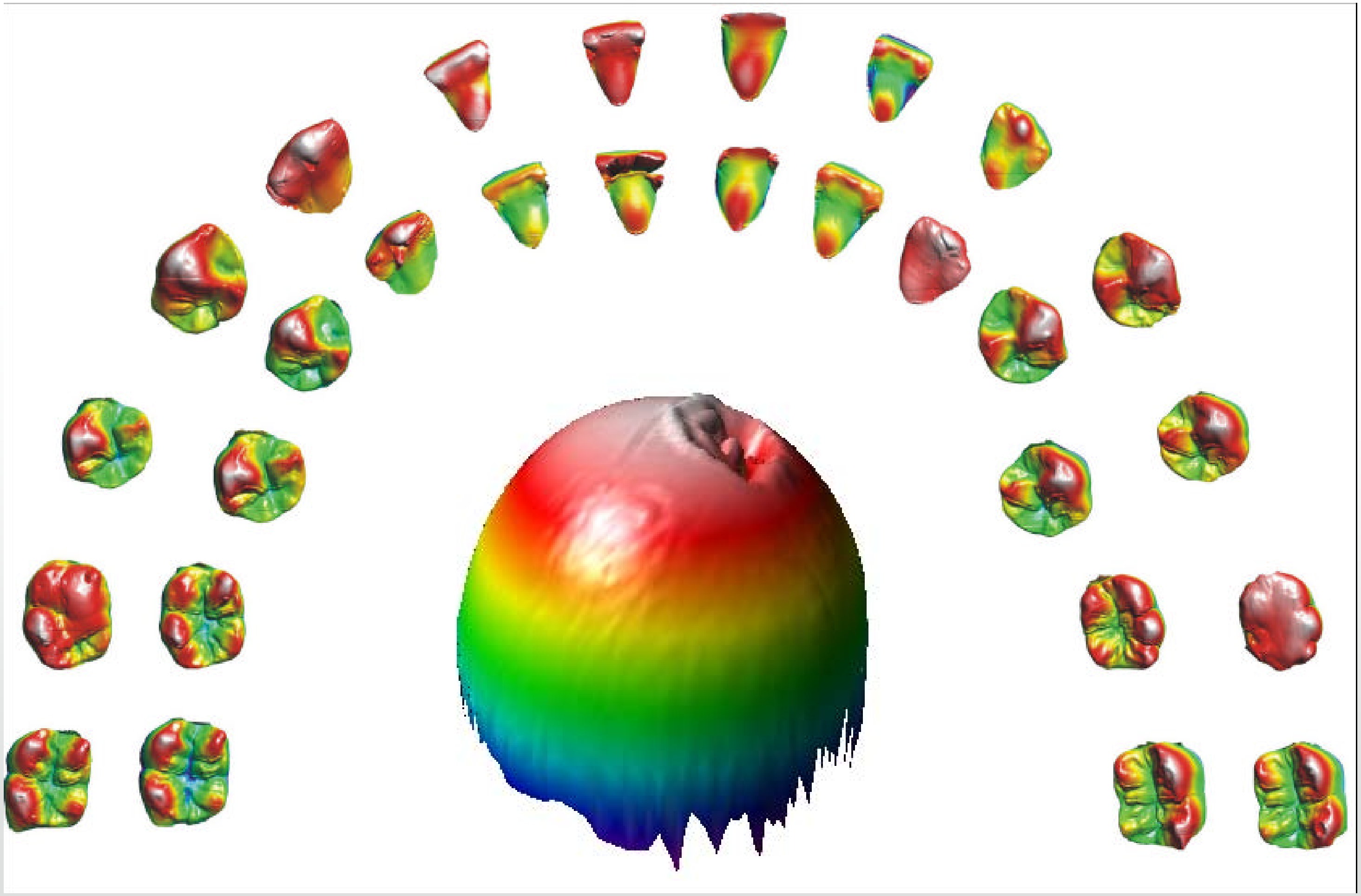


Plate fin heat exchanger

Hip joint implant

Wear of Free Form Surface.

- In collaboration with the metrology company TaiCaan Technologies Ltd.



Free Form Surface Research

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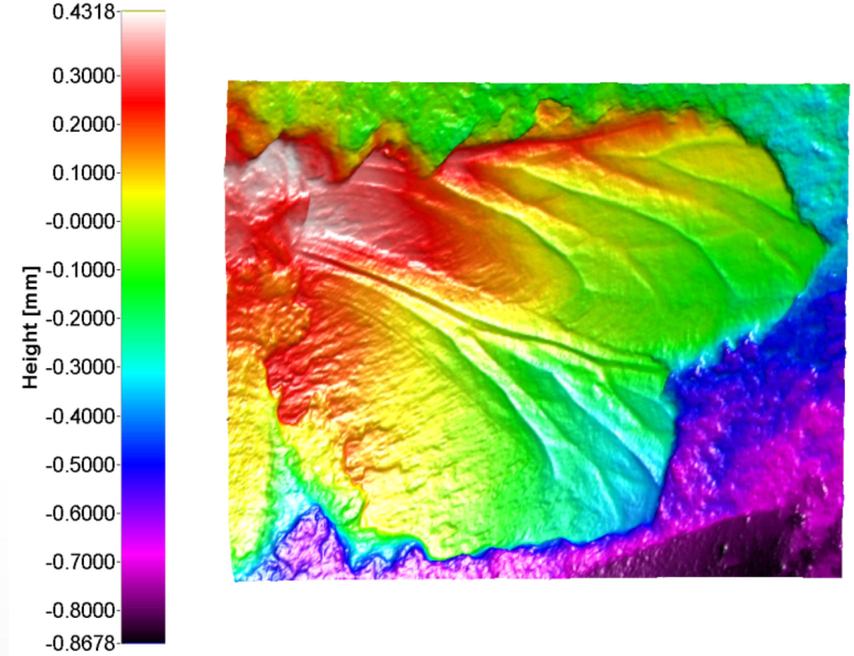
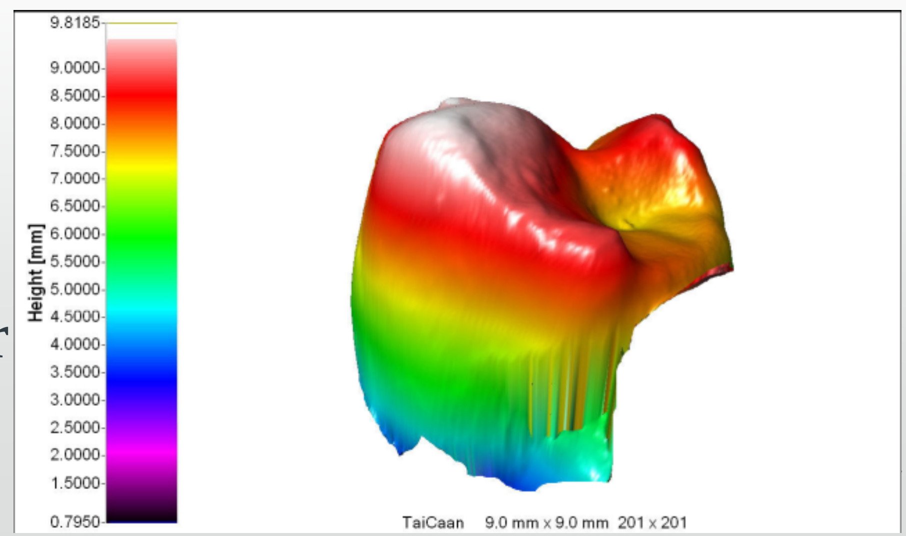
- Collaborations with
- TaiCaan Technologies Ltd.
  - www.taicaan.com

  Micro-Materials Ltd.
- Universities
  - Cardiff University
  - Kings College London
  - Imperial College London
  - University of Montpellier
  - University of Rennes.





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The Sound Archive Project

Selected Journal publications

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- Nascè, Antony, Hill, Martyn, McBride, John W. and Boltryk, Peter (2008) A quantitative analysis of signal reproduction from cylinder recordings measured via noncontact full surface mapping. *Journal of the Acoustical Society of America*, 124, (4), 2042-2052. (doi:10.1121/1.2973238)
- Boltryk, P.J., McBride, J.W., Hill, M., Nascè, A.J., Zhao, Z. and Maul, C. (2008) Non-contact surface metrology for preservation and sound recovery from mechanical sound recordings. *Journal of the Audio Engineering Society*, 56, (7/8), 545-559.
- Boltryk, Peter J., Hill, Martyn, McBride, John W. and Nasce, Antony (2008) A comparison of precision optical displacement sensors for the 3-D measurement of complex surface profiles. (In special issue: Eurosensors XX The 20th European conference on Solid-State Transducers - Eurosensors 2006, Eurosensors 20th Edition). *Sensors and Actuators A: Physical*, 142, (1), 2-11. (doi:10.1016/j.sna.2007.03.006)
- Boltryk, P.J., Hill, M. and McBride, J.W. (2008) Comparing laser and polychromatic confocal optical displacement sensors for the 3-D measurement of cylindrical artefacts containing microscopic grooved structures. *Wear*, 226 (2009) 498-501
- Fadeyev, Vitaliy, Haber, Carl, Maul, Christian, McBride, John W. and Golden, Mitchell (2005) Reconstruction of recorded sound from an Edison cylinder using three-dimensional noncontact optical surface metrology. *Journal of the Audio Engineering Society*, 53, (6), 485-508.

4 Year Project 2005-09

- Collaborations with.
- British Library. Nigel Bewley and Wil Prentice
- Lawrence Berkeley Lab. Carl Haber
- TaiCaan Technologies
  - Kevin Cross
  - Christian Maul
- University of Southampton.
  - Prof. Martyn Hill
  - Dr. Peter Boltryk
  - Samantha Zhao, and Antony Nasce.

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The Sound Archive Project

- Non-Contact Surface Measurement. Development of metrology systems for mapping the surface topology of cylinders and flat discs. PRESERVATION.
- Sensor Development. Design of optical sensors with improved angular tolerance and sensing speed.
- Audio Signal Recovery. Methods of accurate sound reproduction from discrete surface maps of cylinders and discs.
- http://www.sesnet.soton.ac.uk/archivesound/

Scanning process – cylinders (1)

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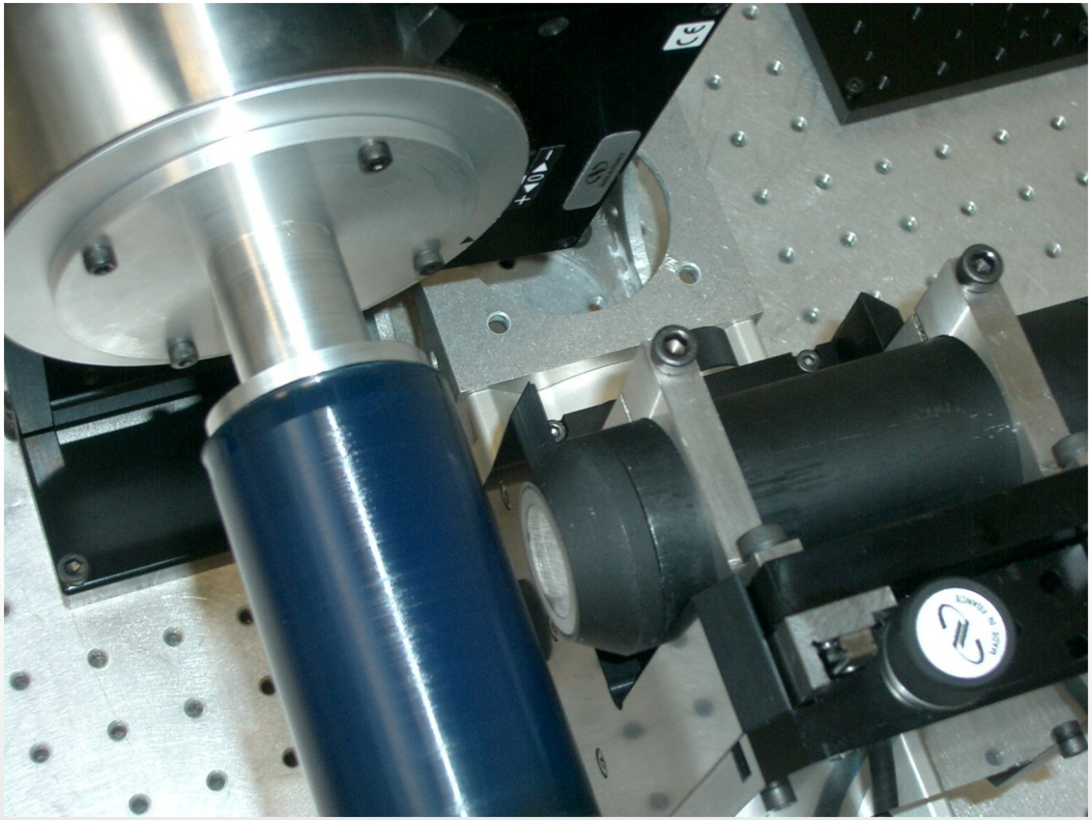
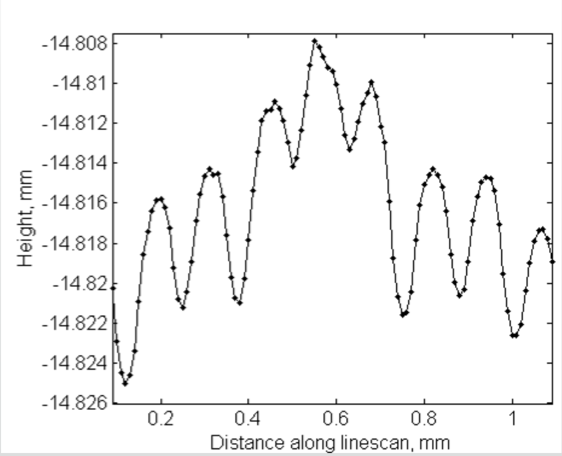
- Traverse displacement sensor along the cylinder axis
- Sensor measures the surface height across the grooves
- Acquire data 'on the fly' at fastest possible



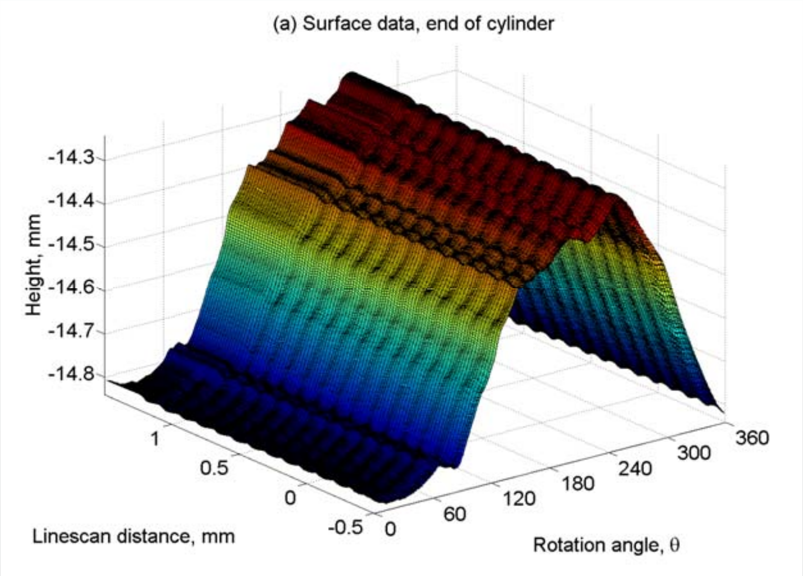
General view of original cylinder system

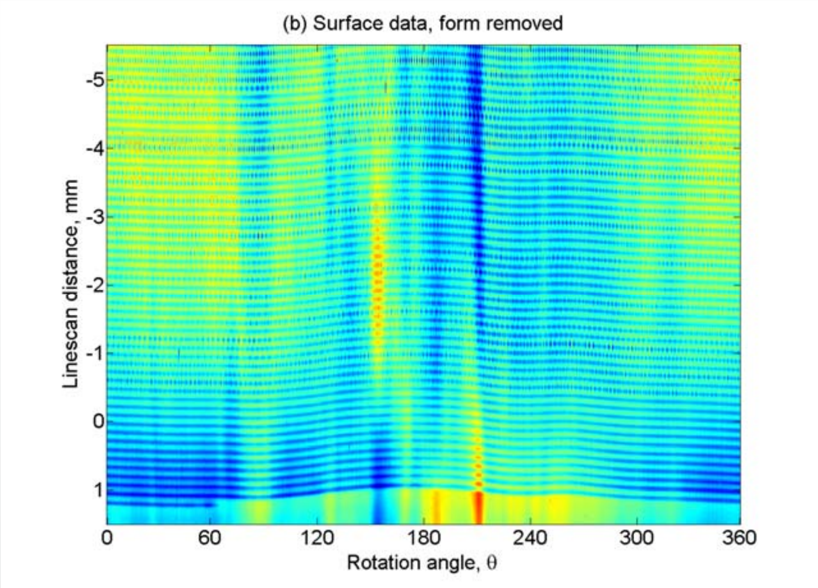


Typical linescan profile

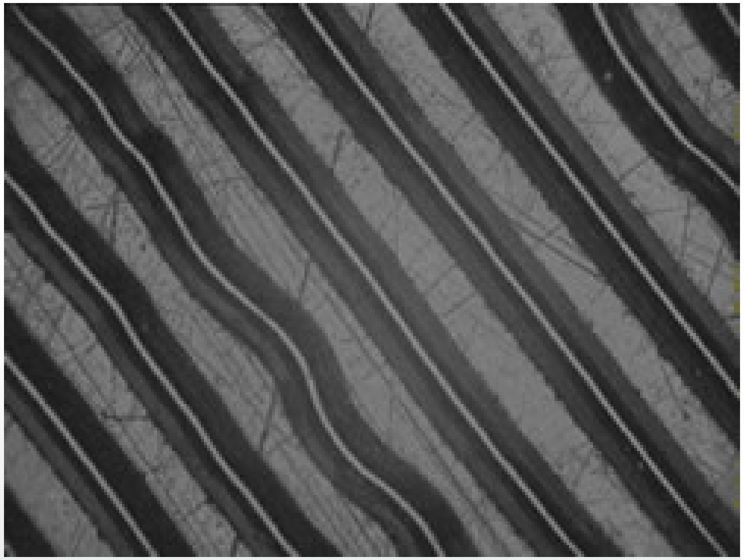
Scanning process – cylinders (2)

- Rotate the cylinder fractions of a degree between linescans
- Repeat for whole surface area
- Results in unwrapped rectangular surface topology

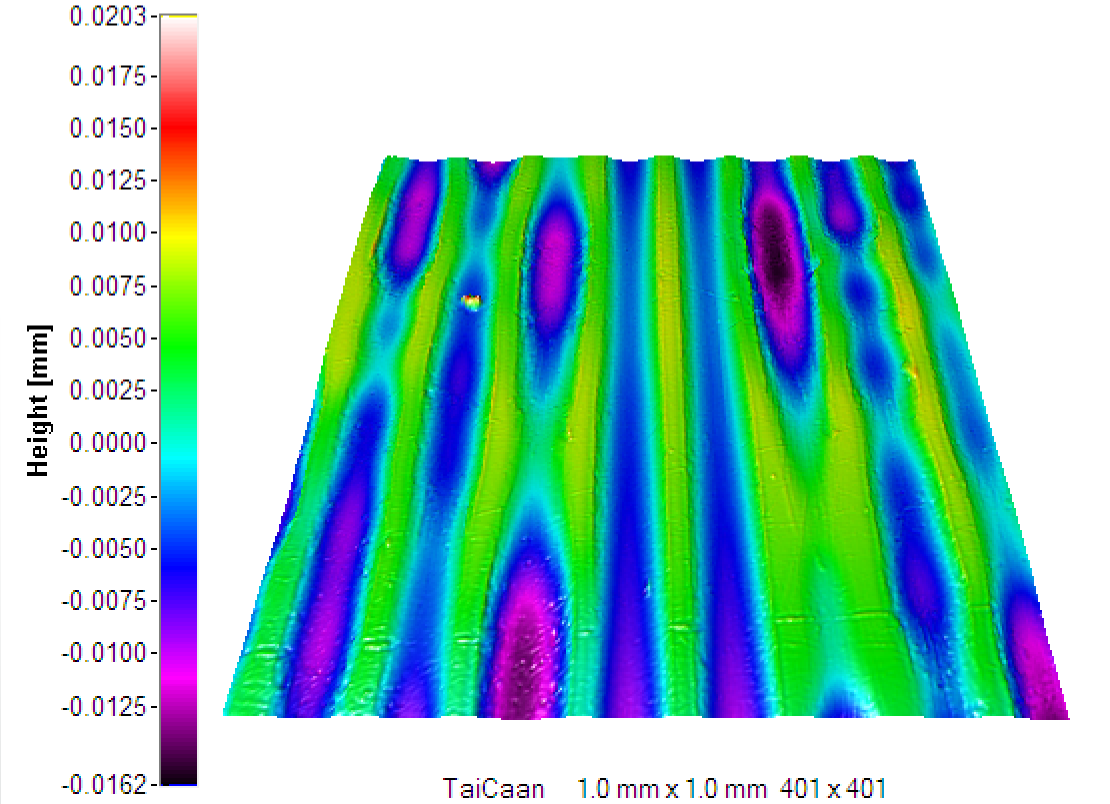




Typical Surfaces



CCD image
of 78 surface



3D map of cylinder
surface

System Requirements

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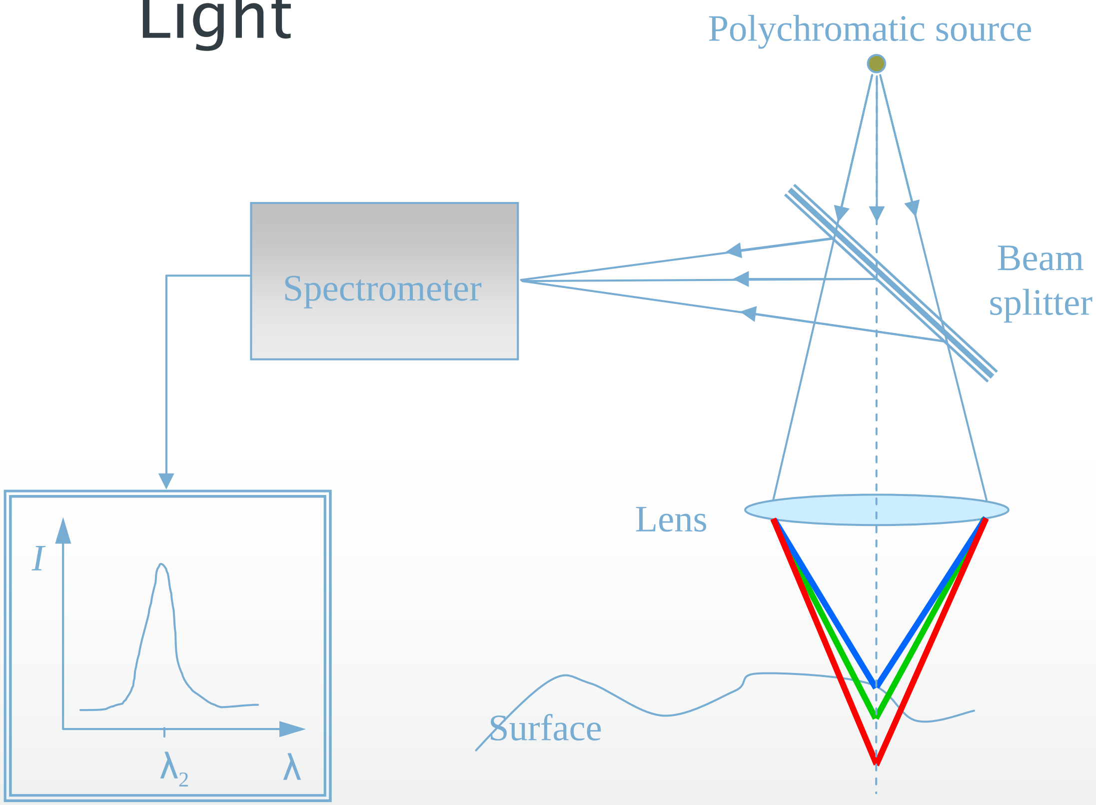
- Typical groove profile is 100µm wide by 40 µm depth
- 10µm spacing across the groove to define profile, but only for vertically modulated sound carriers
- 5µm spacing along the groove, to provide temporal sampling at 96kHz.
- Approximate Surface area 100mm x 150mm
- 150 Million data, sampled in 24 hours
- 4kHz, sensor sampling
- 10nm axial resolution required to define audio
- Angular Tolerance > 30°

SENSOR (1) Con-Focal White Light



Schematic of the measurement principle for the WL system

SENSOR (2) Con-Focal Laser

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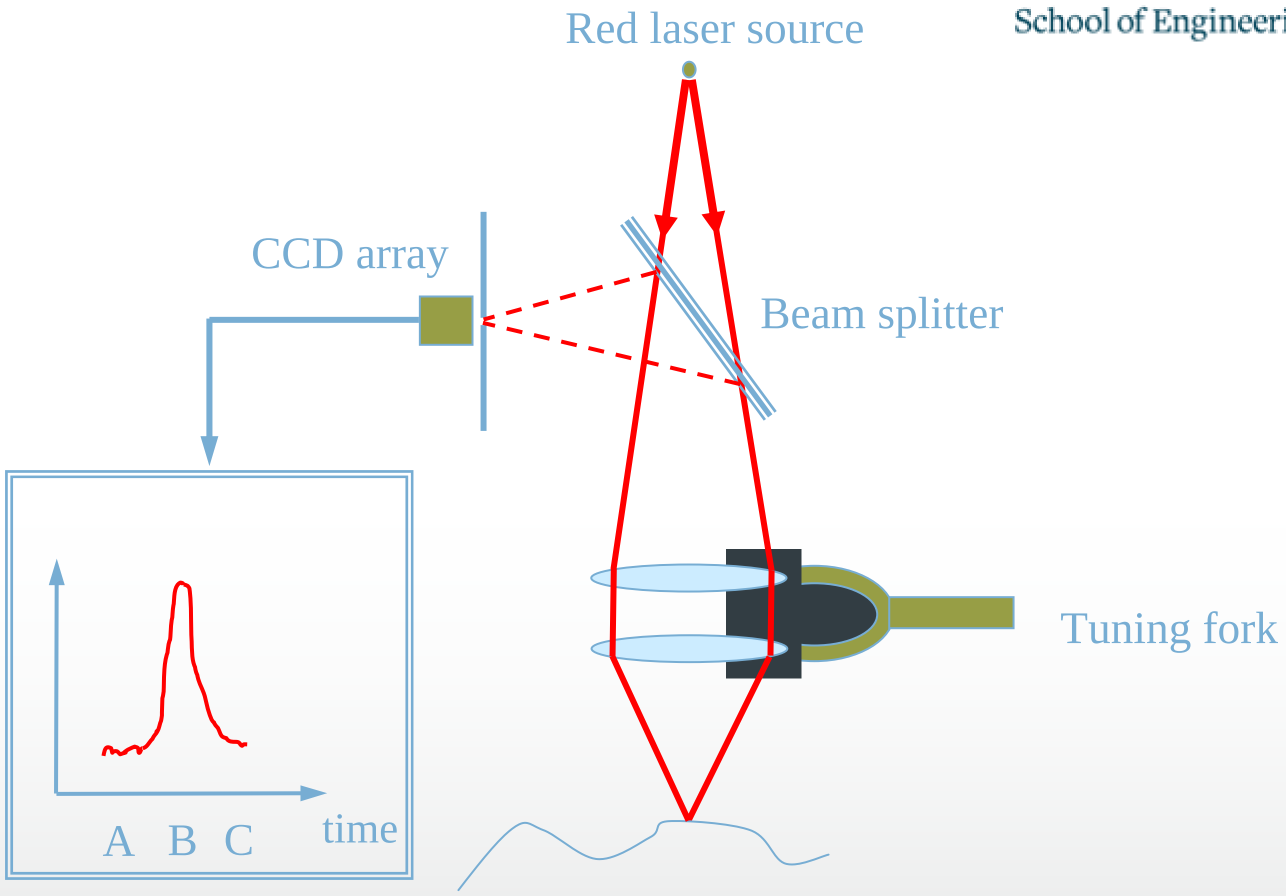

Schematic of the measurement principle for the CL

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Sensor study: sensor comparison parameters

Sensor	Spot size (µm)	Sample frequency (kHz)	Gauge range (mm)	Axial resolution (nm)
TL	30	2	10	1000
CL	2	1.4 (0.08)	0.6 / 17°	10
WL	7	1 -4	0.35 / 27°	10

The Selected sensing technology is the WL system

- Best Angular tolerance for a given resolution and gauge range.
- Capable of 4kHz sampling.

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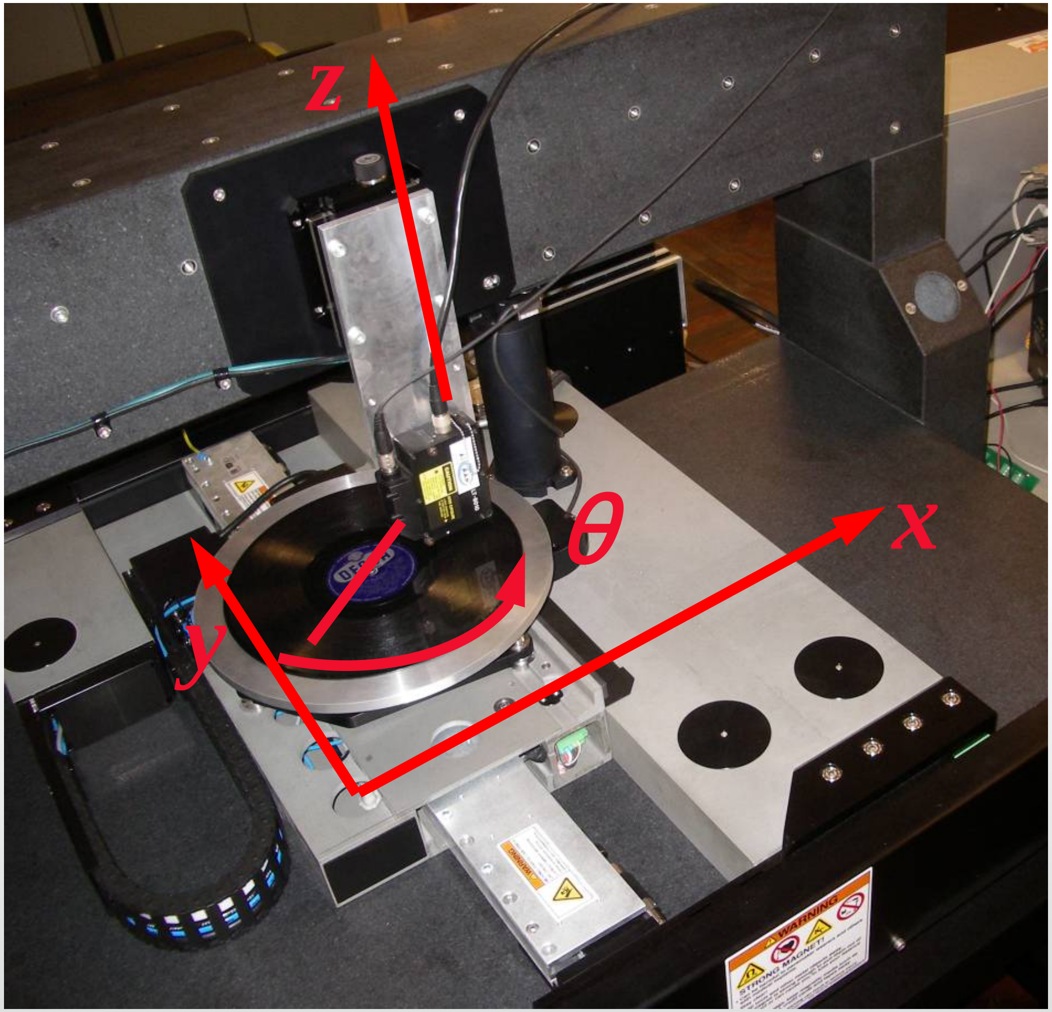
Air bearing system for disc recordings

Overview of system

- System provides planar (*x*,*y*) travel of carriage on air bearing
  - Air bearing provided by ~5µm air 'cushion'
  - Moving carriage fitted with a rotation stage
  - Sensor mounted on overhead granite gantry, whose height controlled by 10nm resolution stage
  - 4 axis of motion



System Requirements for Flat Discs

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- Typical groove profile is 100μm wide by 40 μm depth
- Horizontal Modulation, issues??
  - With the sound carried in horizontal modulations we need to resolve the sides of the groove structure to approximate 10nm in the X,Y (Horizontal) plane.
  - This is the equivalent of a 10nm pixel size.

Angled sensor head

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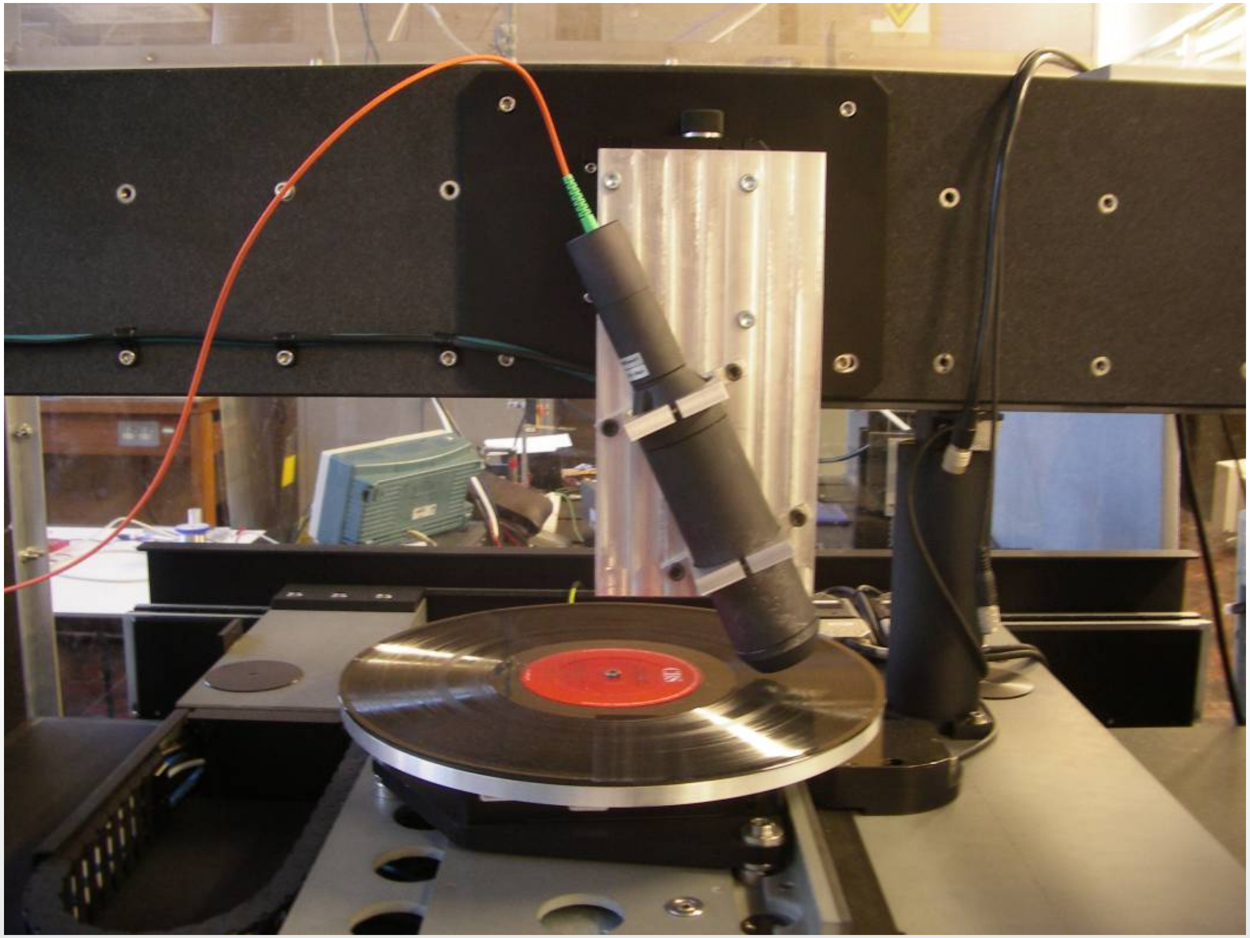
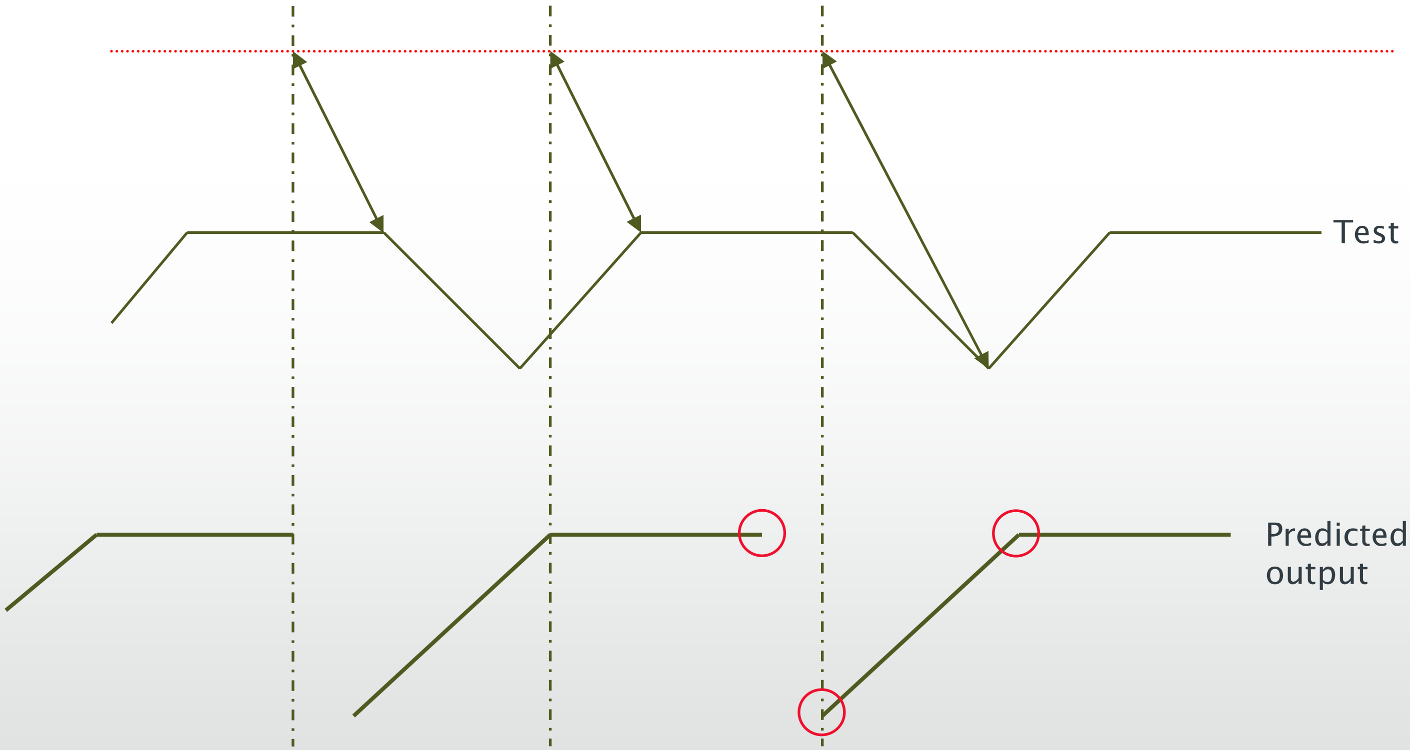


- Sensor head angled at 25° to the vertical
- Now the lateral distance of the groove is being resolved using the vertical measurement of the sensor

Angled sensor head – predicted output



Relative positions of groove cardinal points are related by the sensor's height measurement, rather than just by lateral resolution of the scan

System Requirements for Flat Discs

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- Typical groove profile is 100µm wide by 40 µm depth
- Horizontal Modulation, issues??
  - With a 45 degree groove structure and a 45 degree sensor then the 10 nm vertical resolution can be mapped to an appr0ximate 14nm horizontal resolution.
  - Maximum signal amplitude is 0.127mm for an LP surface and 0.25mm for a 78 surface.
  - This allows for an approximate 13 bit lateral resolution of signals on a LP surface and 14 bit resolution on a 78 surface.

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Understanding Sensor Limitations for inclined surfaces

Aims of Sensor Comparison Study

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- Compare how systems interact with small scale samples with sloping surfaces. Recorded surfaces have typical wavelengths of 100µm by 40µm PV.
- Using sinusoidal reference samples with 25 and 8µm wavelengths and various PV dimensions.
- Investigate the limits of the white light system, as this has been identified as offering the best combination of scanning speed, angular tolerance and vertical resolution (10nm).
- Study data robustness during high speed (low precision) scanning. Typical scan rates of 25mm/sec, with 1kHz sensor rate.

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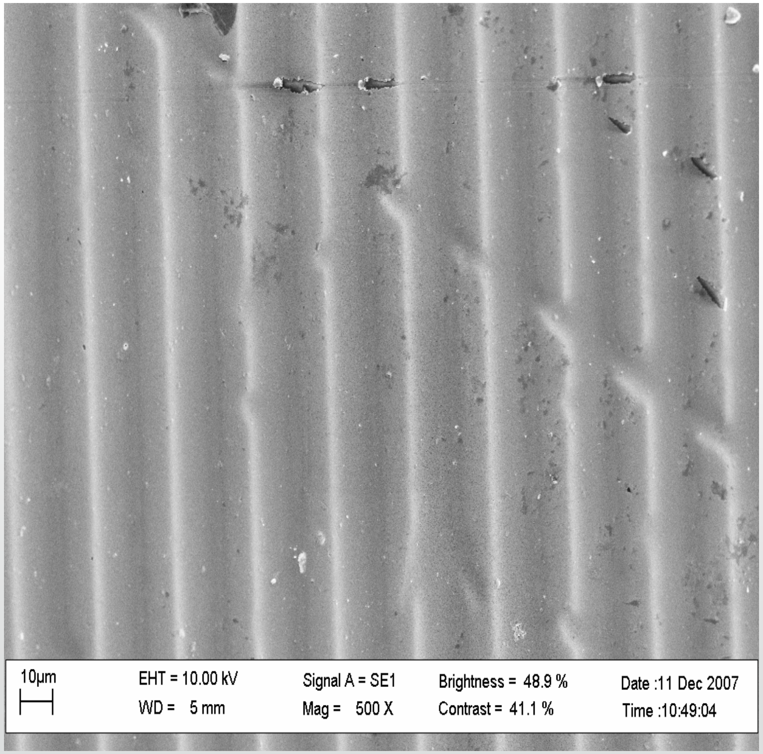
- Comparison of Sensors and Systems
  - Con-focal white light sensor (WL)
  - Con-focal laser (CL)
  - Atomic force microscope (AFM)
  - White light interferometer (WLI)



Reference samples

- Four 25μm pitch sinusoidal artifacts
- Four 8μm pitch sinusoidal artifacts
- 8μm pitch rectangular.

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Period (μm)	Peak-to-valley amplitude (μm)	Maximum Gradient (°)
25A	2.720	37.20
25B	0.654	5.30
25C	0.531	3.90
25D	0.134	1.10
8A	0.496	17.10
8B	0.124	3.00
8C	0.068	1.50
8D	0.020	0.50

Specifications of the sinusoidal samples

SEM measurement of the 25μm sample C

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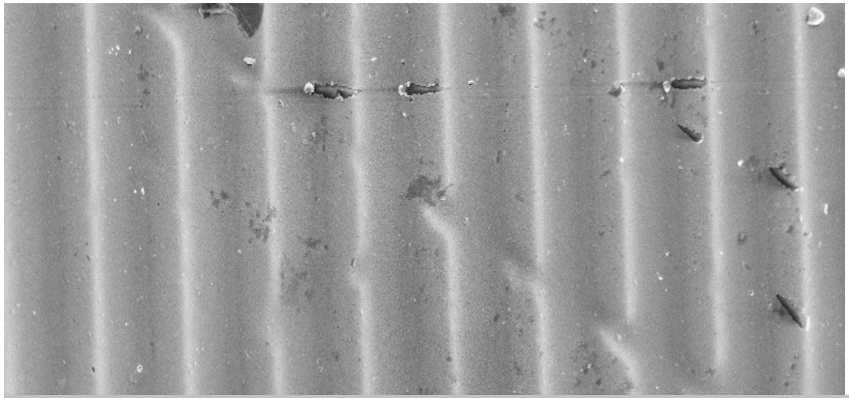
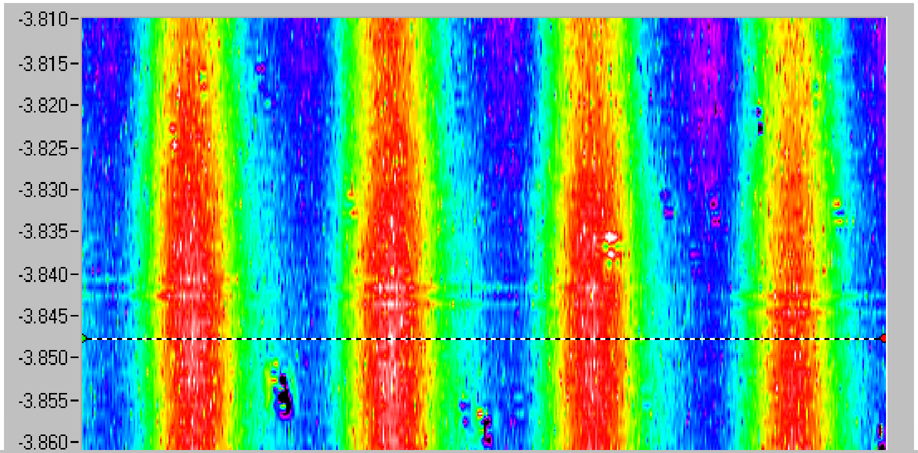
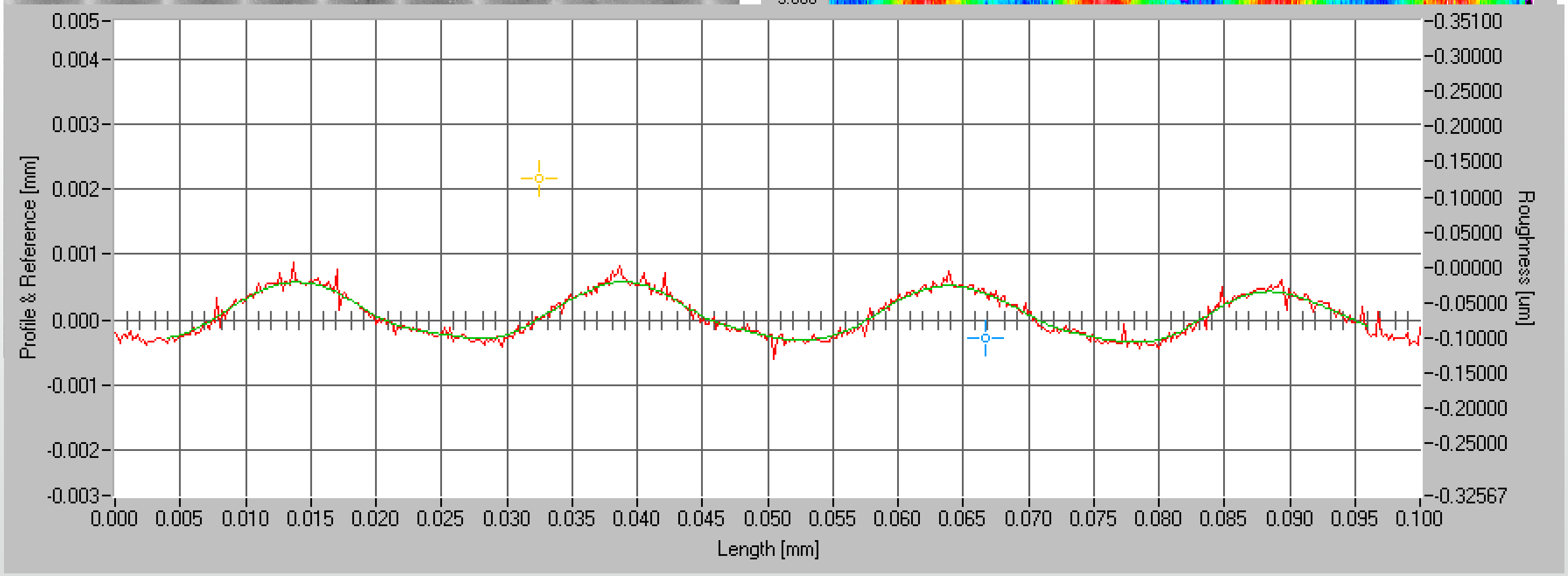
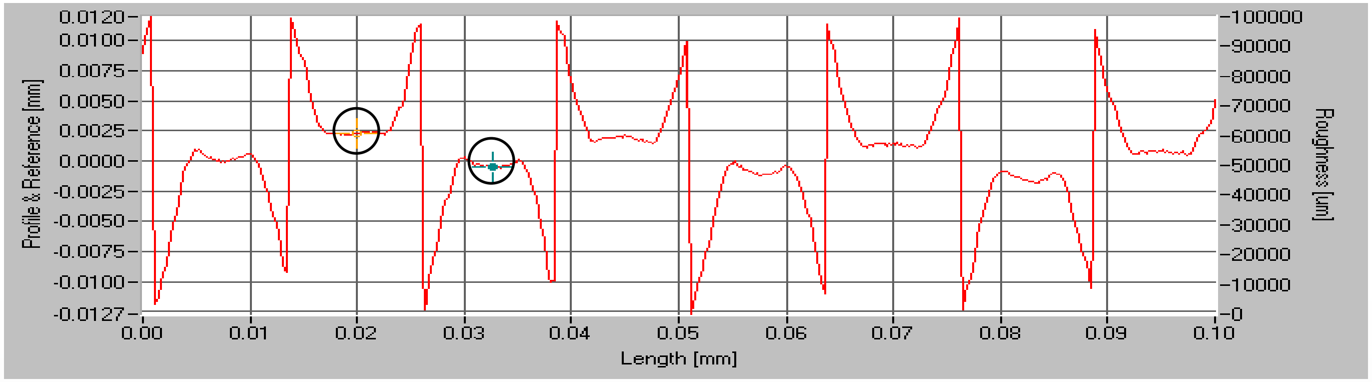






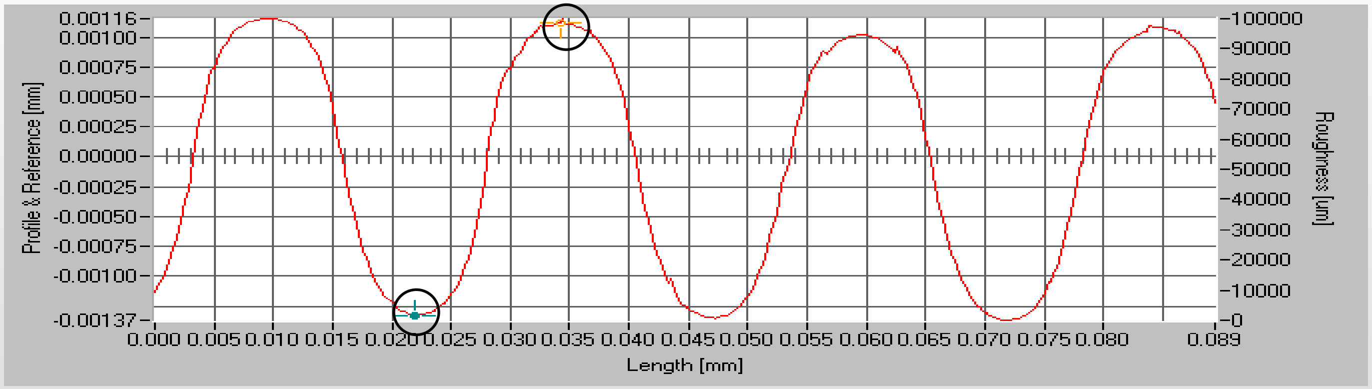
Measurements on the sinusoid of 25μm period, 2.72μm peak-to valley (PV) distance

- CL



501×101, 0.1mm×0.1mm, 0.2μm grid spacing, low precision

- AFM



448×56, 0.09mm×0.0125mm, 0.2μm grid spacing, contacting mode

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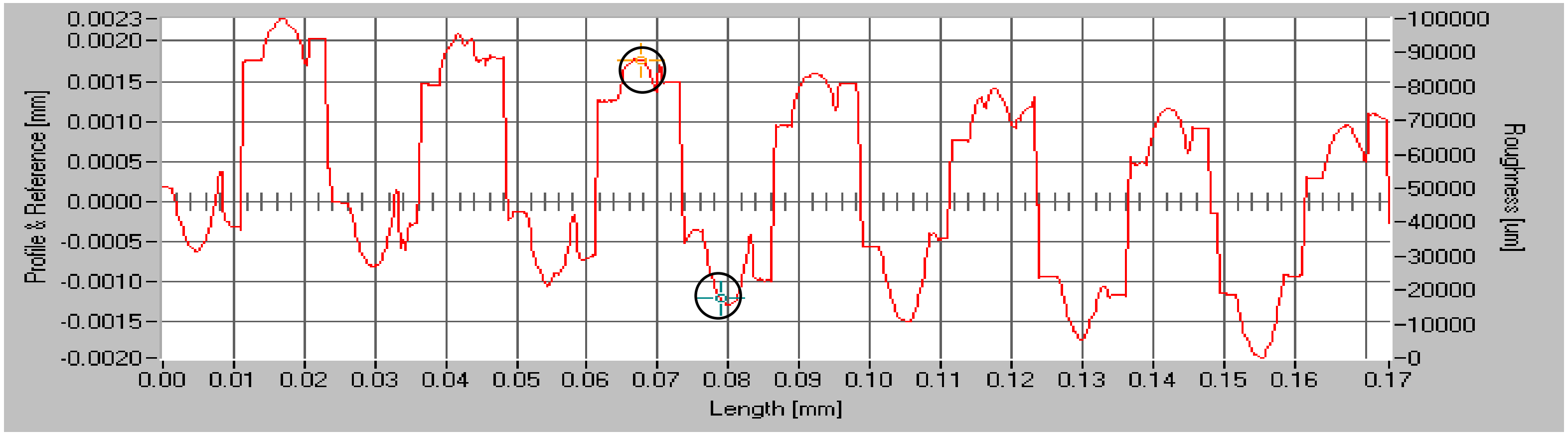
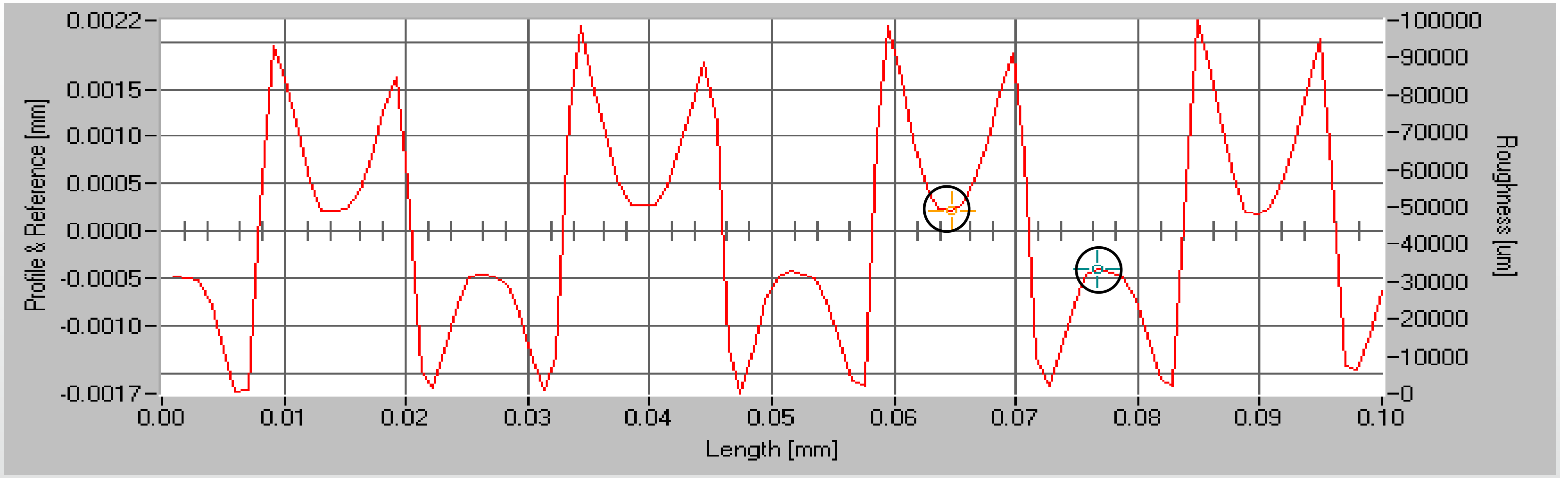
- WLI



752×480, 0.174mm×0.129mm, 0.23μm grid spacing

- WL



501×101, 0.1mm×0.1mm, 0.2μm grid spacing, low precision

Error of three lines average PV for each sample on the two WL systems

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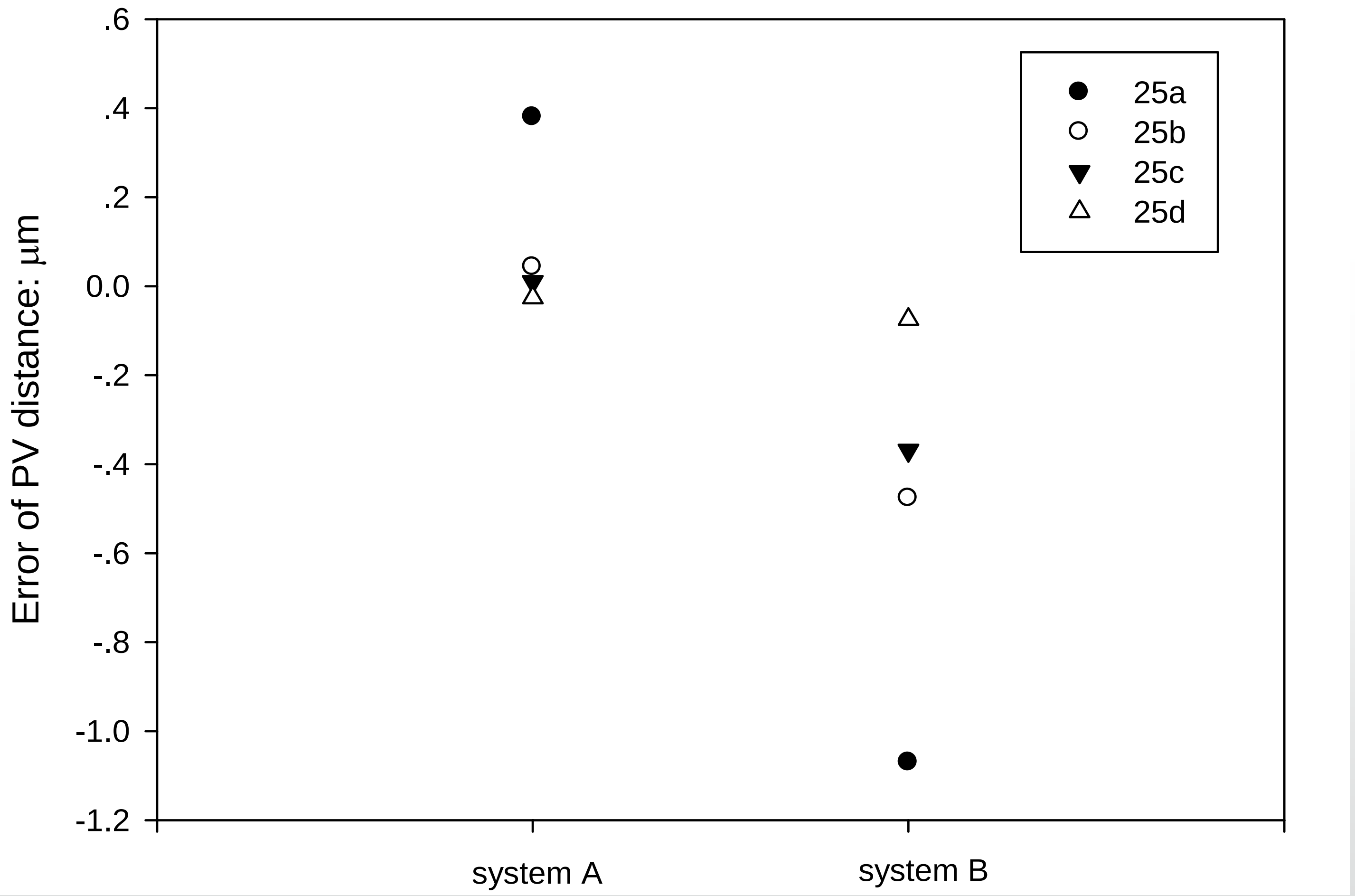

Error of three lines average PV for each sample on the three CL

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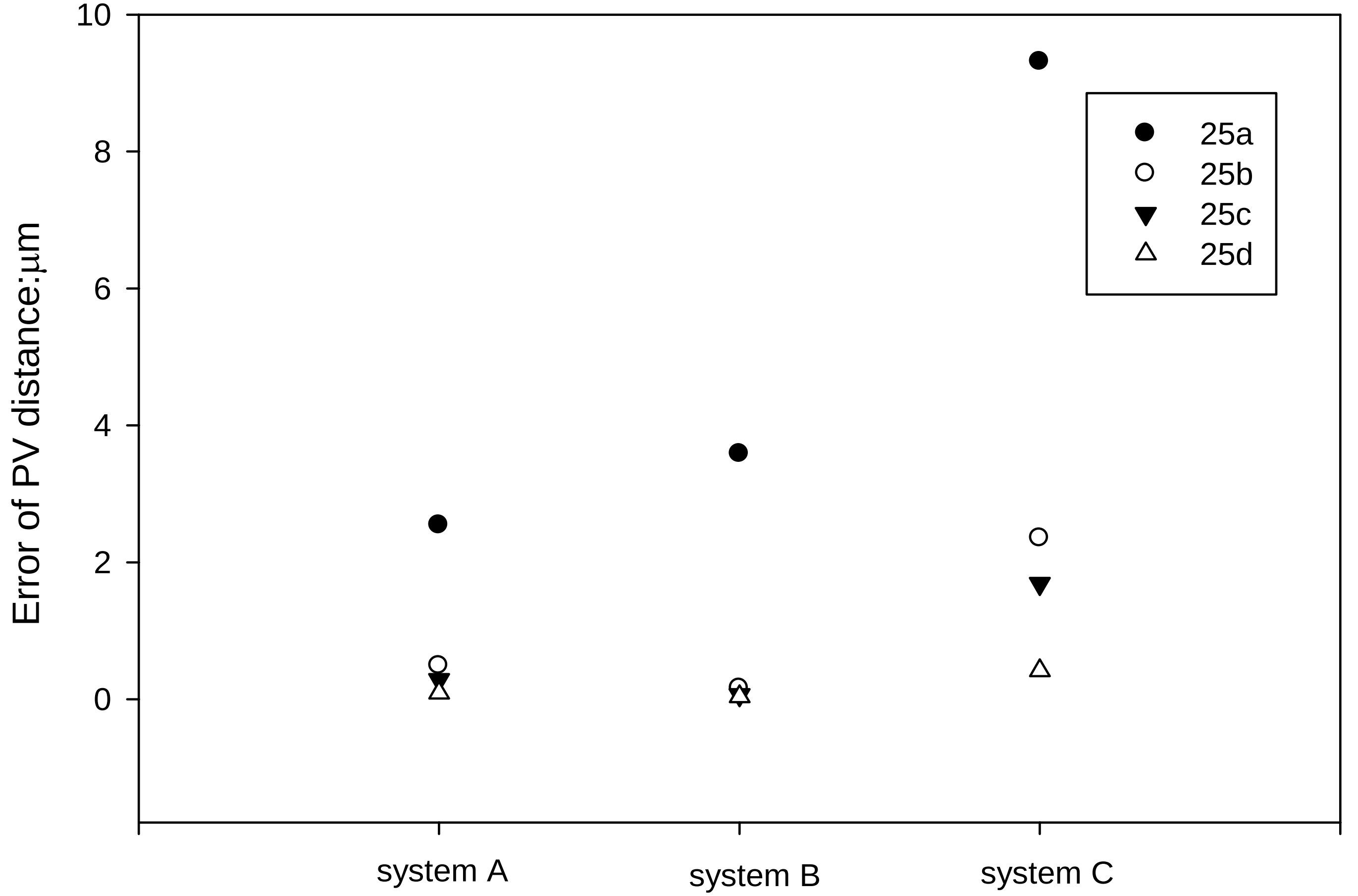
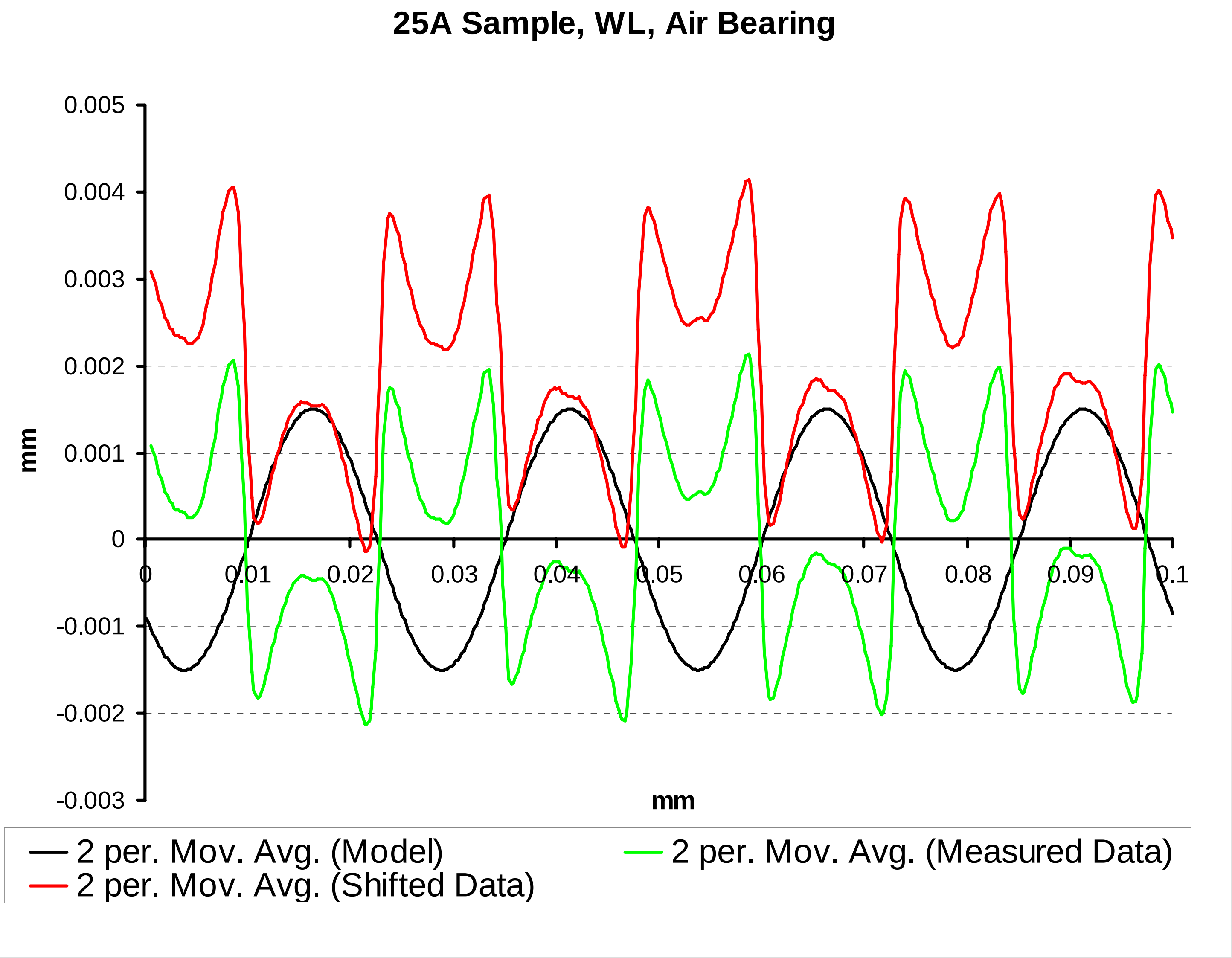


Re-evaluation of PV for 25A



Sensor output at the limit of the angular tolerance.

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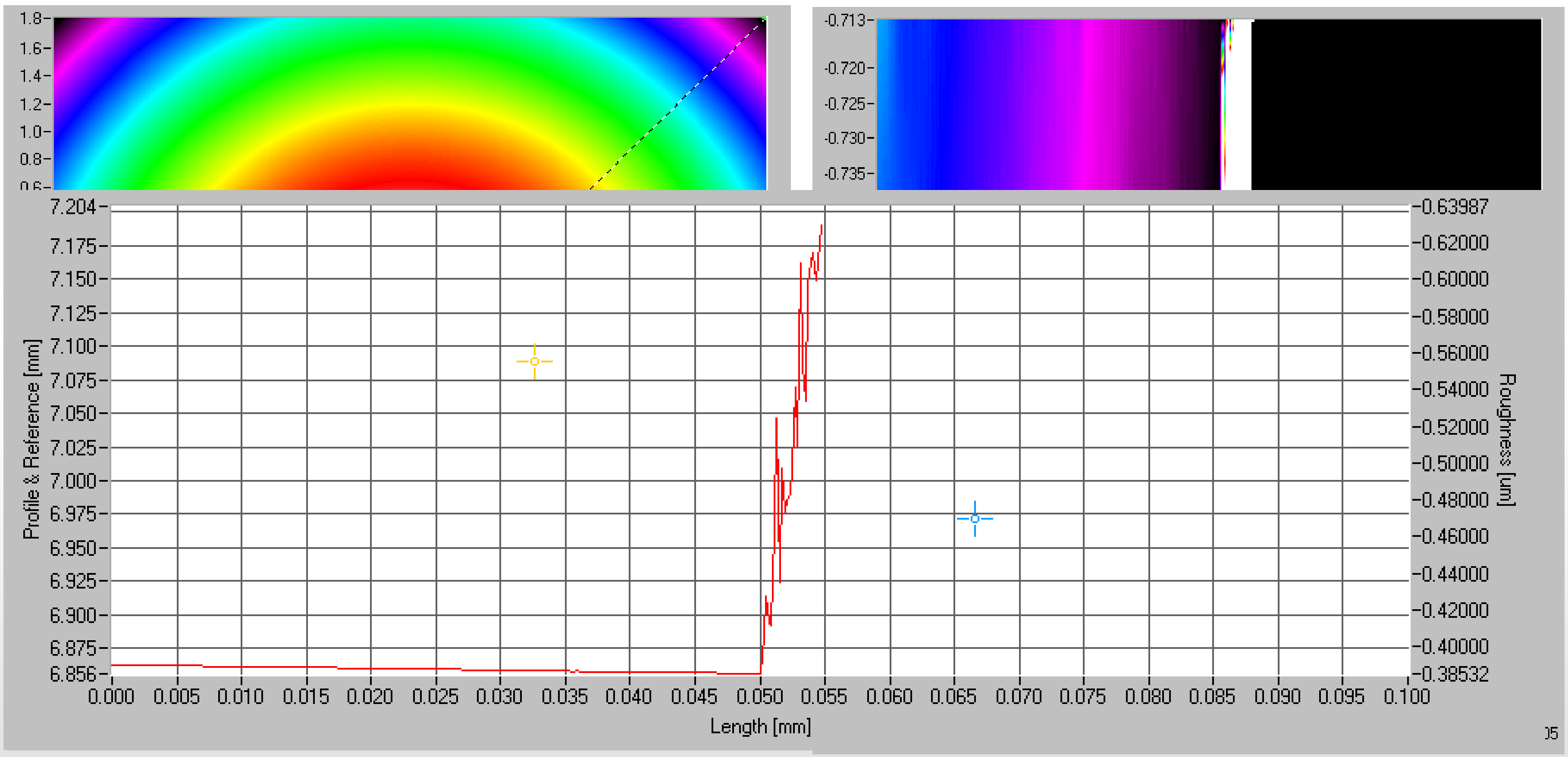

22mm Calibration ball, 101 x 101 5mm x5mm

Edge of 22mm Calibration ball, 501 x 5 0.1mm x0.1mm

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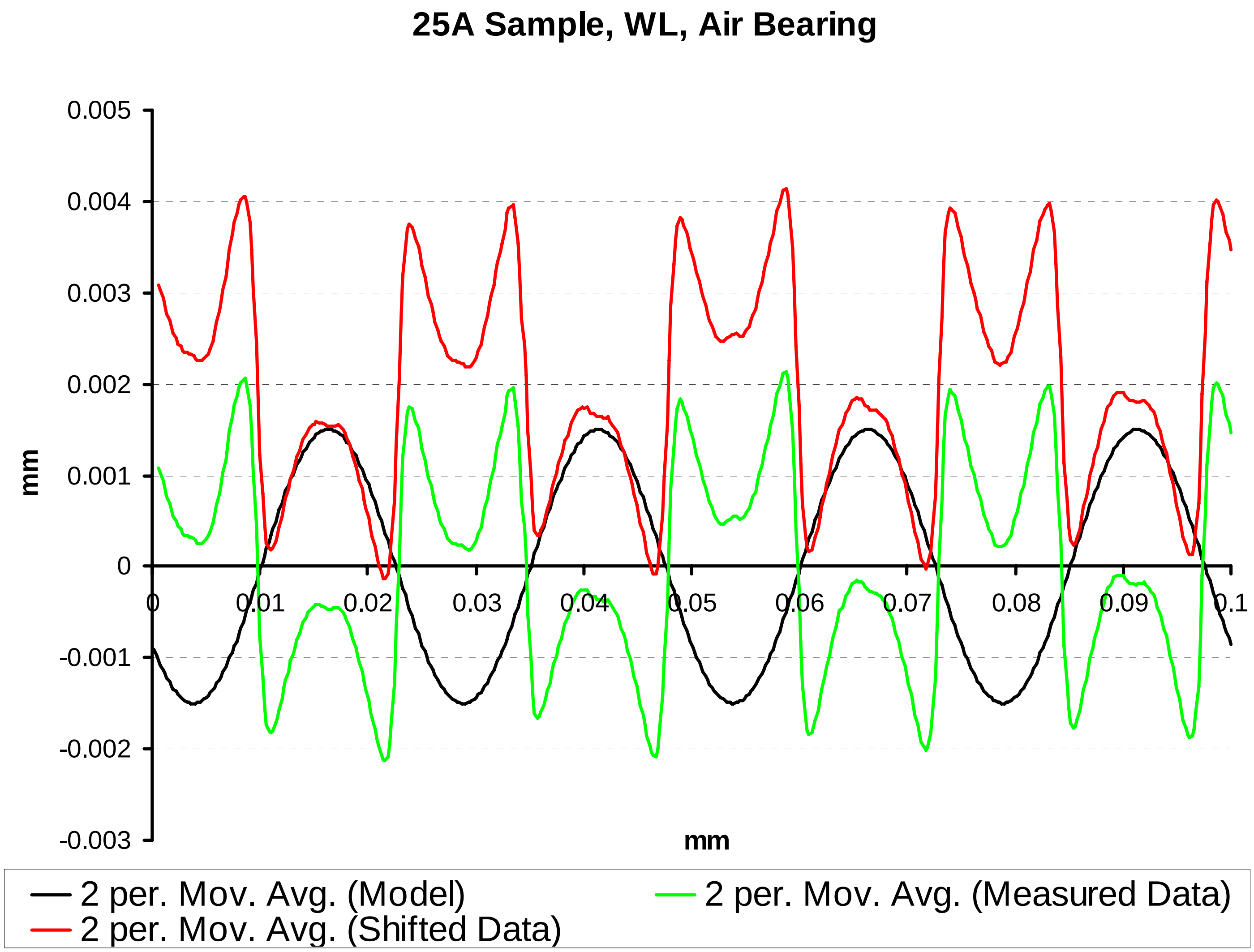

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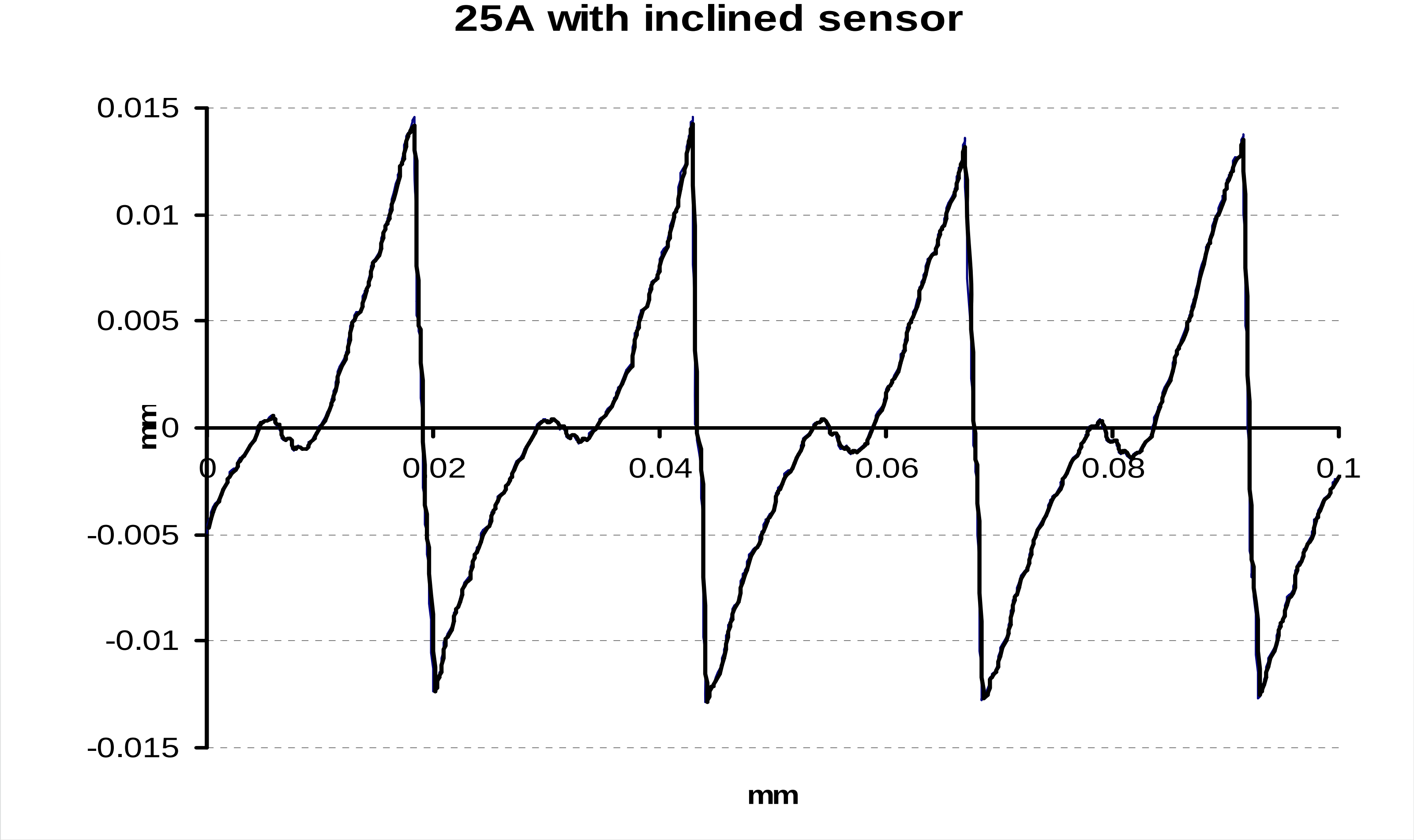

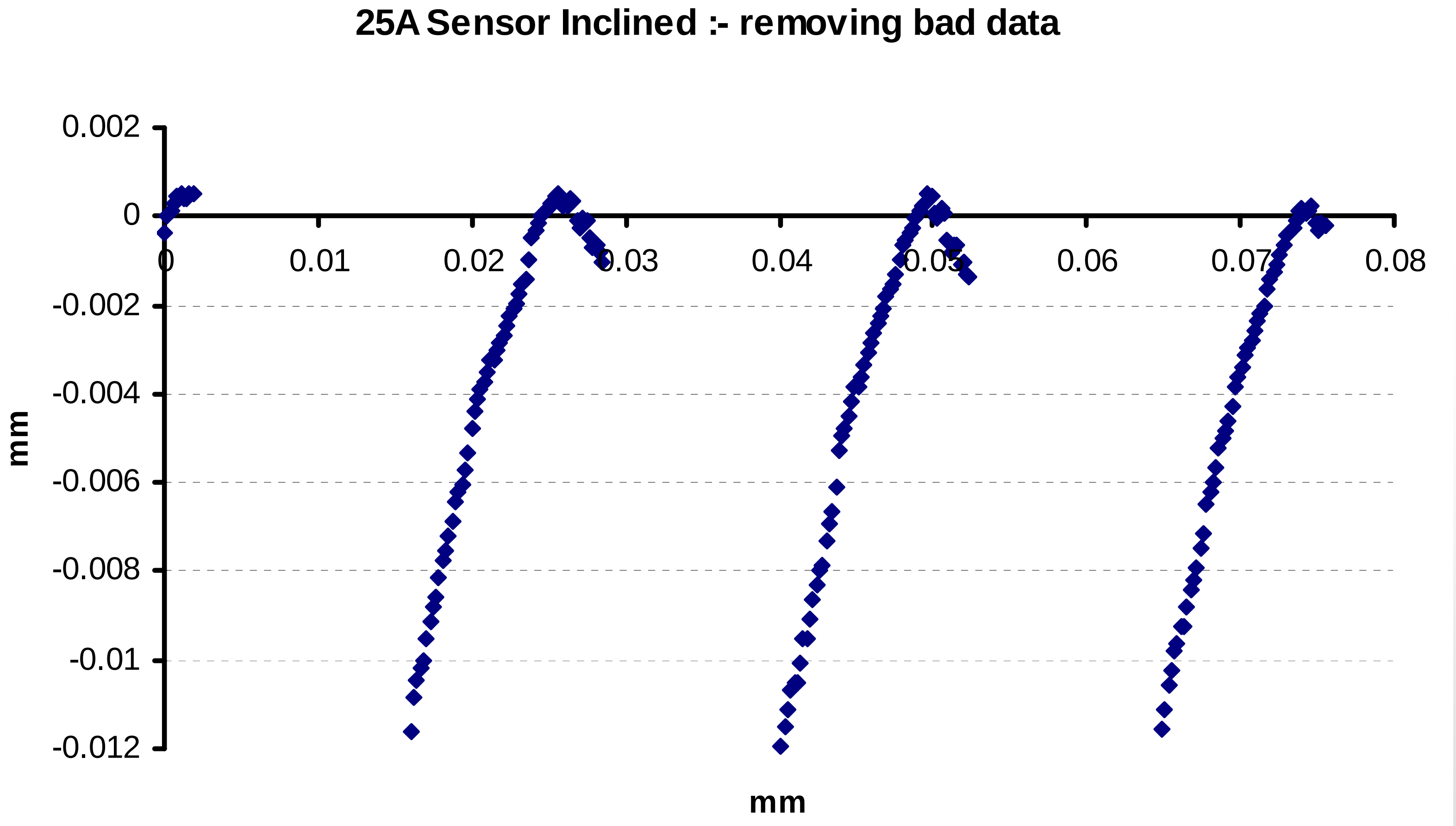
25A Sensor Inclined :- removing bad data
0.002
0
-0.002
-0.004
-0.006
-0.008
-0.01
-0.012
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
mm
mm

Rendered surface of a 78 groove profile 501 x101 0.5x0.5mm

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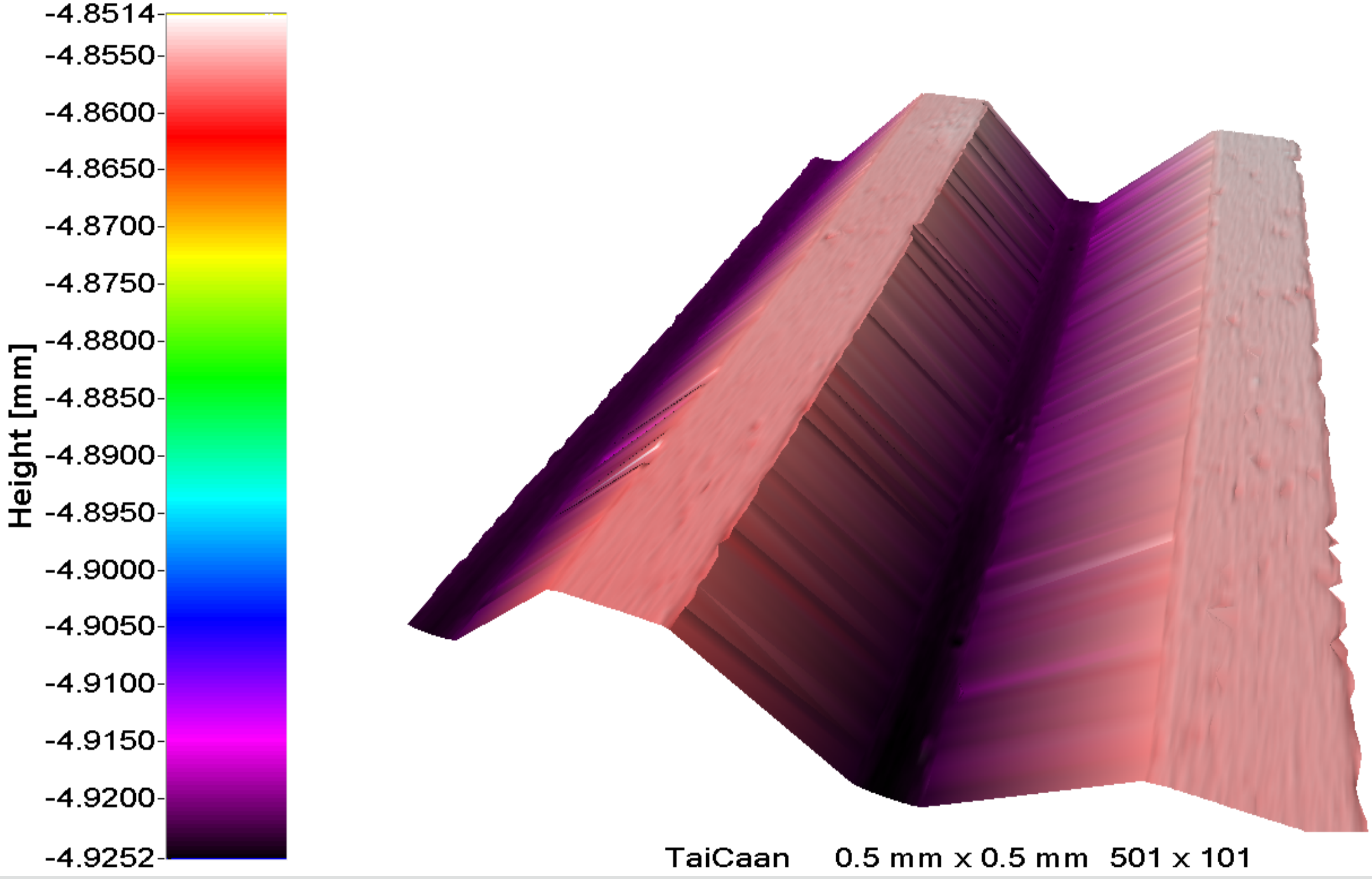

Raw data profile 78 501 x101 0.5mm x 0.5mm

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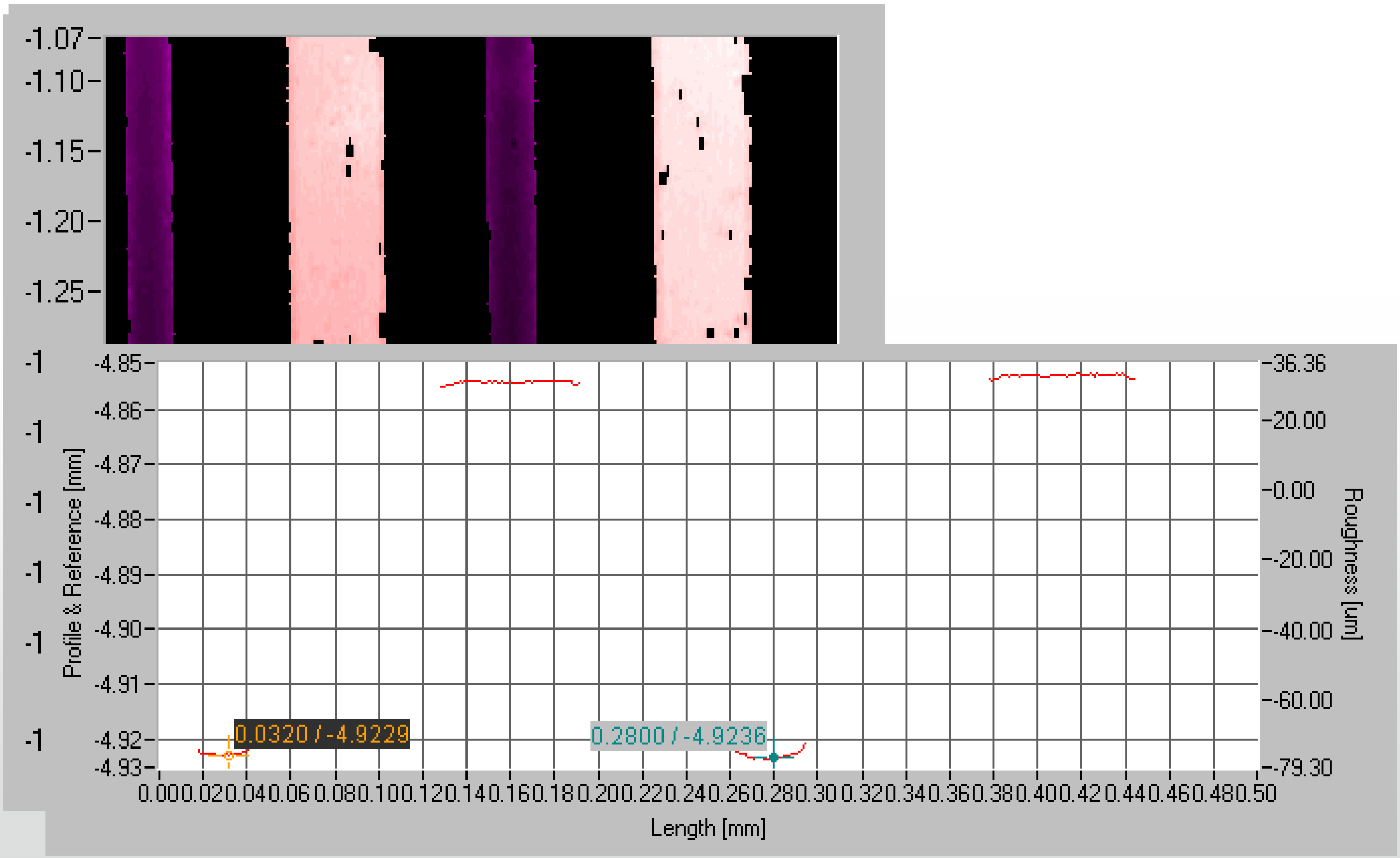

LP groove section, 501 x101 0.5mm x0.5mm

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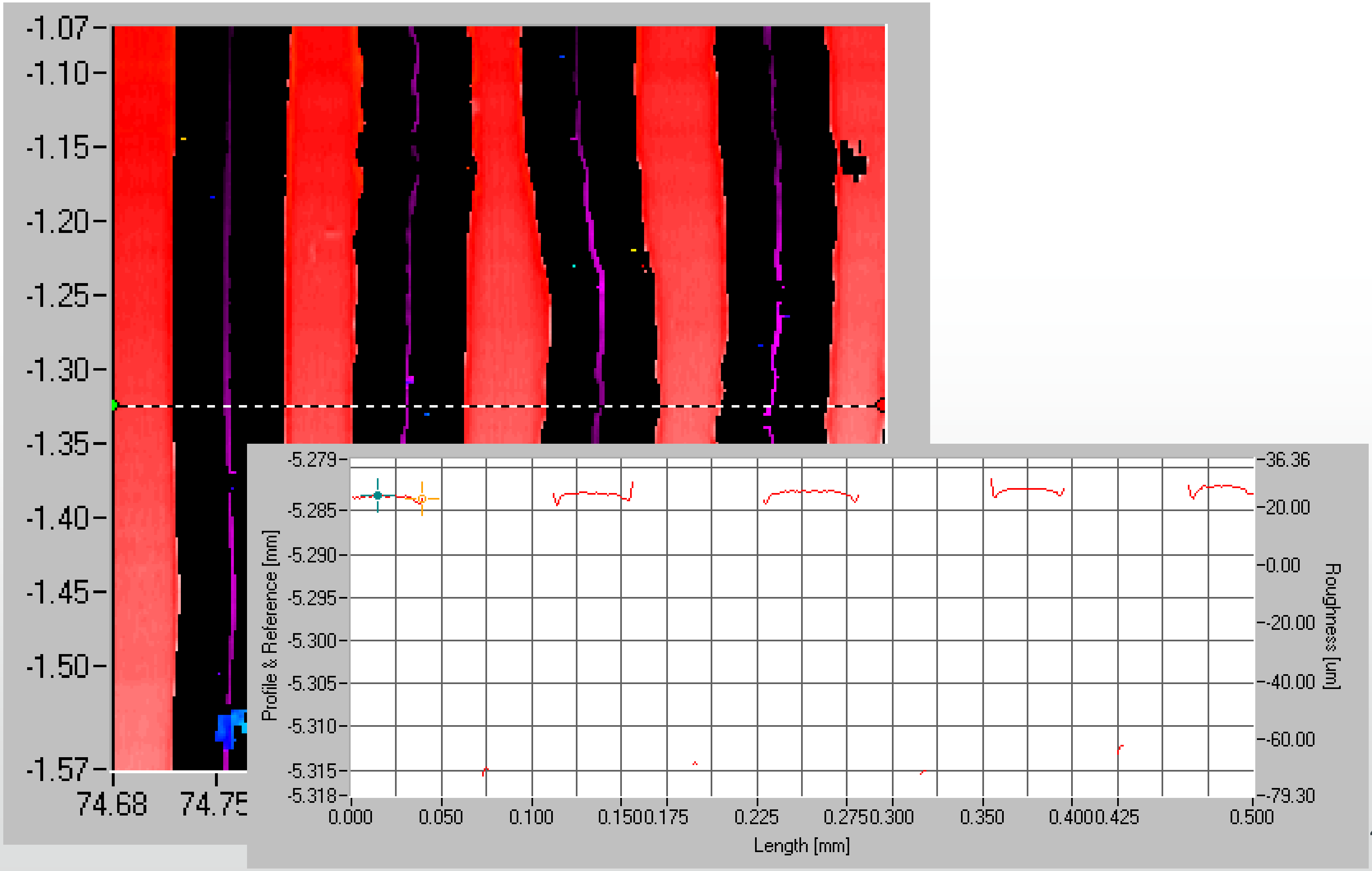

27 degree sensor 78 101 x101 0.5mm x 0.5mm

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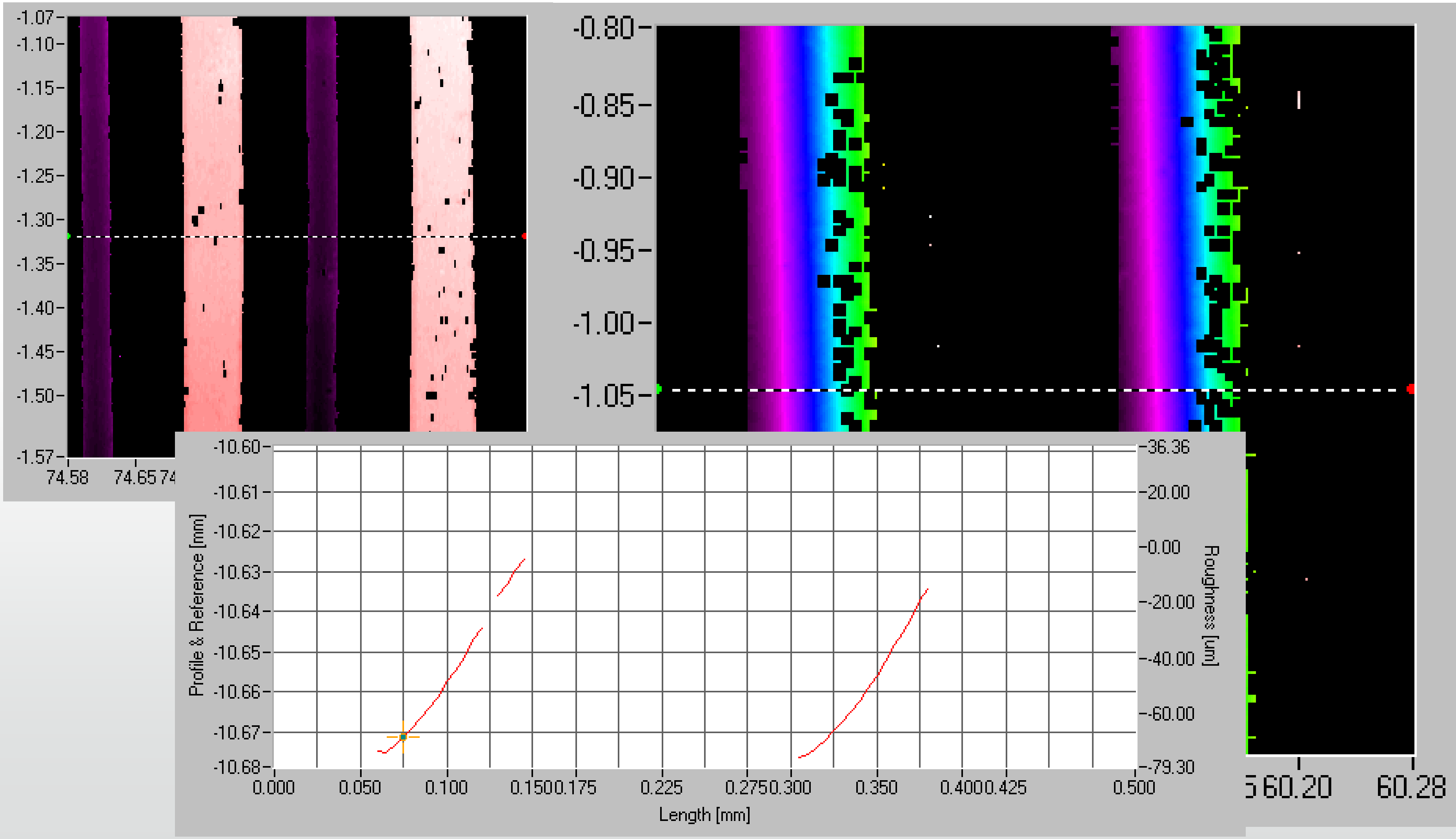

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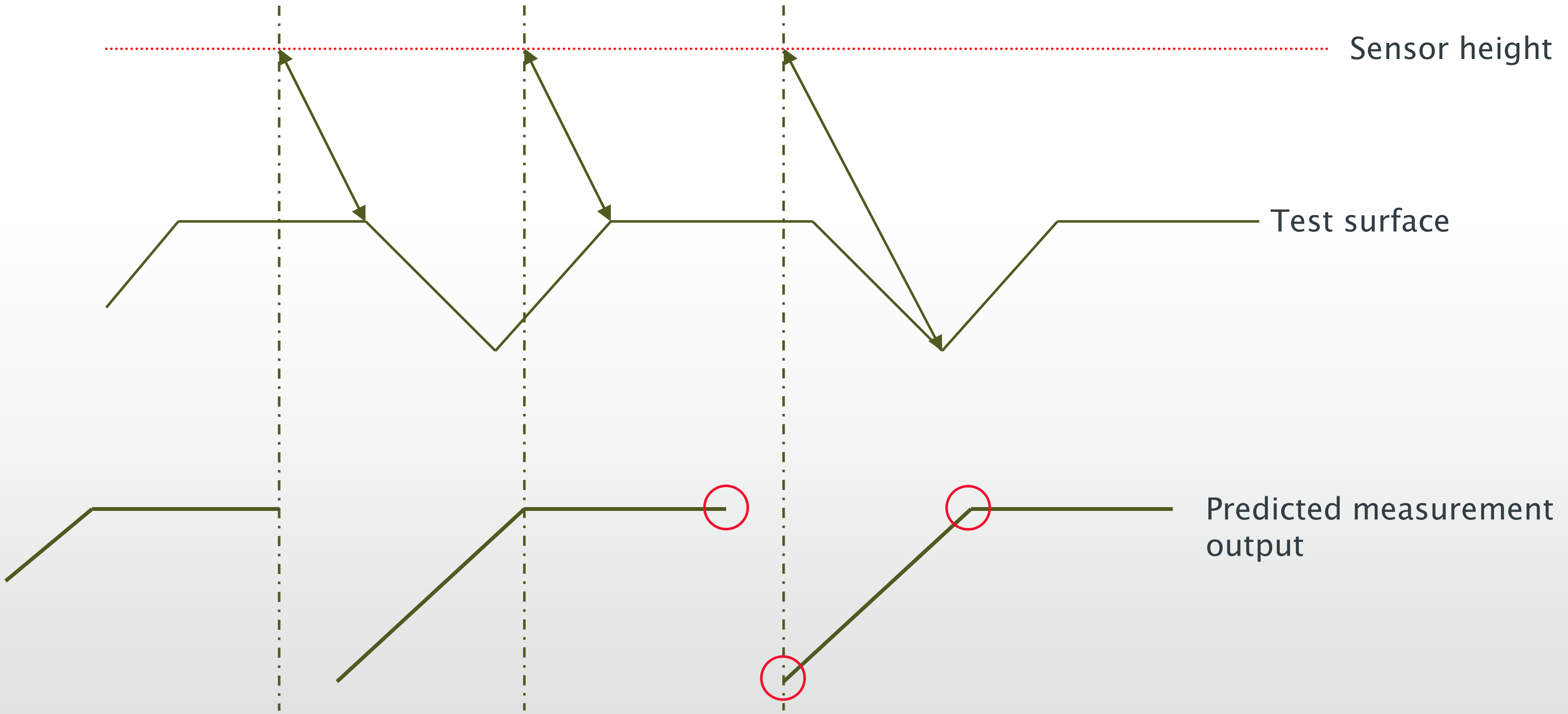
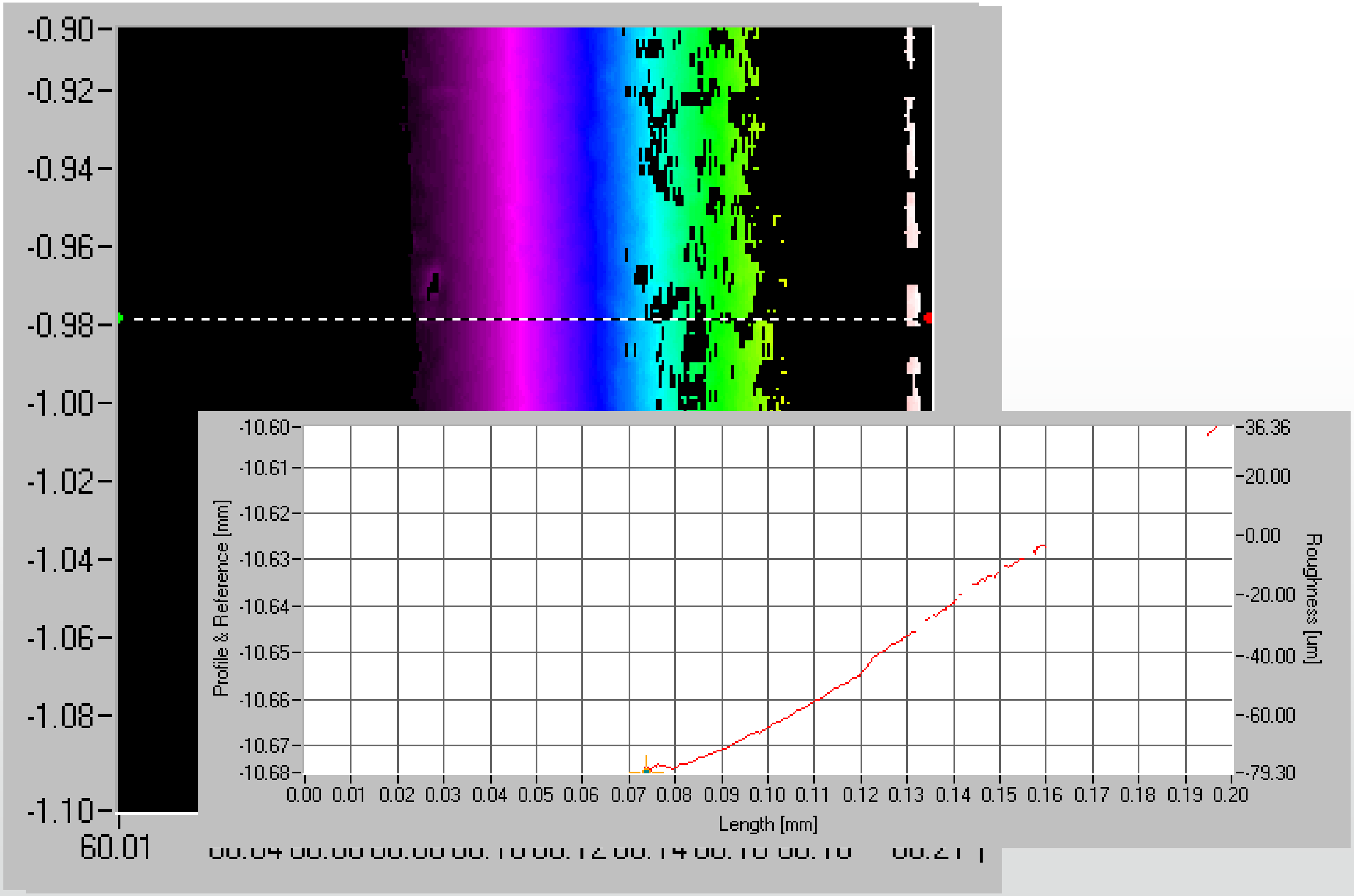
Angled sensor head – predicted output

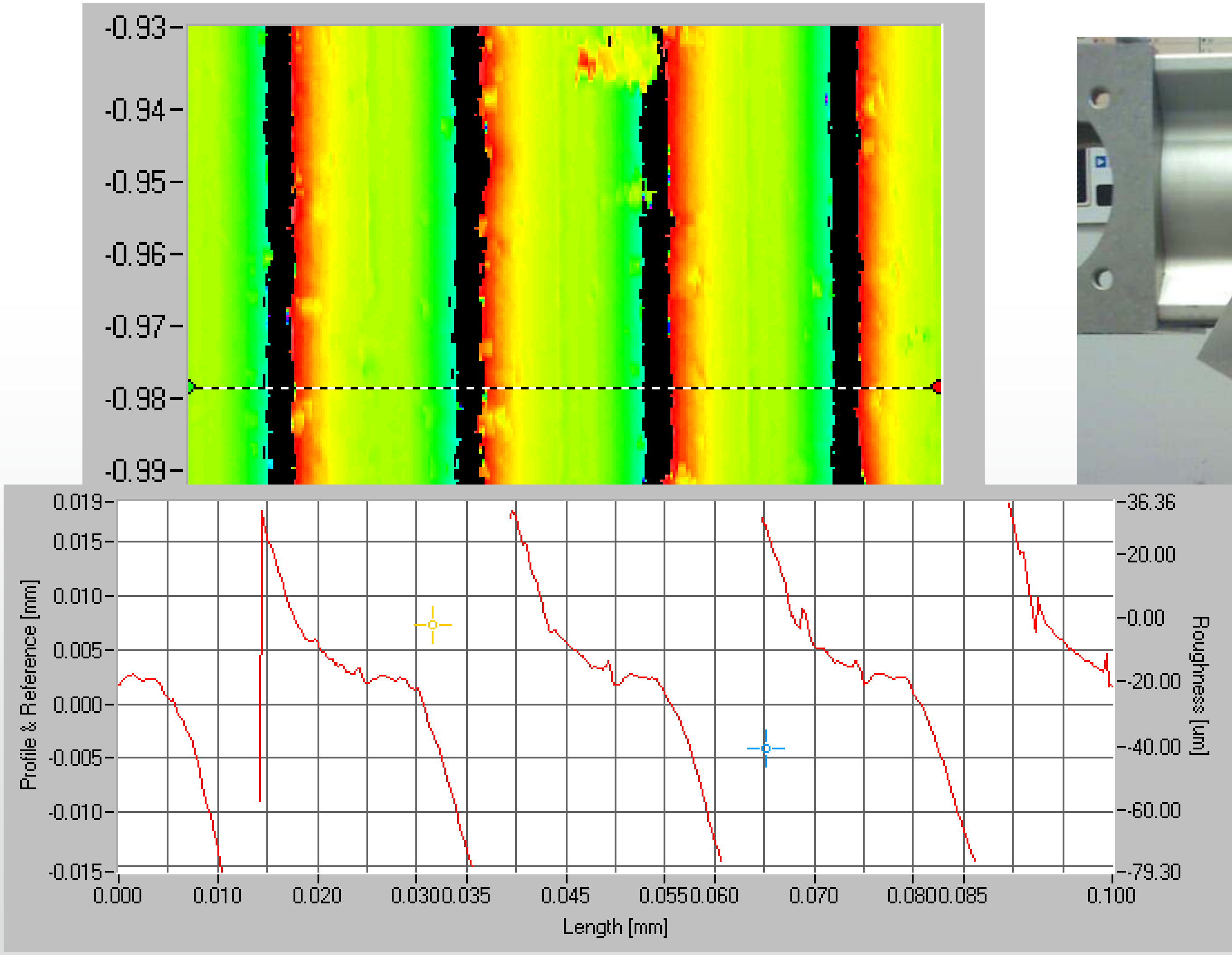


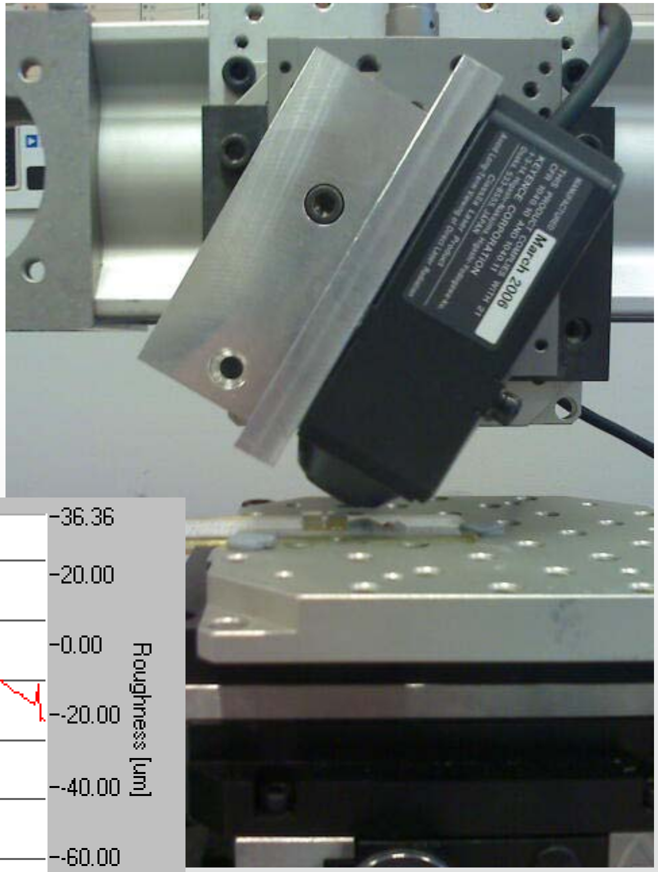
Relative positions of groove cardinal points are related by the sensor’s height measurement, rather than just by lateral resolution of the scan

78 surface 501 x 101 0.2mm x 0.2mm



Application of CL sensor





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Conclusions and Recommendations

- For the preservation of flat disc recorded surfaces the X,Y (horizontal) resolution is required to match the 10nm in vertically modulated surfaces.
- It has been shown that the resolution required can be achieved using an inclined sensor, (with some loss of sensor resolution).
- Current research is focused on modelling expected data output and in the integration of multiple sensors with sensor angles of 45 degrees.
- Both Con-Focal Laser and Chromatic WL Sensor have been demonstrated as offering potential solutions.