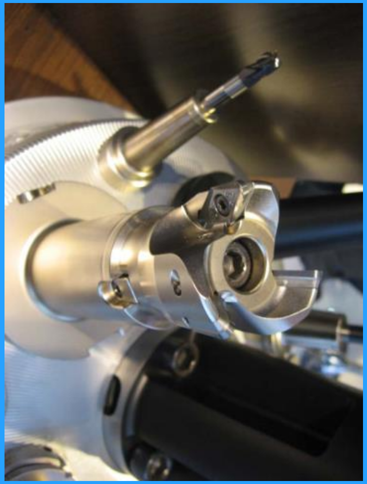
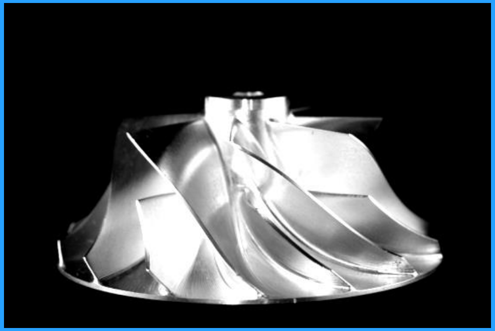


EMRP collaborative project

TIM

(Traceable In-process Metrology)



Development of multi-purpose material standards for mapping task-specific measurement errors of machine tools (Final meeting – PTB)

Stephen Brown and Michael McCarthy

18 May 2016

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NPL in brief

We are UK's national standards laboratory

- Founded in **1900**
- World leading **National Measurement Institute**
- ~700 staff, from over 150 different nationalities; 500+ specialists
- State-of-the-art laboratory facilities
- Engineering measurement, design, manufacturing facilities and instrument development.
- The heart of the UK's **National Measurement System** to support business and society
- Experts in **Knowledge Transfer**
- Government owned and operated in conjunction with two UK universities, since early 2015

36 000 m^2

388 Laboratories

purpose built

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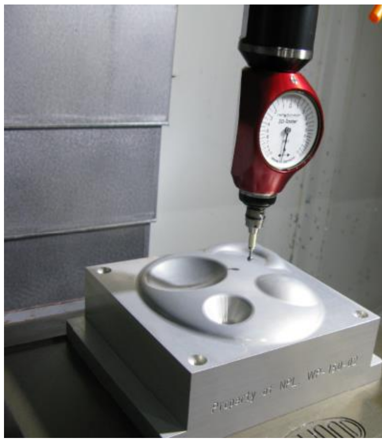
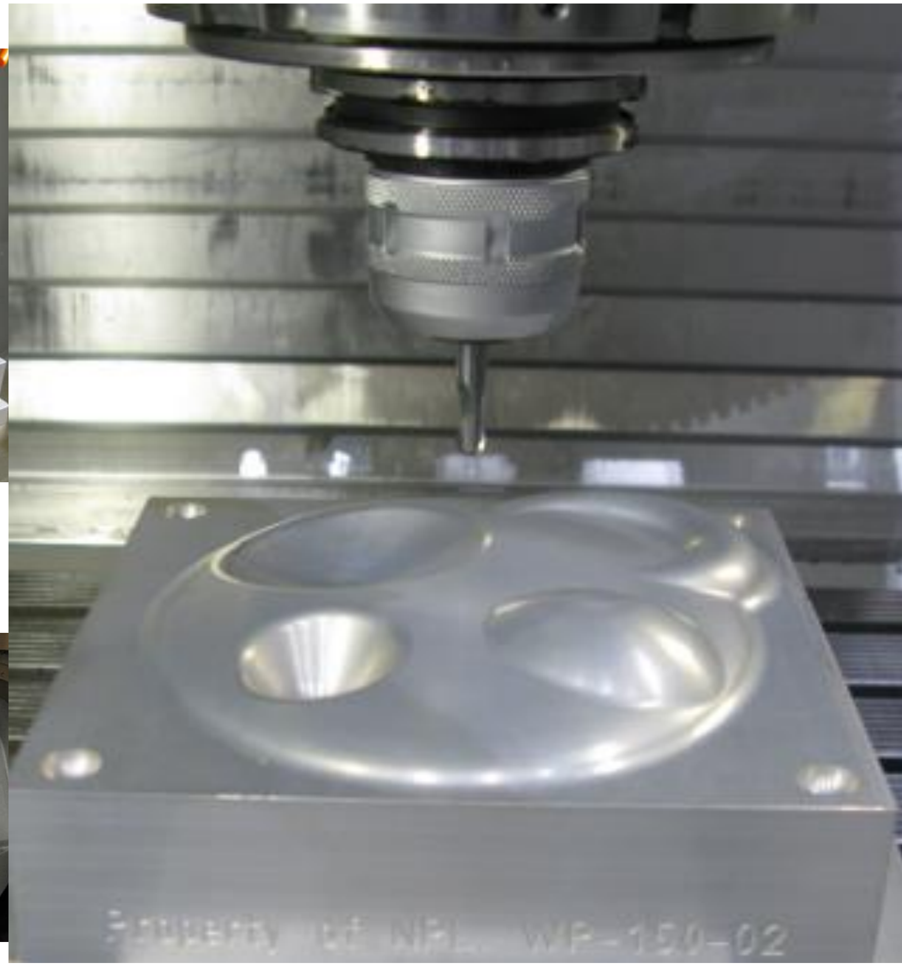
In-process measurement

National Physical Laboratory

Manufacture validation

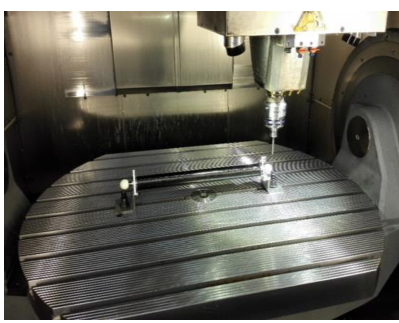


Artefact being manufactured

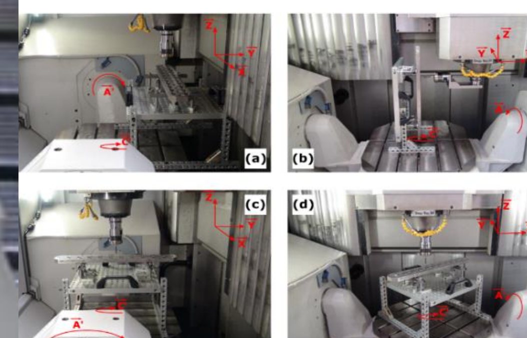


Manufacture validation

System validation



System calibration



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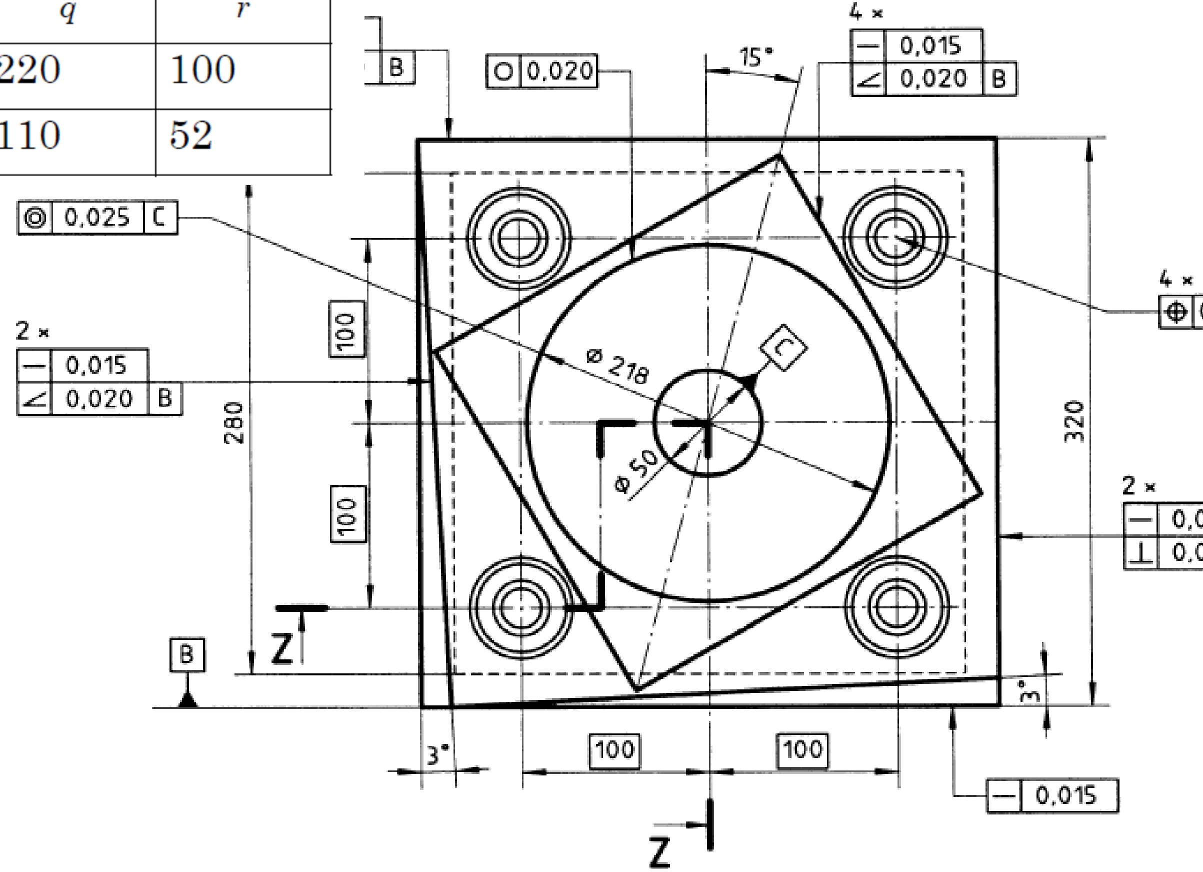
NPL and BS/ISO 10791-7 Artefact design concept

Dimensions in millimetres

Nominal size, l	m	p	q	r
320	280	50	220	100
160	140	30	110	52

Note: NPL has further developed this concept (a non-Freeform standard).



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What do we mean by:
Task Specific

- We want it to measure typical machine manufacturing geometries:
  - Cylinder, Sphere, Flat…
- We want to be able to check:
  - Their form
  - Their position
  - Their relative position

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Initiating the design

Solution

Problem

- What has it got to do
- Single design or multiple designs
- Is it for comparison
- Does it do any analysis
- How do we get traceability

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What information do we want it to divulge

Form

- Sphere
- Cone
- Cylinder
- Torus

Position (Tool tip)

- Location (x,y,z), form, radius
- Location (x,y), form
- Location (x,y), form

Trajectory

- Smooth
- Resolution

The system may be capable of doing:

- Manufacture the form to the n^{th} degree of precision
- Place it in the correct place

However, it may not be able to do both

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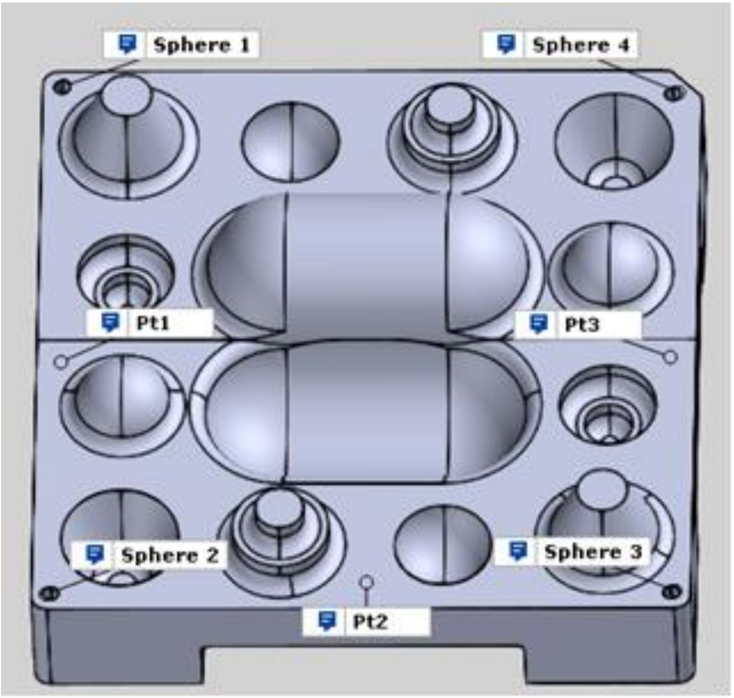
NPL Prismatic form 200 mm square

National Physical Laboratory



- Simple robust mathematical form:- Sphere, cone, cylinder, flat…
- External and internal design (*z*-axis)
- Centre of shape, intersection with plane (*x*,*y* axis)
- Gaussian and Chebyshev analysis (position, goodness of fit)
- Regular grid allows 180° rotation

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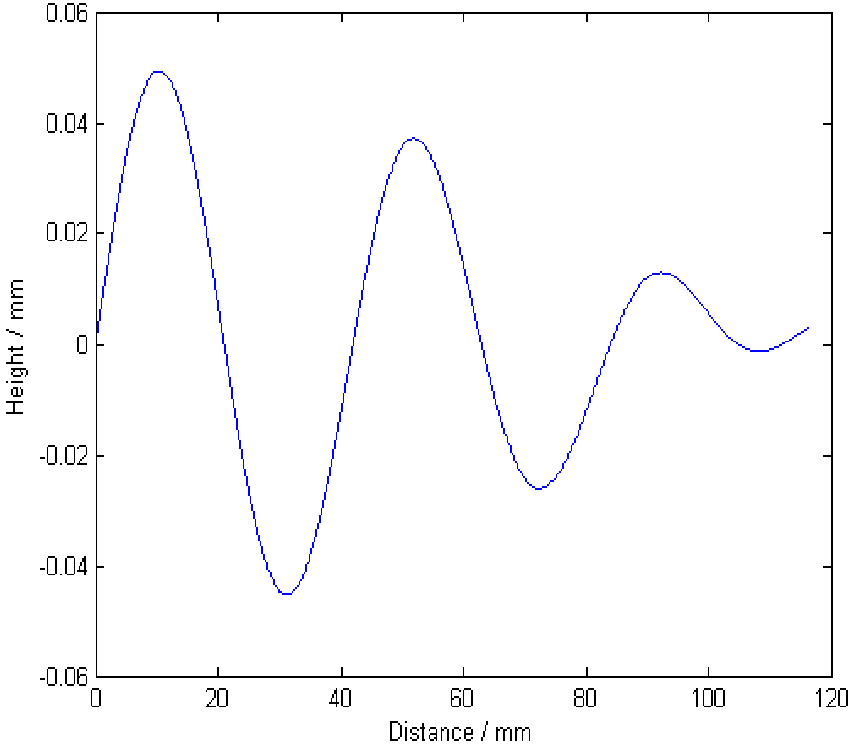
Perturbation surface - sensitivity



- Systems ability to measure
- Small form error
- Size of perturbation 20 µm – 50 µm
- 50% of surface
- Decreasing sine wave
- Manufacturing – CAD to CAM control

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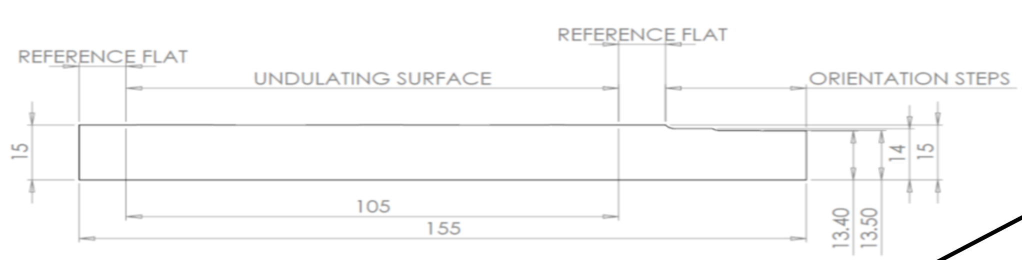
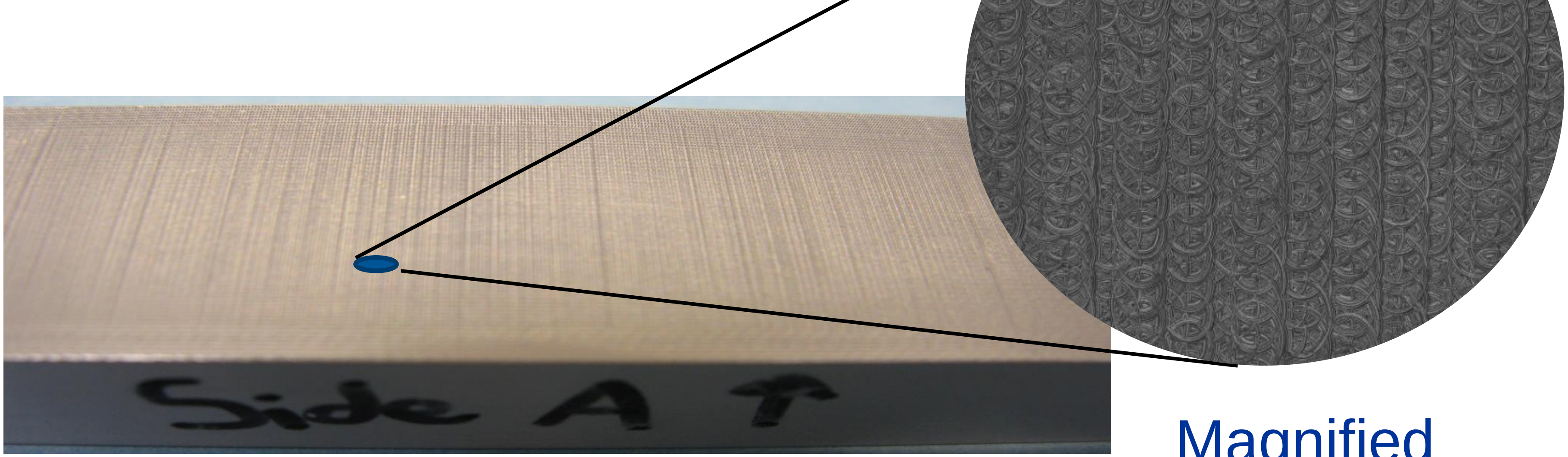
Manufacture check - Transverse





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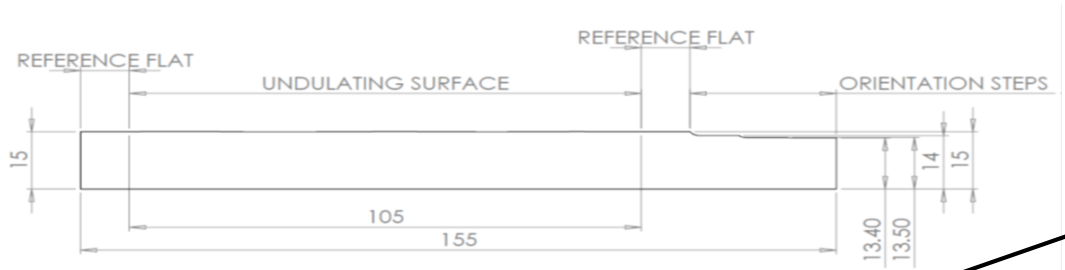
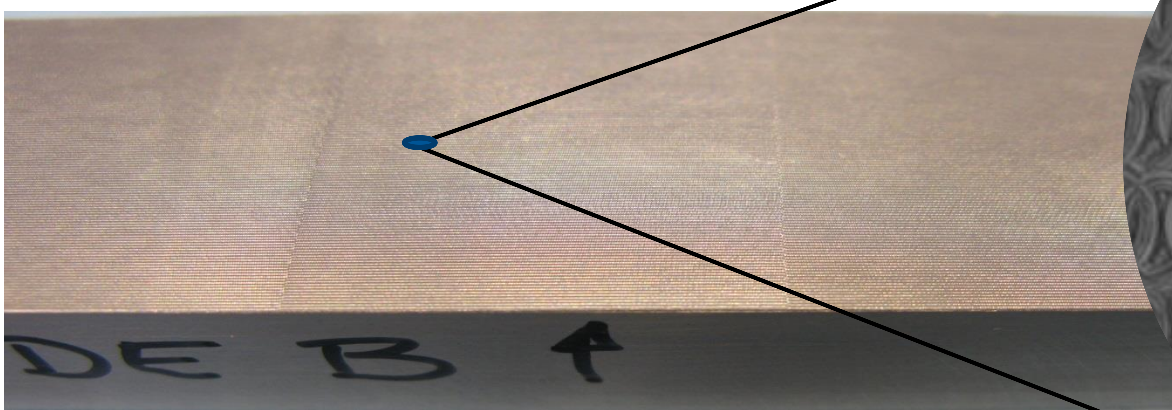
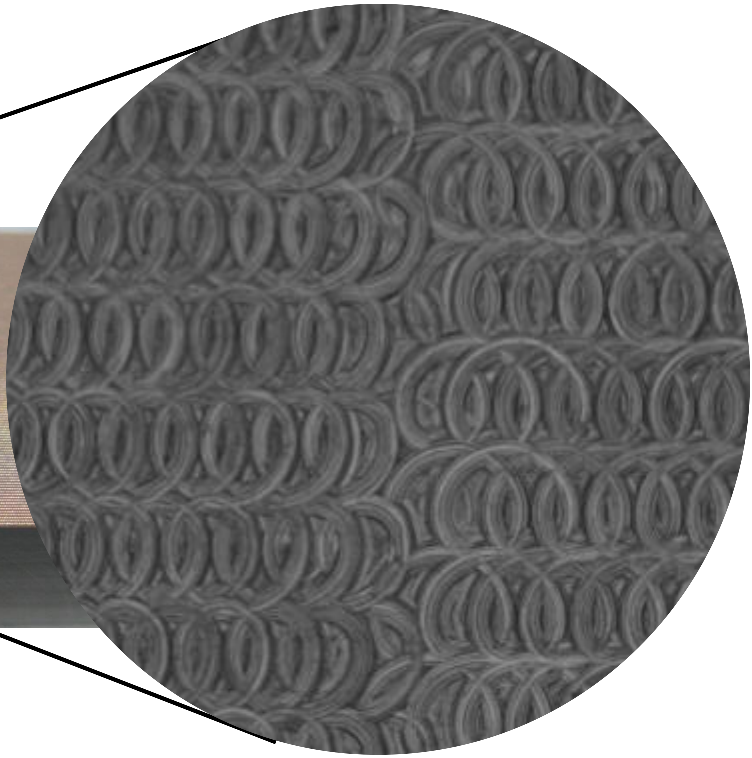
Manufacturing check - Longitudinal







Magnified

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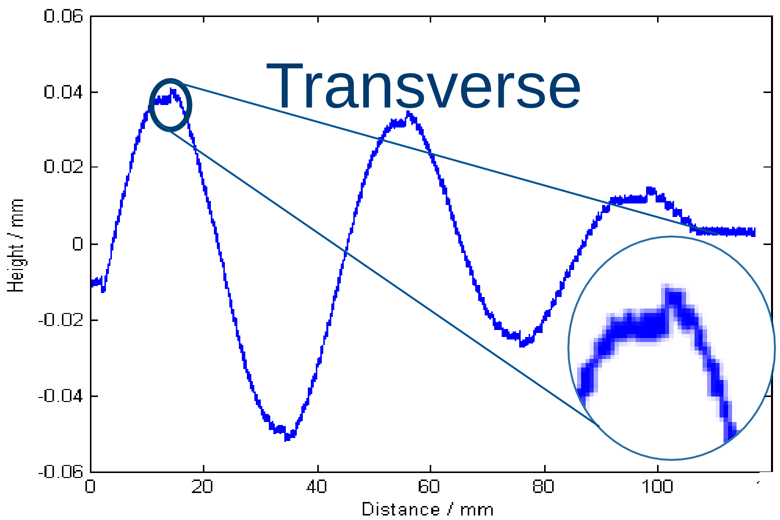
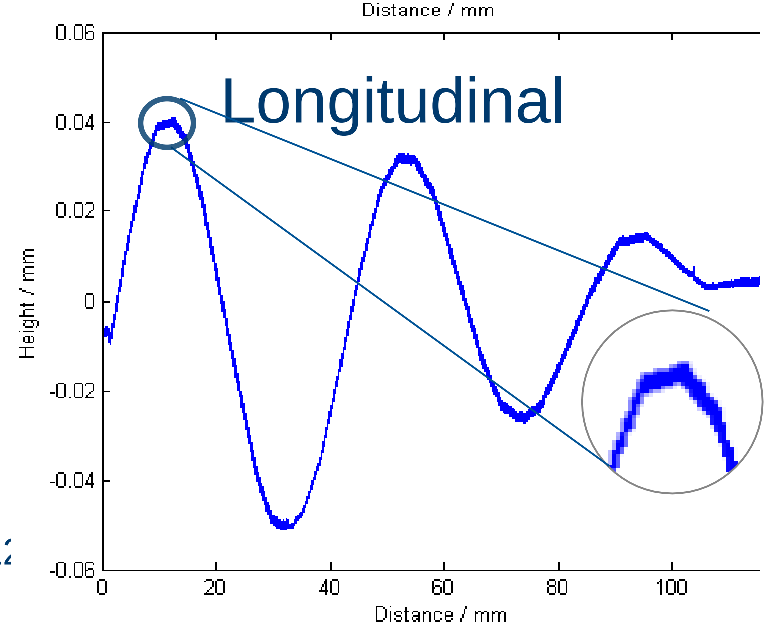
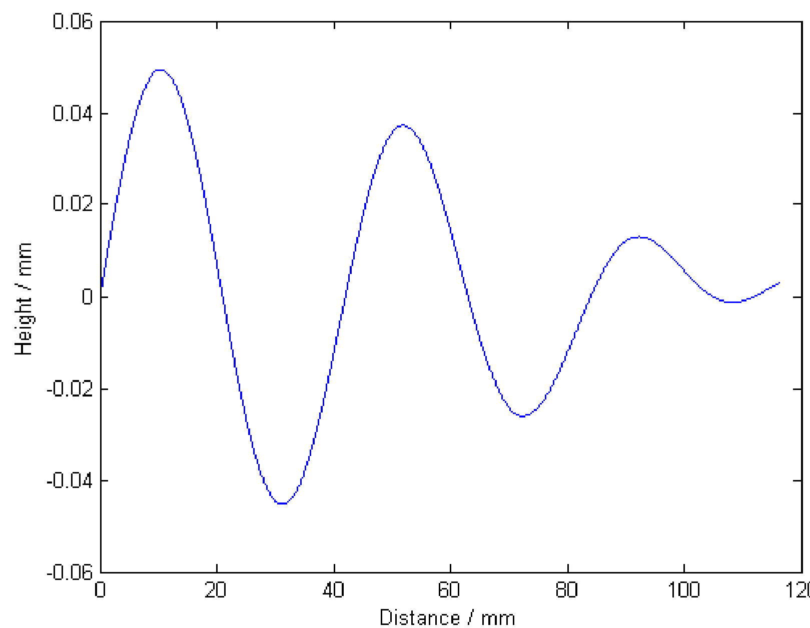
Profile measurement of perturbation

- Taylor Hobson PGI 1000
- 20 µm stylus, every 0.125 µm
- 5 mm ‘Bull nose’ mill
- 0.1 mm steps

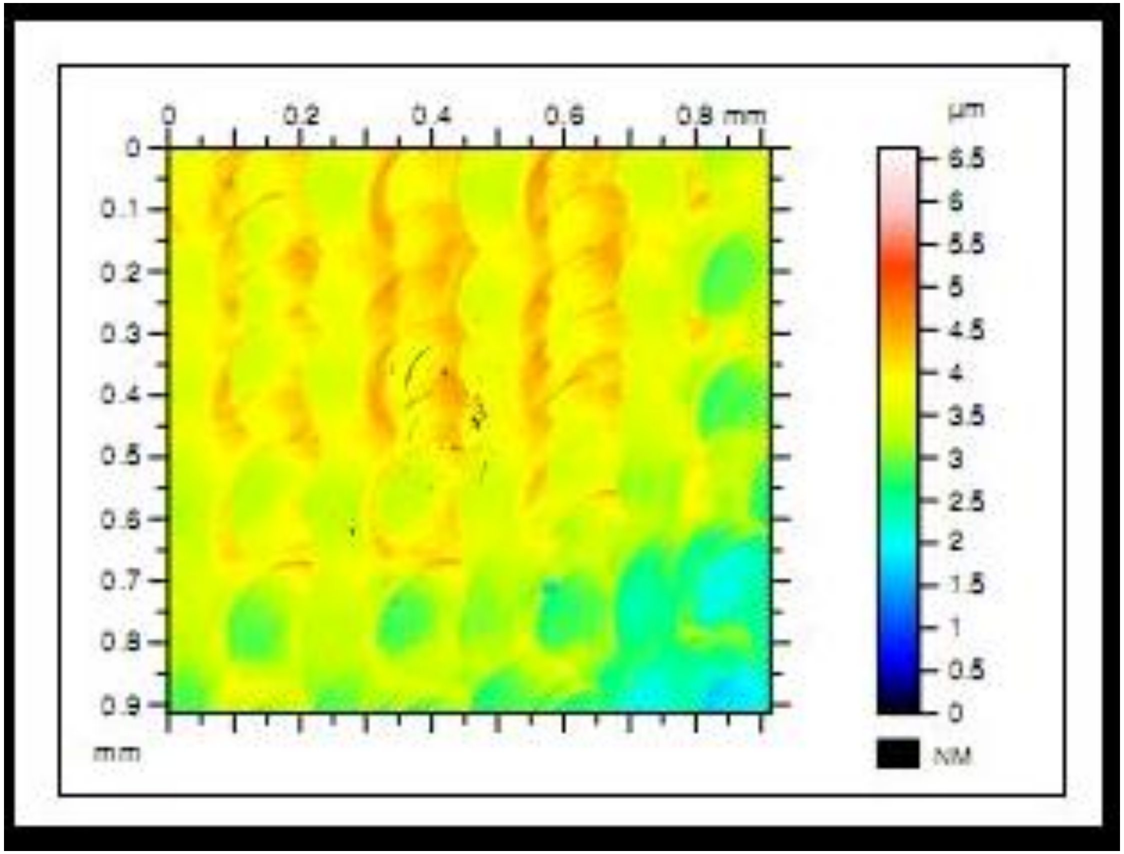






Optical measurement of finished surface

National Physical Laboratory



Optical scan of sample surface: PV<< 1 µm

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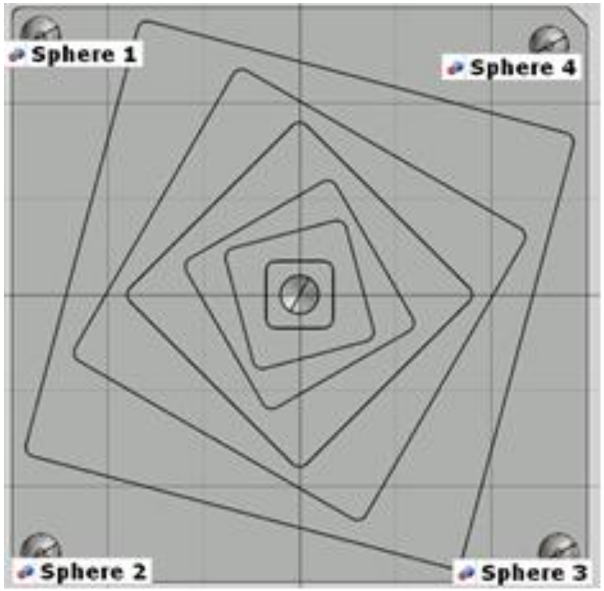
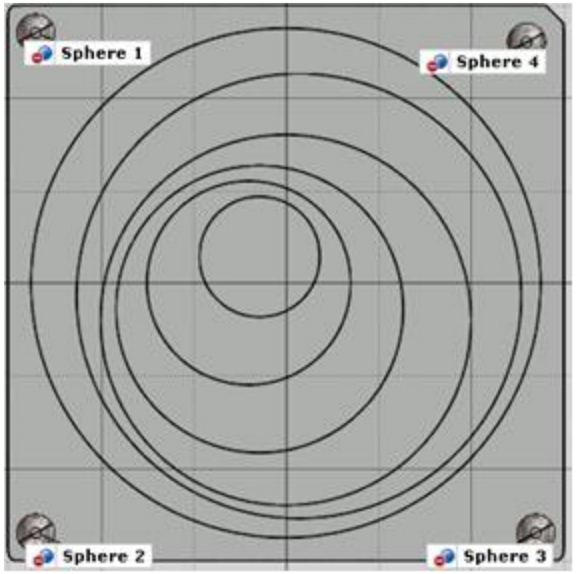
NPL's work replica standards

Square material standard



Cylindrical material standard



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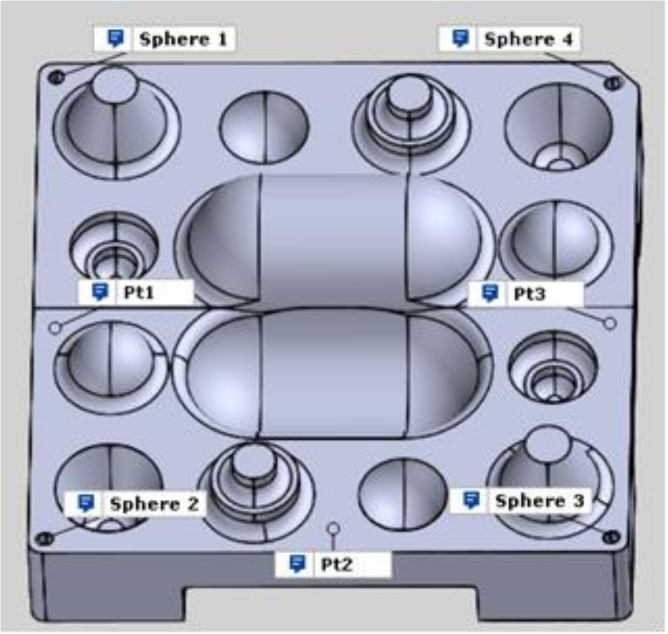
NPL's prismatic material standard (200 x 200)mm

Form measurement



- Calibration: CMM < 2 µm
- Form:
  Sphere, cone, cylinder, flat, perturbation
- Properties:
  Form NOT position
- Scalar check:
  Tooling spheres (not shown)
- Mass: 20 kg
- Coating:
  Electroless nickel

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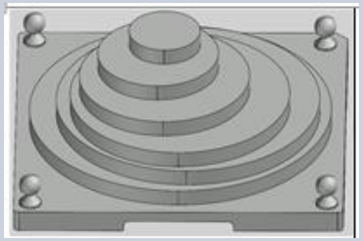
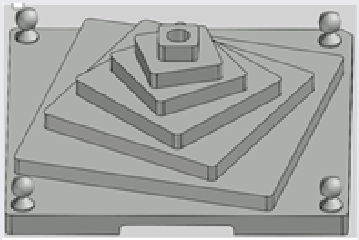
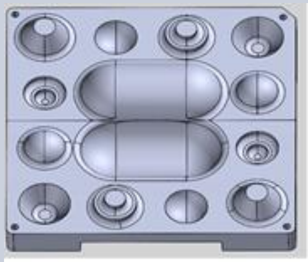
NPL's: TSEM-MS (smooth surface)
NPL's: TSMU-MS (perturbed surface)

National Physical Laboratory

Name	NMI	Design
Non-Centric cylinders	NPL	
Centric squares	NPL	
Prismatic shape	NPL	

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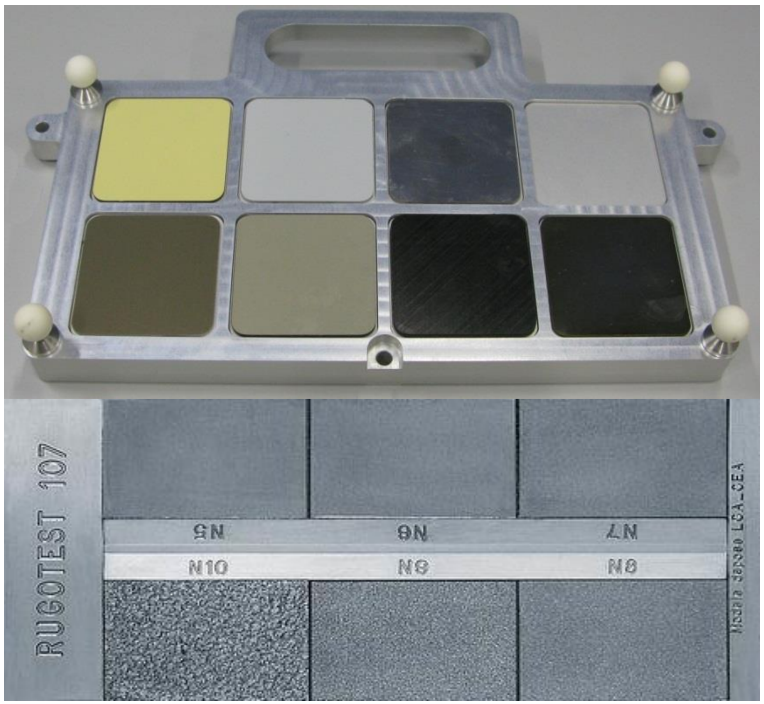
Optical properties of materials



- Scanners
- Opacity
- Surface finish:
  - Structure
  - Colour
- Plating:
  - Electroless
  - Brighness
- Orientation

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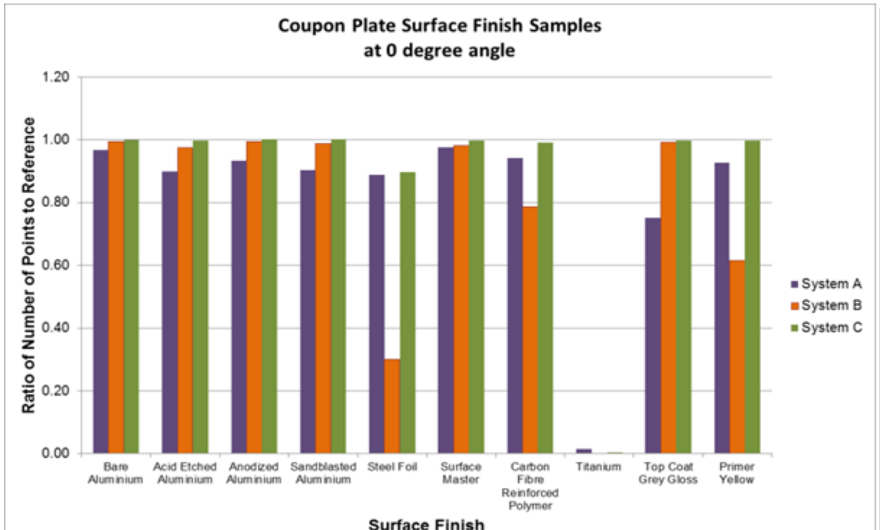
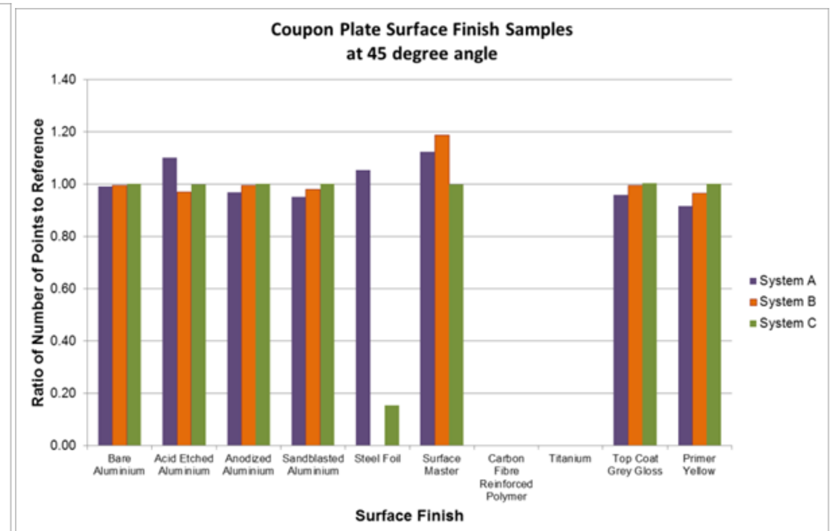
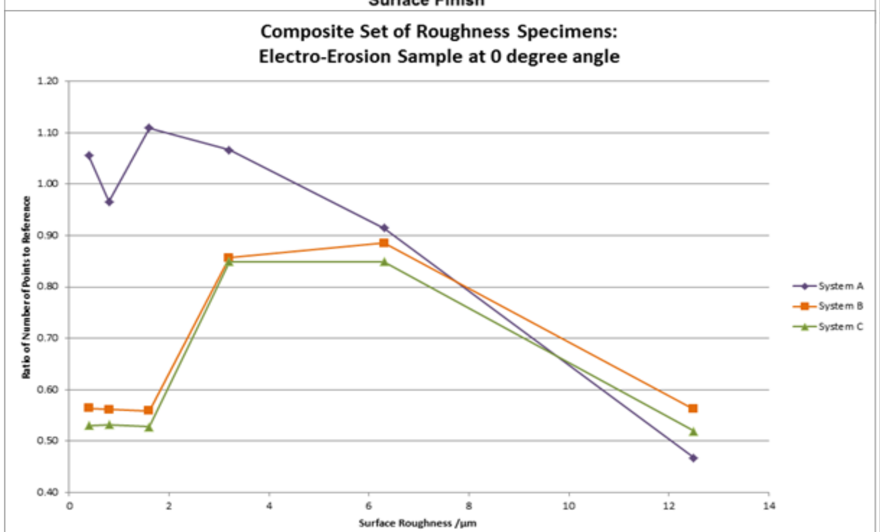
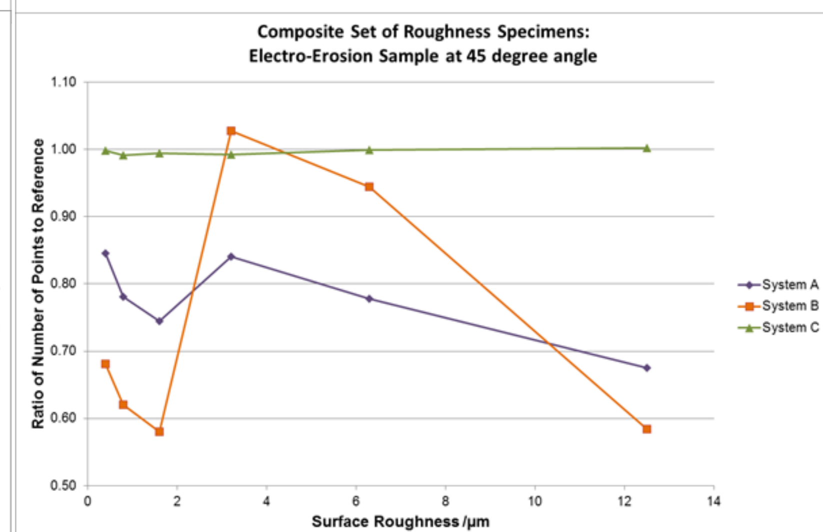
Optical properties results









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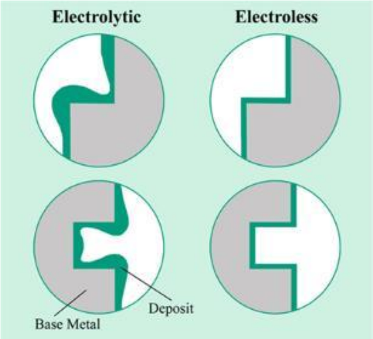
Material properties

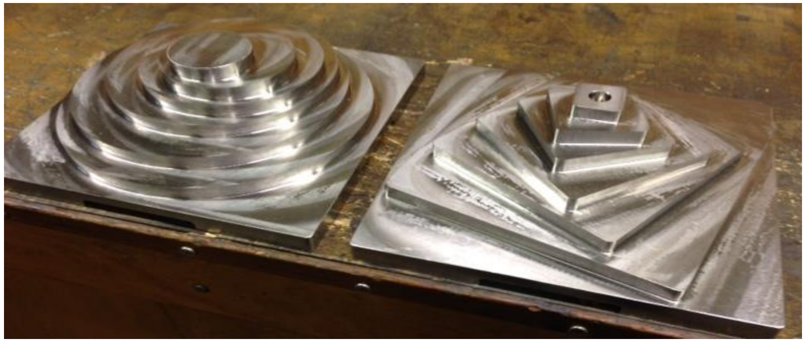
Against

- Invar will corrode
  Handling causes corrosion
- Shiny surface
  Scanner problem
- High mass
  Manual handling

Solution

- Coat the surface:
  Paint, plating,
- Treat the surface
  Acid etch, anodize
- Reduce size, hollow out
  Scale down, machine out.



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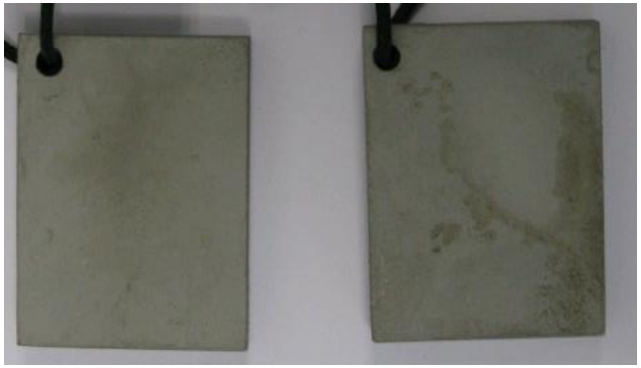
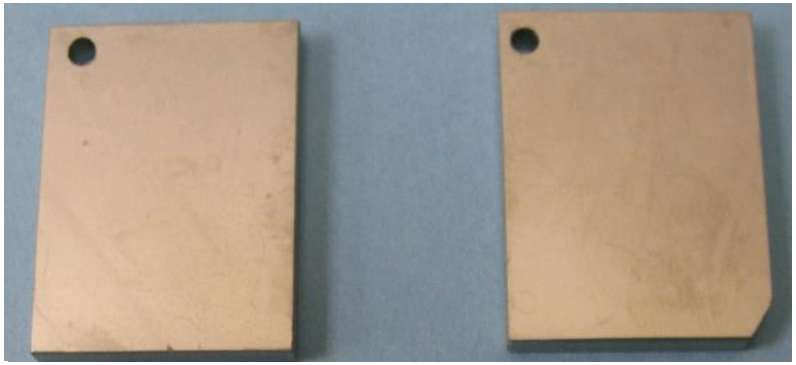
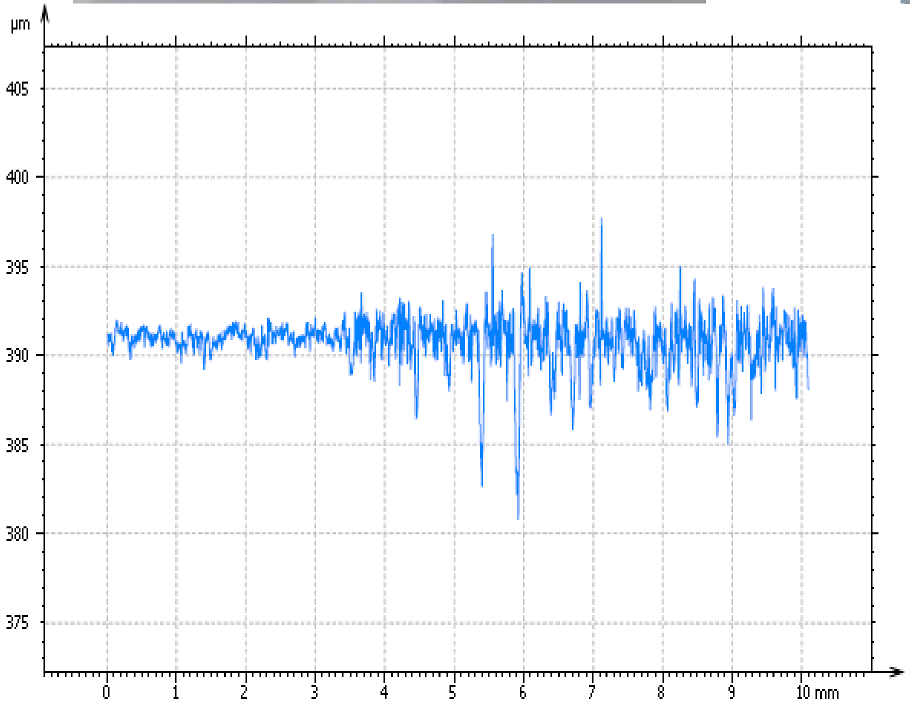
Plating the material standard







Change in surface due to bead blast

- Several sample, solutions, times, concentrations tried
- Size matters
- Bead blast, then dip, copper coat and electroless nickel plating.

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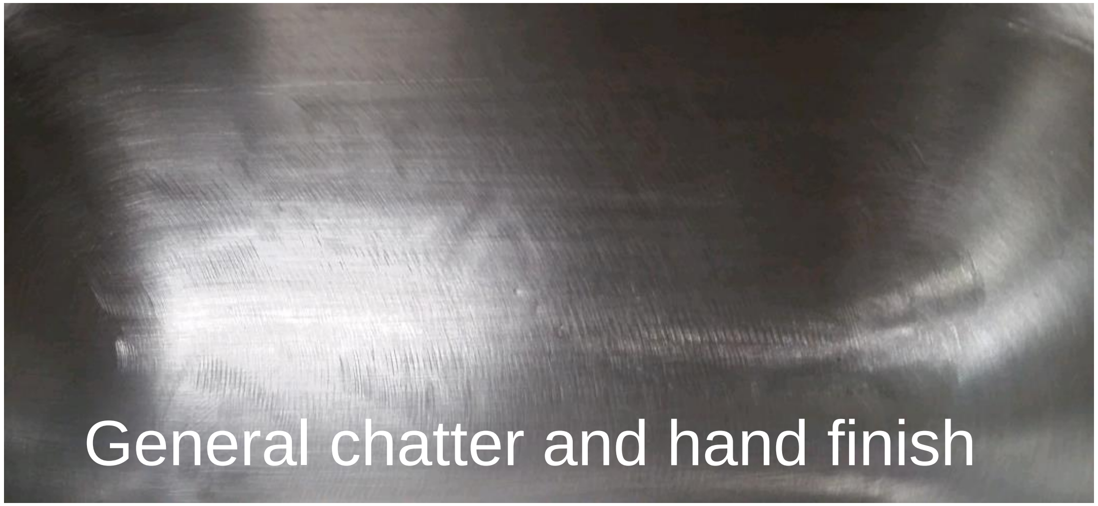
Manufacturing issues



Invar is not easy to machine:

- Rough machining
- Annealing
- Does no polish

Mathematical modelling of material standard - FEA

- Assume that the material standard has an initial uniform temperature of 20 °C
- It remains in an environment of 20 °C
- The lower surface remains at a fixed temperature
- What is the temperature variation within the standard
- Examine the subsequent stress distribution and deformation

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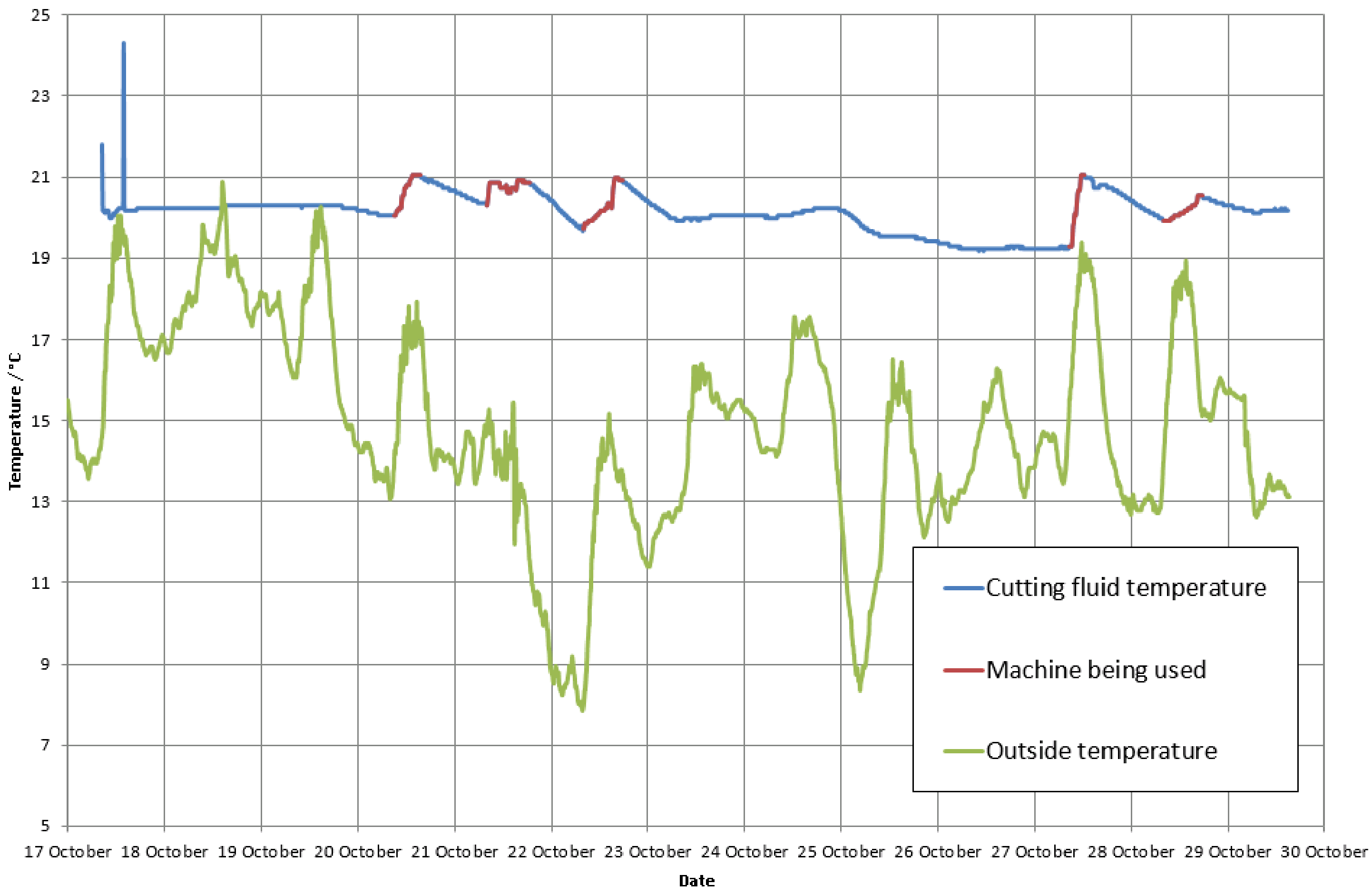
Typical NPL engineering workshop environment - temperature

NPL National Physical Laboratory



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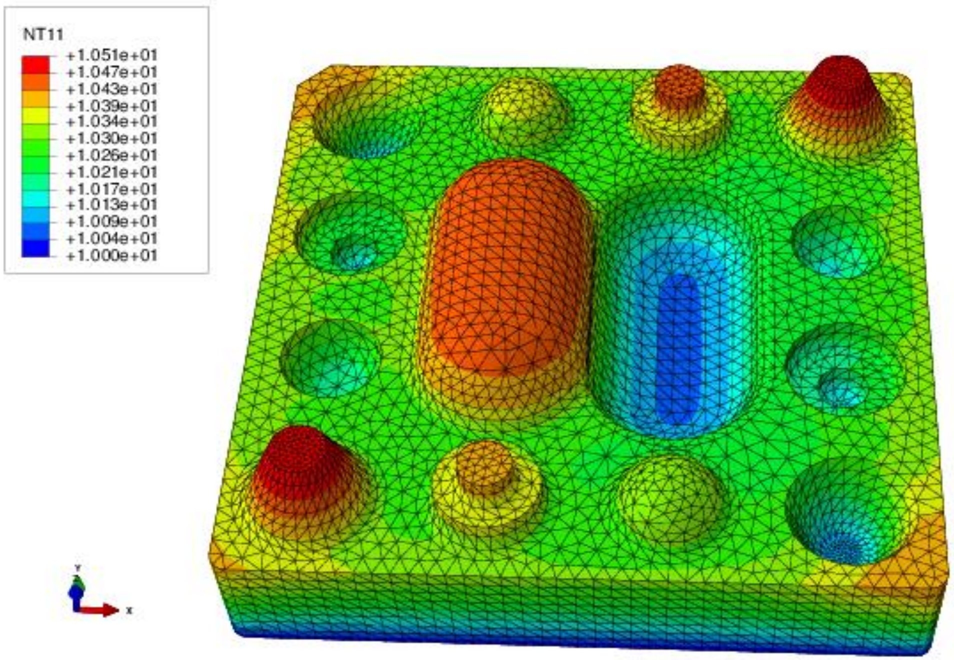
Final temperature distribution



- Temperature distribution of hollow prismatic material standard
- Base temperature at 10 °C
- Thermal equilibrium:

  Hollow – 50 min

  Solid – 40 min
- Maximum displacement

  ±10 °C = 0.96 µm
- Temperature difference of standard on equilibrium

  ±10 °C = 0.76 °C

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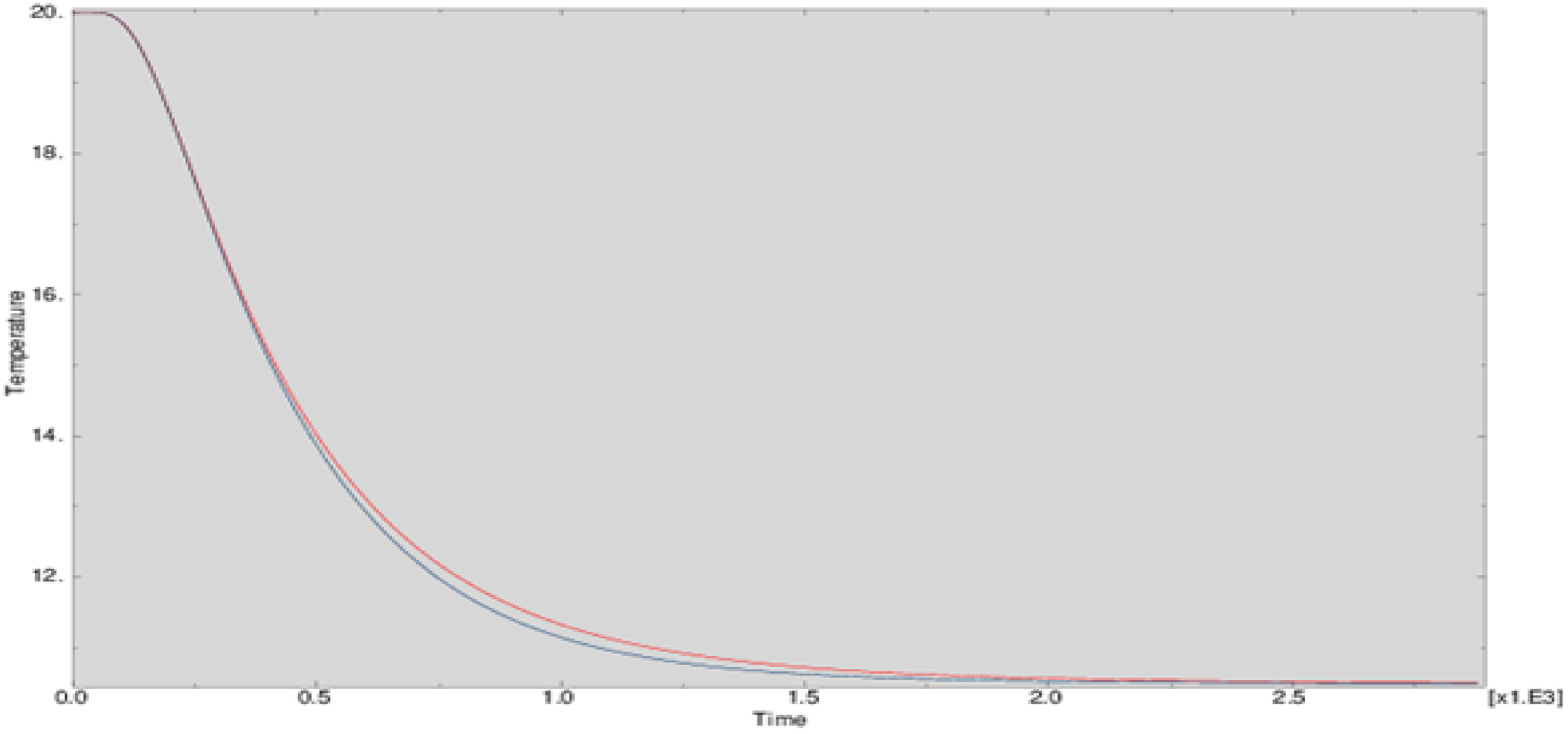
FEA thermal analysis of NPL's TSEM-MS



Temperature versus time: Hollow prismatic material standard – Initial base temperature 10 °C.

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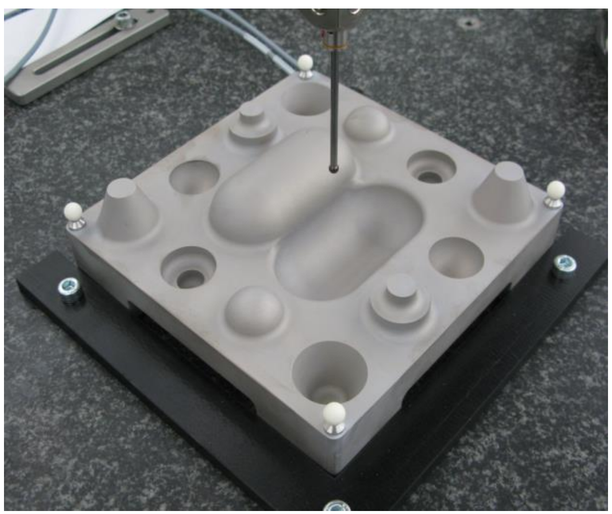
TSEM-MS/TSMU-MS
NMI: NPL



- Invar – Temperature invariant
- (200 x 200 x 50)mm 25 kg
- Tactile and optical measurement of prismatic shapes
- U<2 µm *k*=2

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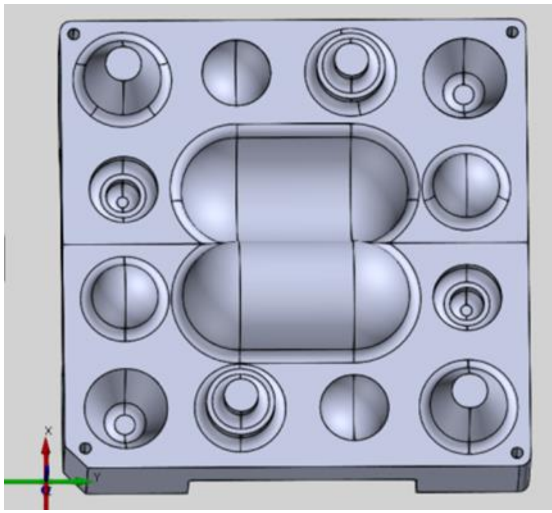
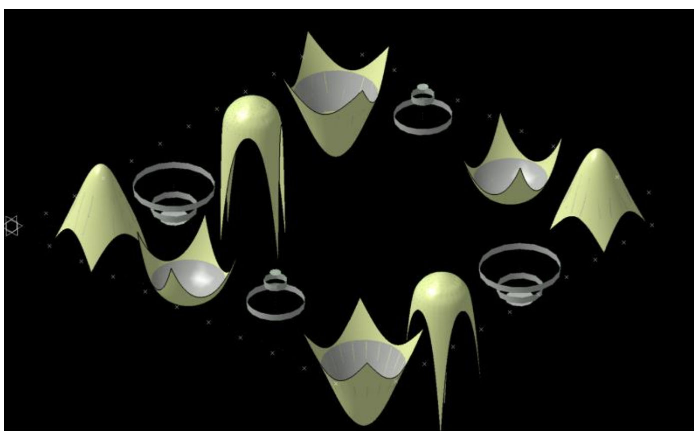
Reverse engineering of CAD – The approach





Reverse engineering of the Prismatic material standard has been completed.

Due to point density, it was not possible to re-engineer the total surface.

As individual prismatic are the concern, these individual parts were redefined in the CAD model.

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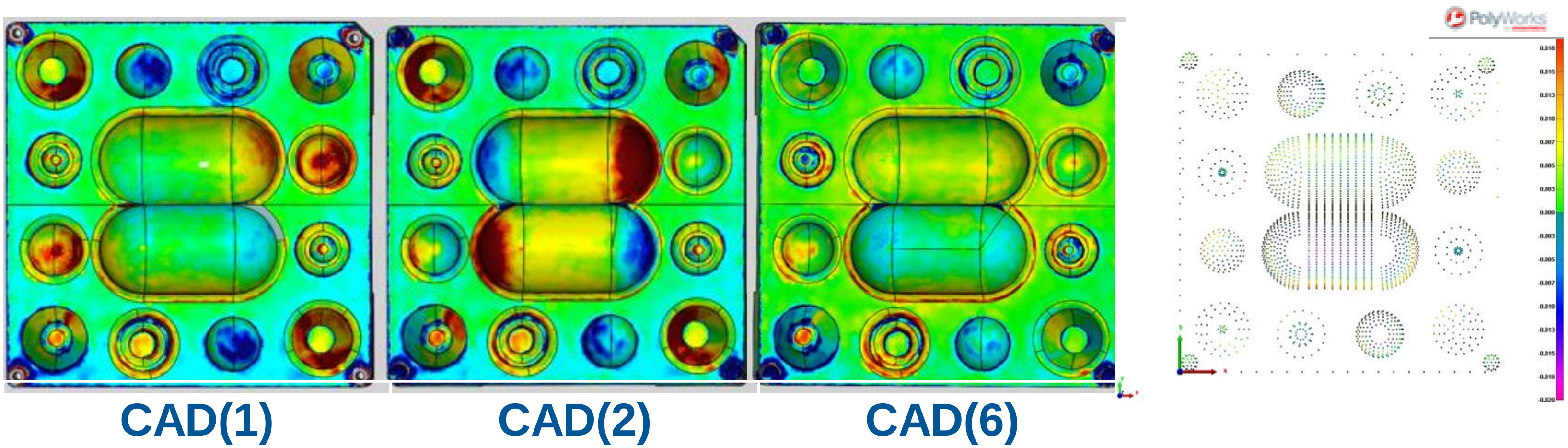
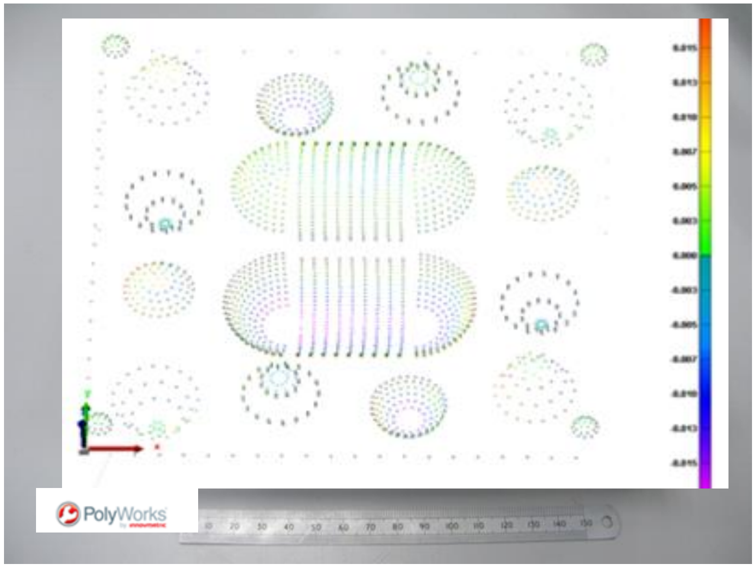
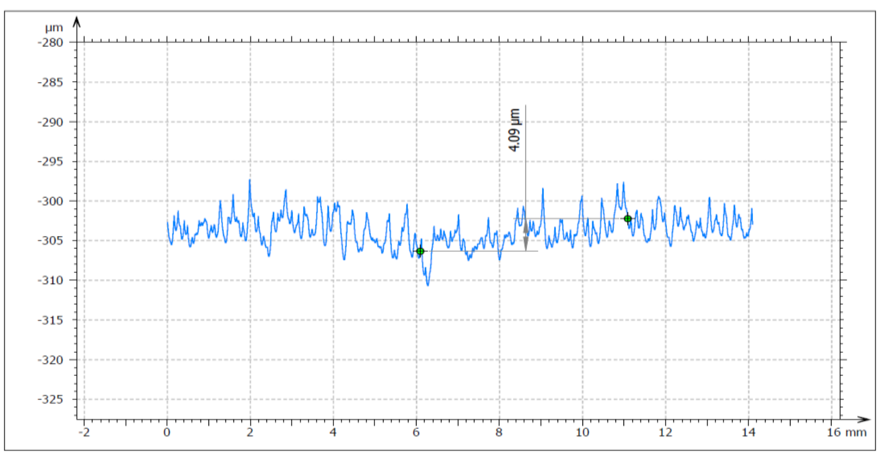
Reverse engineering of CAD – The results



- The CMM data was compared to the original CAD(1)
- First iteration, CAD(2), inferred that the model was getting worse; due to compound entity.
- Separation of bathtub and single prismatic adjusted
- CAD(6) final CAD model.

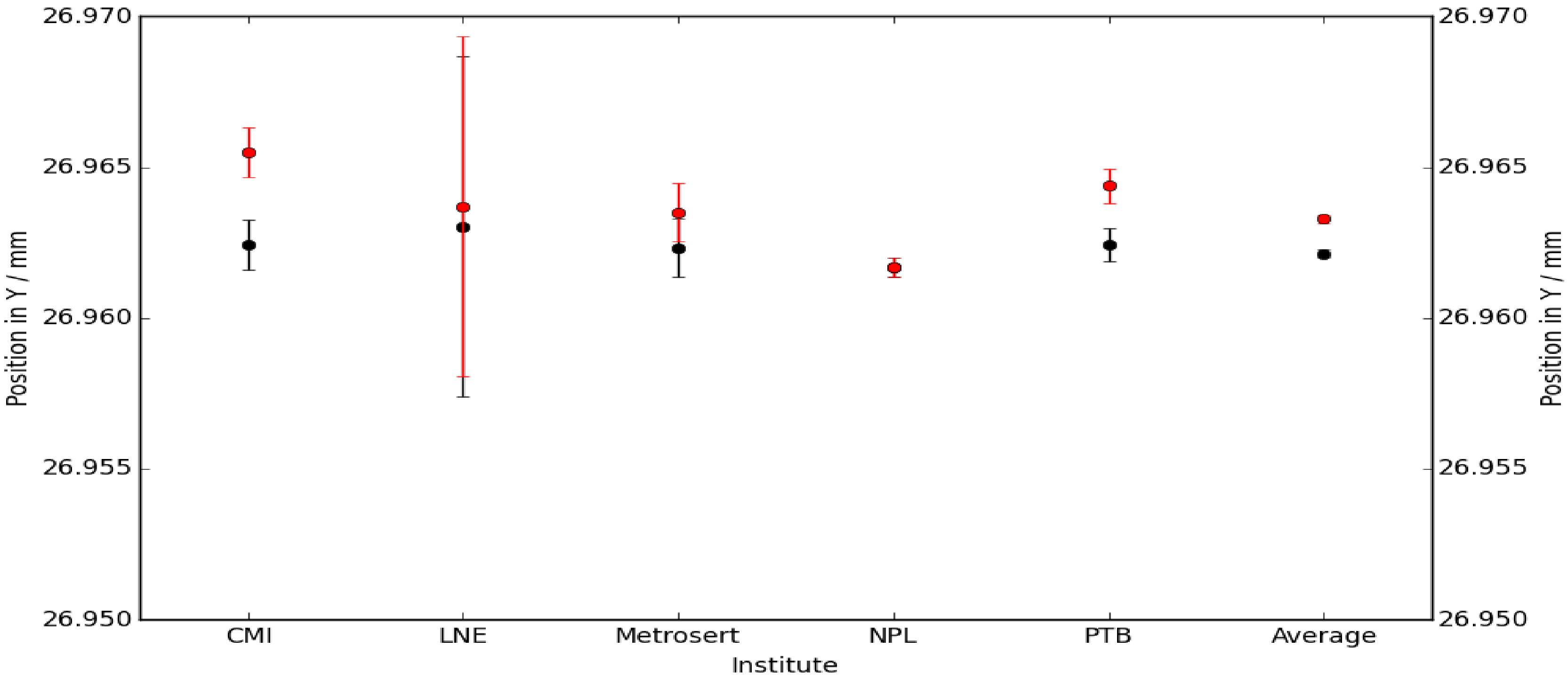
Computation of uncertainties





- Two software packages used: Pundit and VCMM.
- The original data used, defined the surface roughness to be 0.5µm.
- Profile plot indicates the true roughness to be more like 5 µm. VCMM model adjusted.

Inter-comparison of NPL's prismatic material standard



External Cone 2, axis intersection with z = 0 plane, relative to y axis. Black points represent the alignment adjusted values and red points represent the measured values

Conclusion

- Multiple geometries
- More difficult than first imagined to coat Invar
- Re-engineering CAD do not over constrain
- Surface roughness affects cleaning
- Storage container insert must be inert
- Due consideration must be given to alignment points

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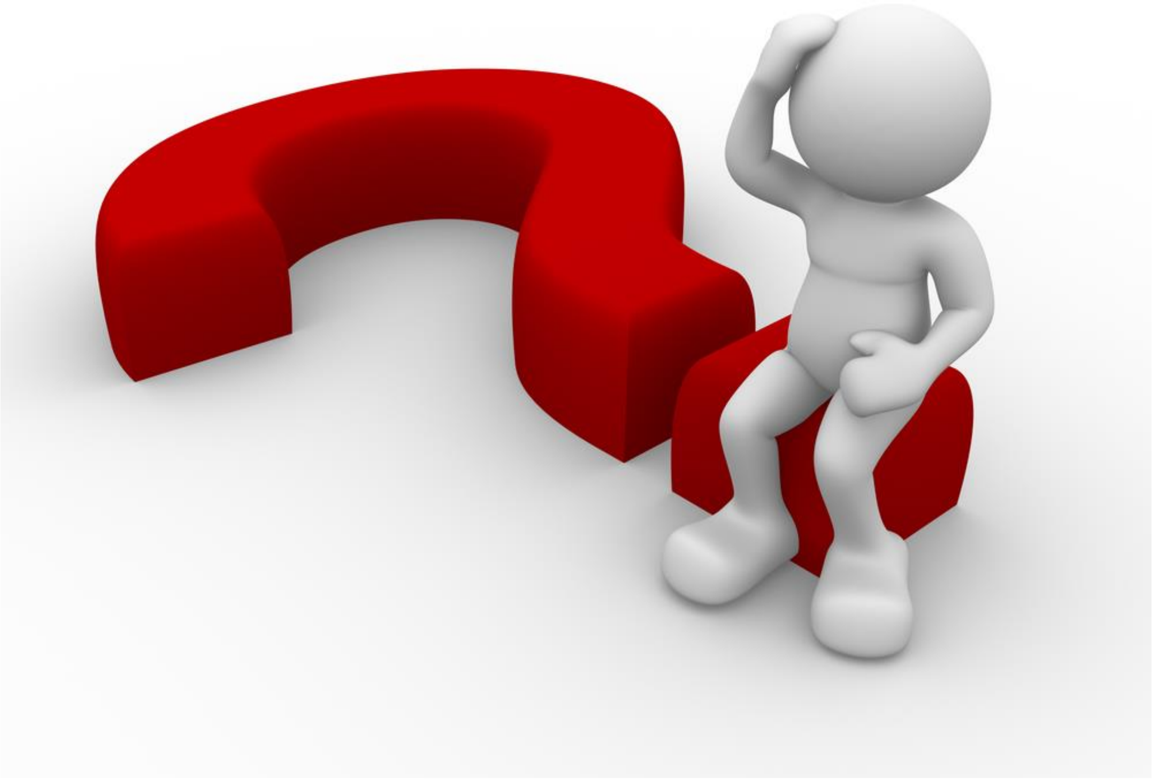
Questions…. if time permits



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