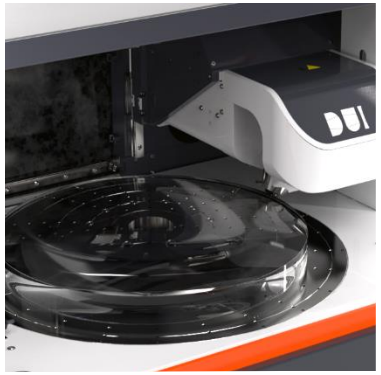
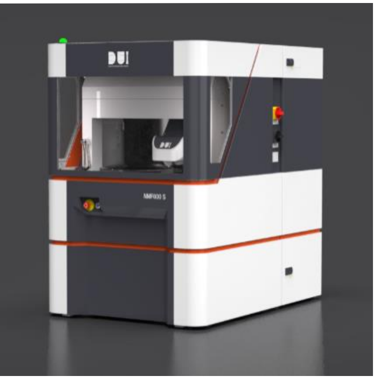
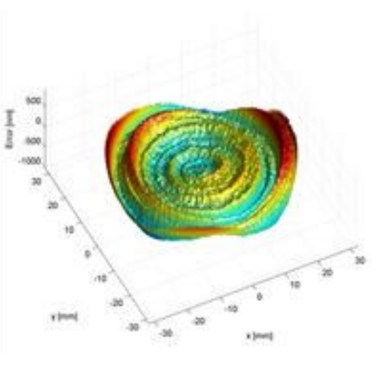





NMF products introduction

The fast and accurate measurement solution for aspherical and freeform optics

Dutch United Instruments

Dutch United Instruments

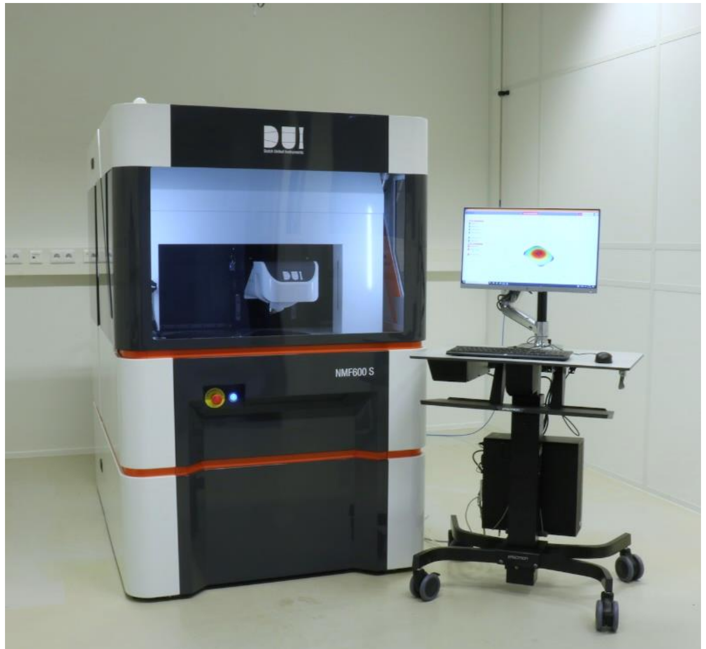
'To provide the fast and accurate measurement solution for aspherical and freeform optics'

DUI:

- Founded in 2017
- Part of DEMCON group (>900 FTE, >100 ME turnover)

NMF platform:

- Based on NANOMEFOS technology of TNO (2009)
- **NMF800 S**, **NMF600 S** and **NMF350 S** machines now available
- Easy to use NMF OS control and analysis software
- Multiple hardware and software module options
(Off-axis, extreme freeform, analysis, ground surfaces, mounting tool etc.)



NMF600 S at TNO, Delft

Contents

- Dutch United Instruments
- NMF platform
- Key principles
- Measurement examples
- NMF OS software
- NMF benefits

NMF platform approach

NANOMEFOS prototype of TNO

Combine 5 characteristics:

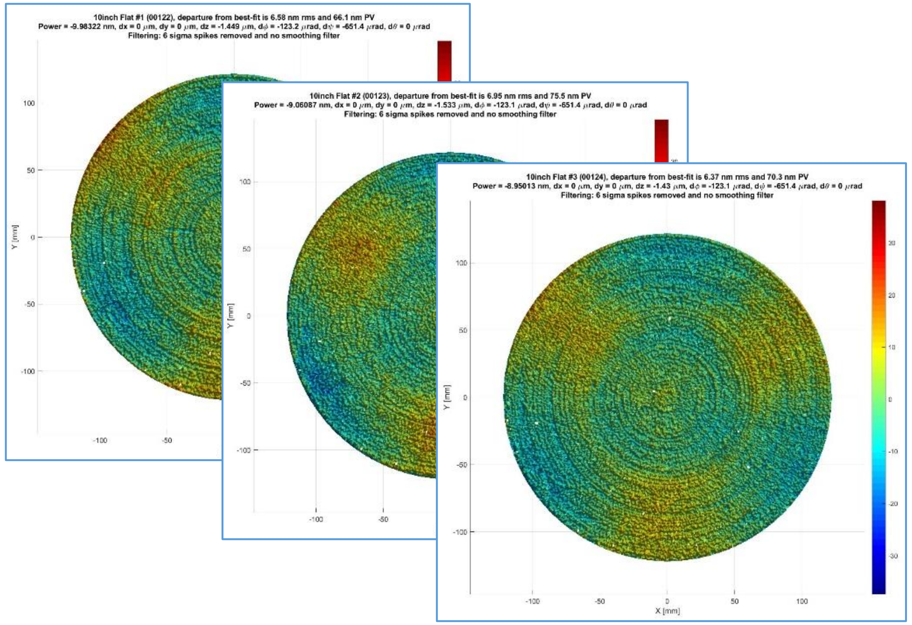
- Universal
- Large volume
- High accuracy
- Non-contact
- Fast

NMF platform

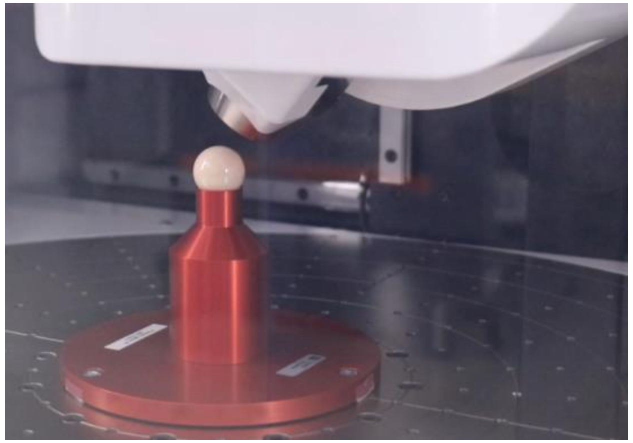
One tool to cover all form metrology needs in modern high-end optics manufacturing

- Setup for any type of surface in minutes
- No setup costs
- Easy to use, results in minutes
- Measure during entire manufacturing process (from ground to finished)
- High-density error map and line scans, including absolute radius error
- Single nanometer rms form error repeatability
- Traceable calibration to NMI certified artefacts (flats, spheres, balls etc)

Demonstrated by many measurement examples!

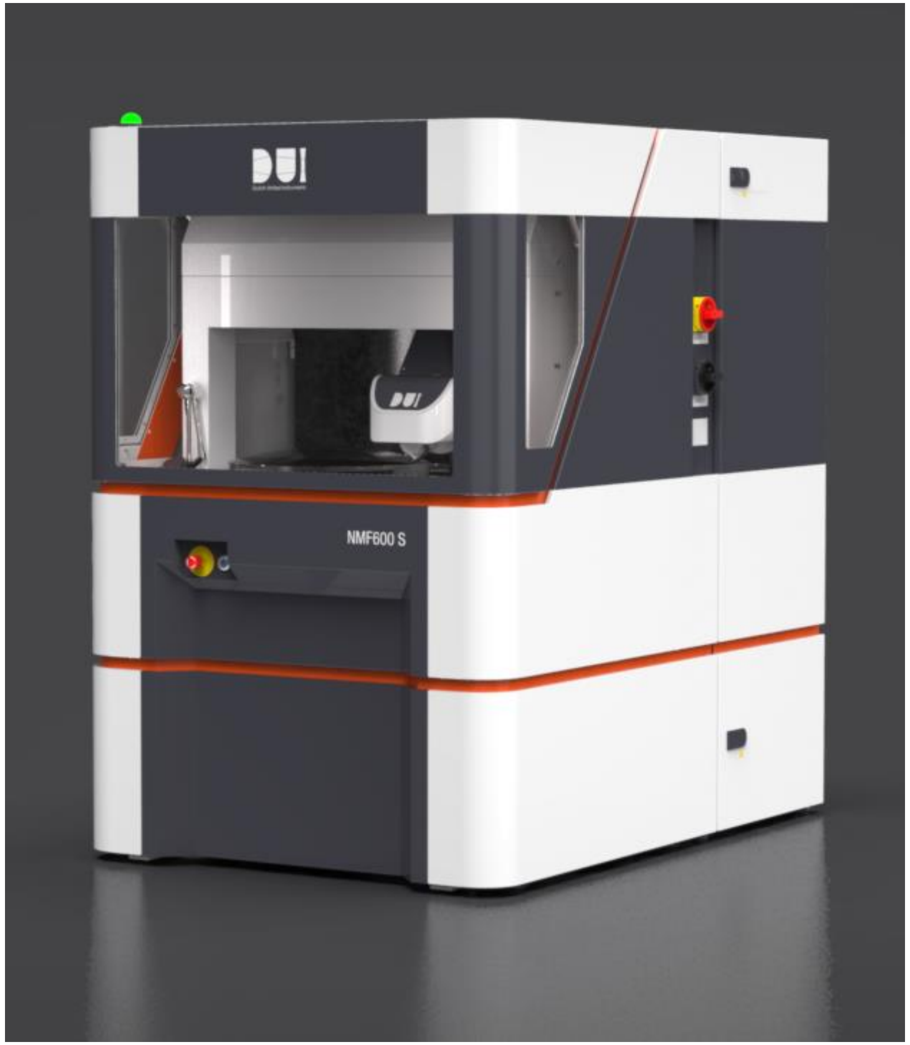


3 x ∅250 mm flat: 6.6, 7.0 and 6.4 nm rms



Calibrated 1” radius reference sphere

NMF Products



- Versatile
  - Flat, convex, concave, sphere, asphere, freeform, off-axis, non-circular
  - Measurement volume

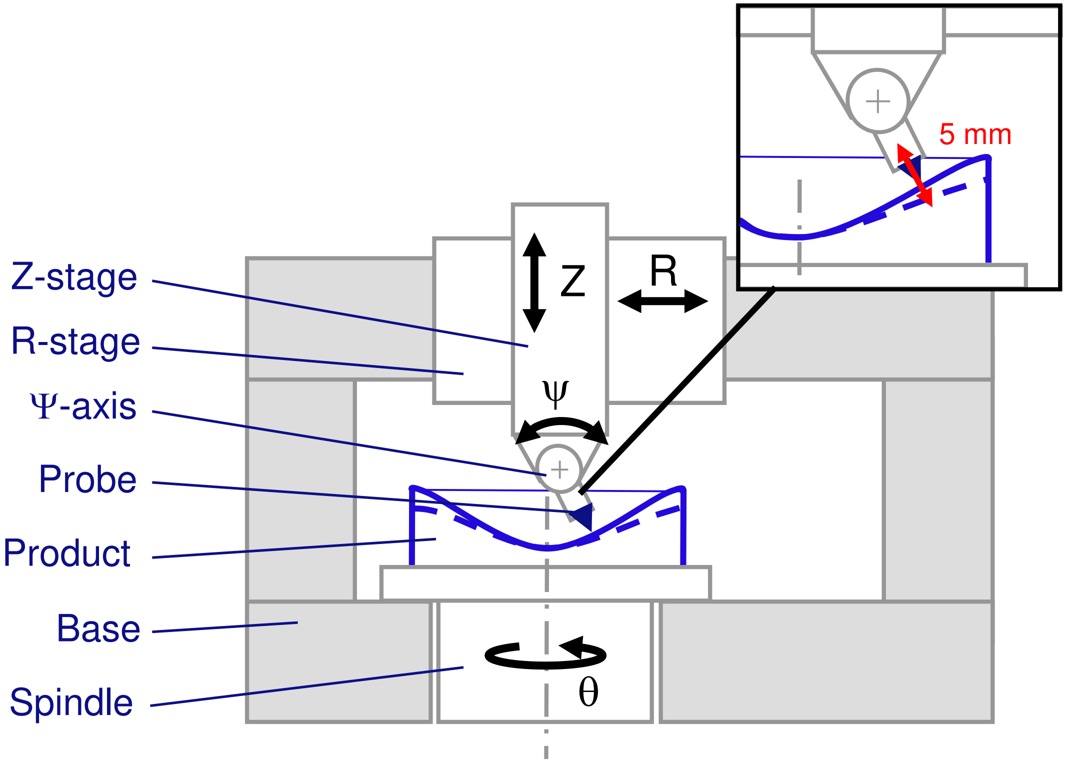
Volume	Max ∅	Max h	-45°	+45°	+90°
NMF350 S	∅350 mm	150 mm	∅350 mm	∅170 mm	∅100 mm
NMF600 S	∅600 mm	150 mm	∅600 mm	∅420 mm	∅100 mm
NMF800 S	∅800 mm	300 mm	∅800 mm	∅620 mm	∅400 mm

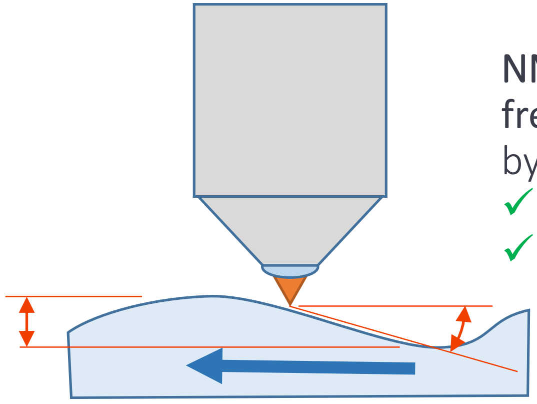
  - Unlimited asphere departure
  - Up to 5 mm PV departure from best-fit asphere
  - Selectable objectives (local slope up to ±20°, working distance up to 8 mm)
- High point density for mid-spatials (typical up to 4M points)
- Uncertainty generally < 15 nm rms (worst case freeform < 30 nm rms)
- Glass, mirror, polished & ground surfaces
- Non-contact
- Fast (minutes)
- Easy loading, programming & results processing

NMF Key Principles

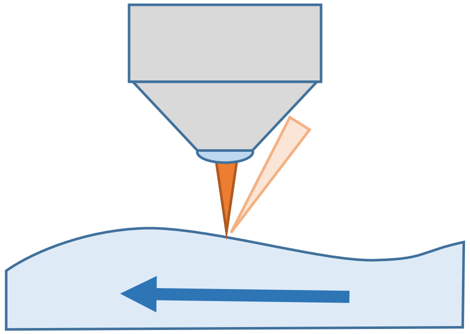
Based on original NANOMEFOS concept:

- Universal large volume by cylindrical machine
- Non-contact high speed by long range optical probe (Patented)
- High accuracy by a separate closed-loop metrology system (Patented)
- High accuracy out-of-plane airbearing guidance (Patented)



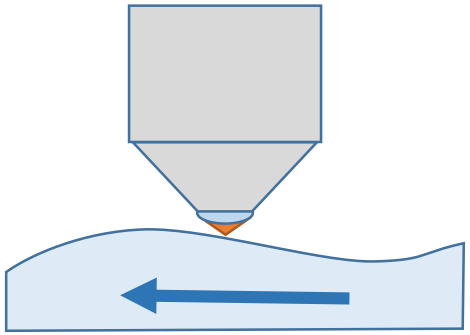


NMF enables **fast freeform measurement** by combining:
✓ Axial range (5 mm)
✓ Local slope (± 5°)



Low NA objective
✓ Axial range
✗ Local slope

⇒ No freeforms



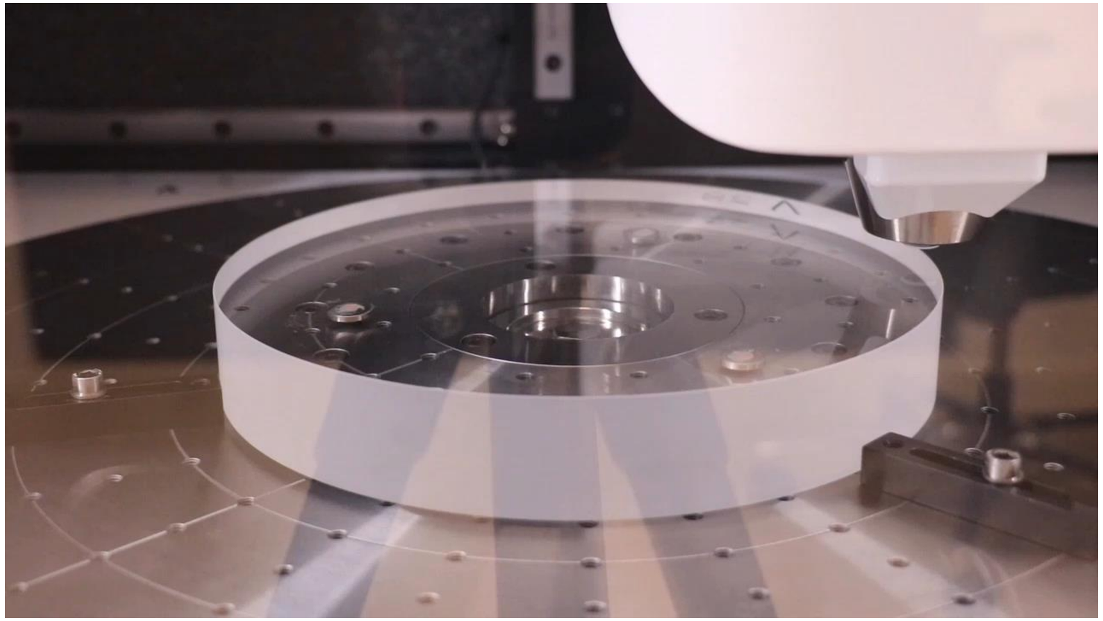
High NA objective
✗ Axial range
✓ Local slope

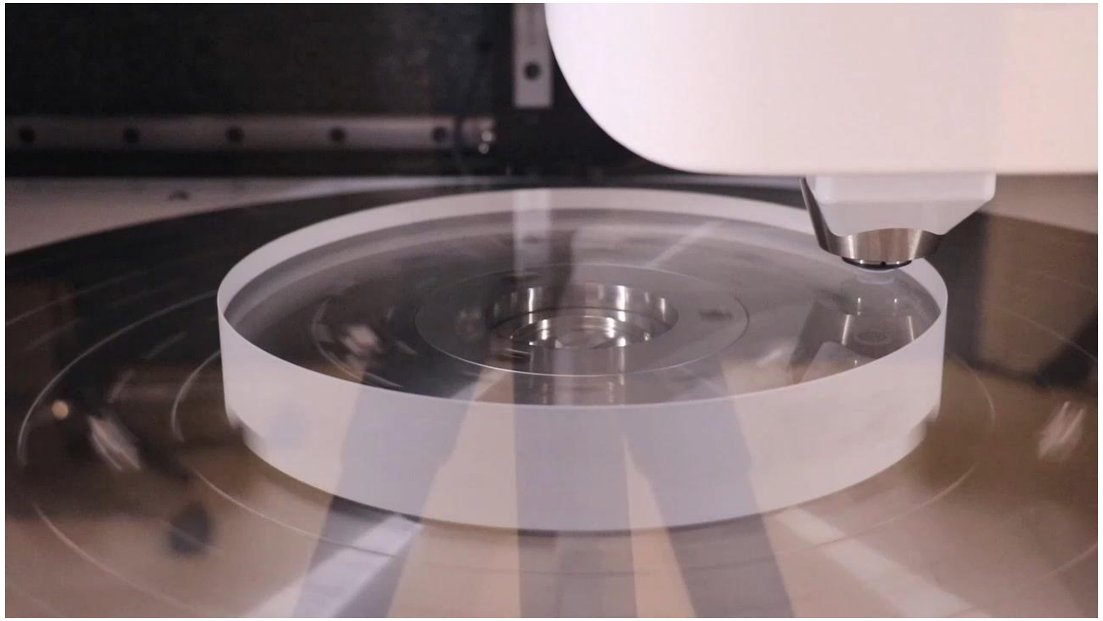
⇒ Very slow
(large machine motion)

Measurement examples

10” flat

- Flat 10” λ/20, supported on three points
- ∅254 mm diameter, ∅245 mm measured
- 4x radial scan, 0.5 mm point spacing surface scan (1 rev/s)
- Measurement time 6:15 minutes

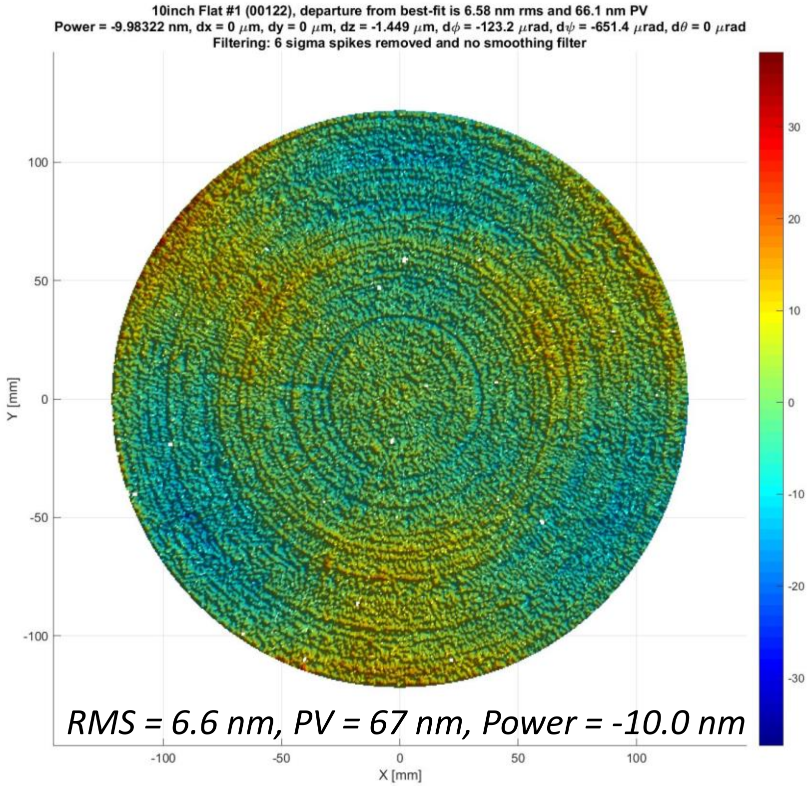


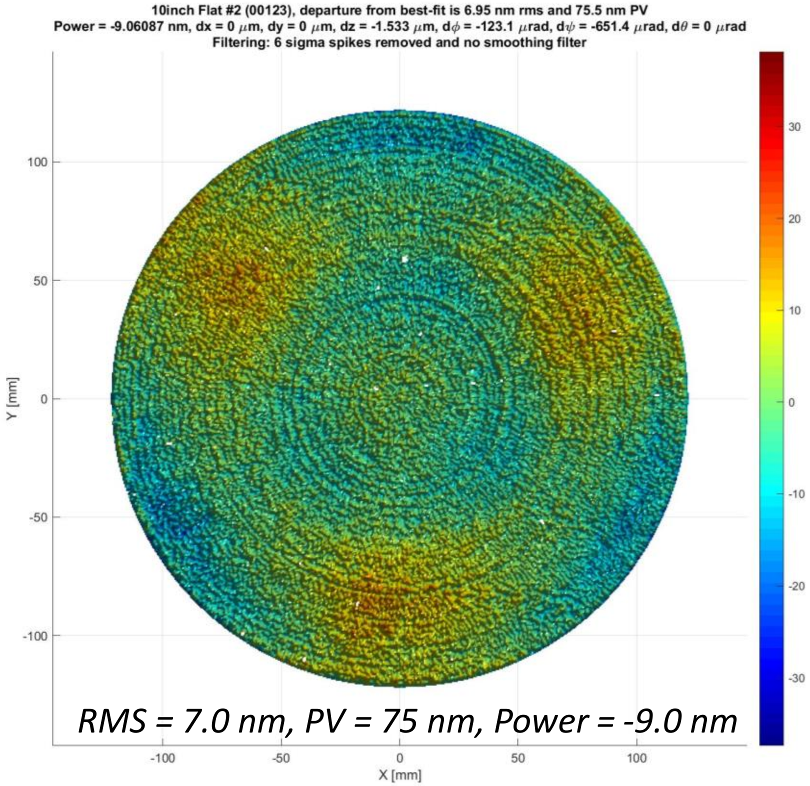


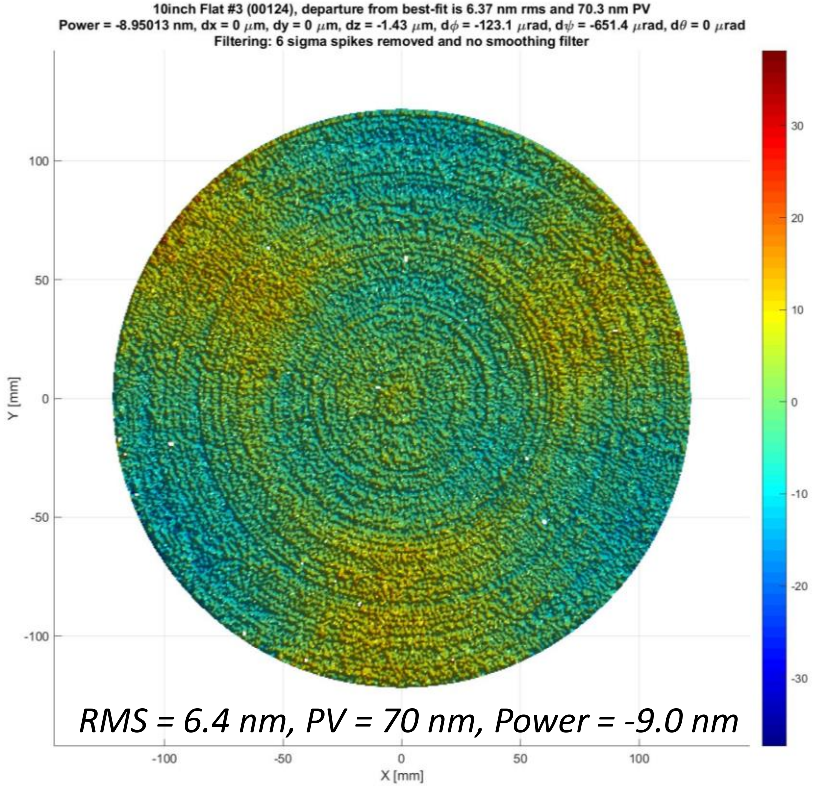
Measurement examples

10” flat

- ∅240 mm aperture
- Fit position & tilt & power
- Form error repeatability << 1 nm rms





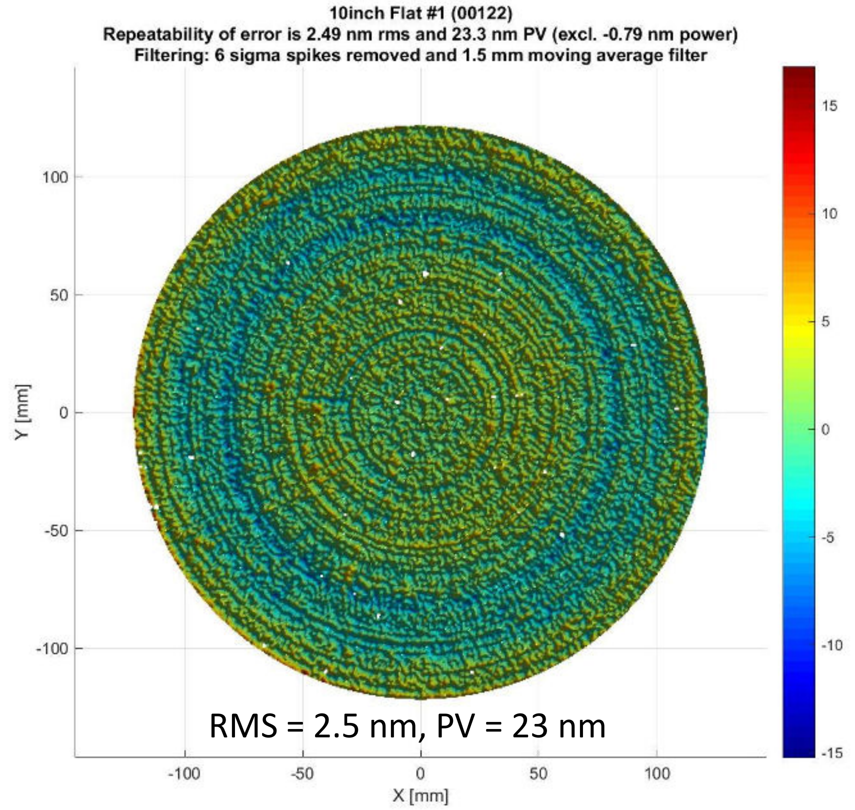


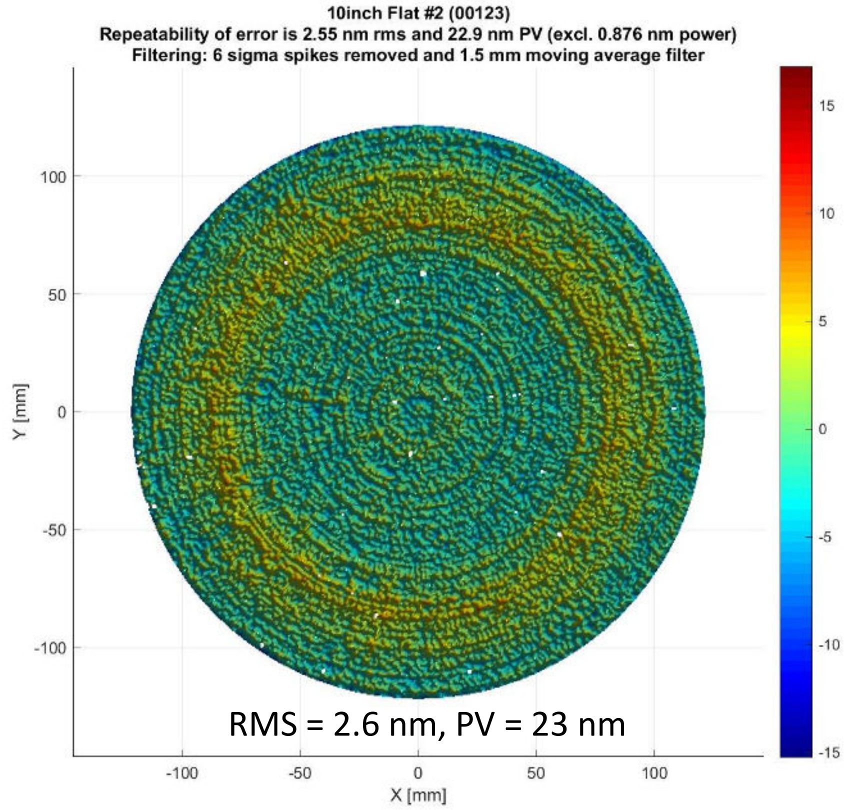
Trefoil corresponds to gravity sag from location of 3 support points

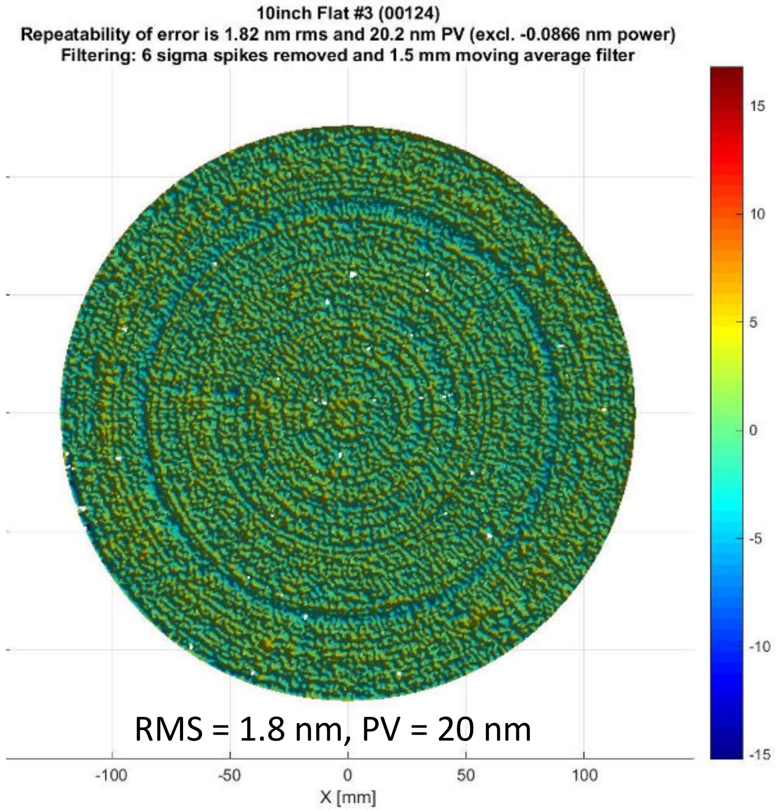
Measurement examples

10" flat

- Difference from average form (point-by-point repeatability)
- Piston-tip-tilt removed
- Point-by-point repeatability about 2 nm rms, power variation < 1 nm



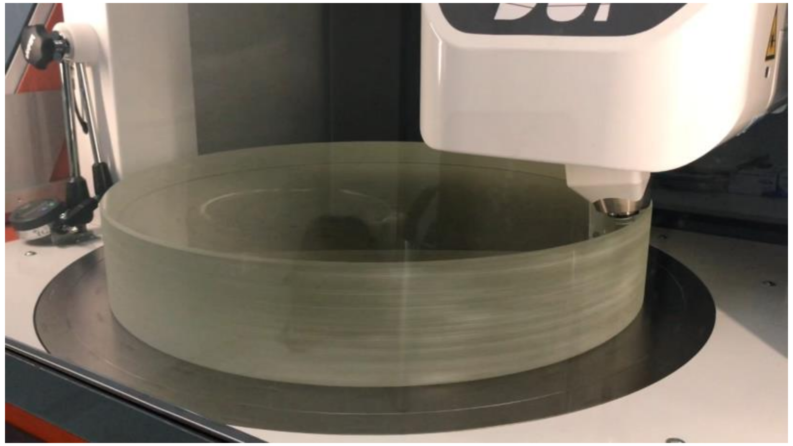


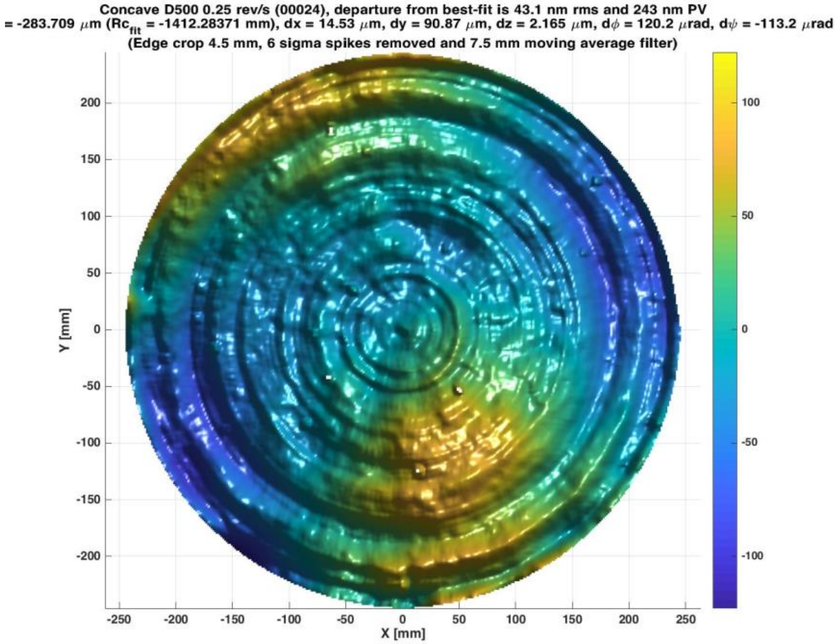


Measurement examples

Large optics

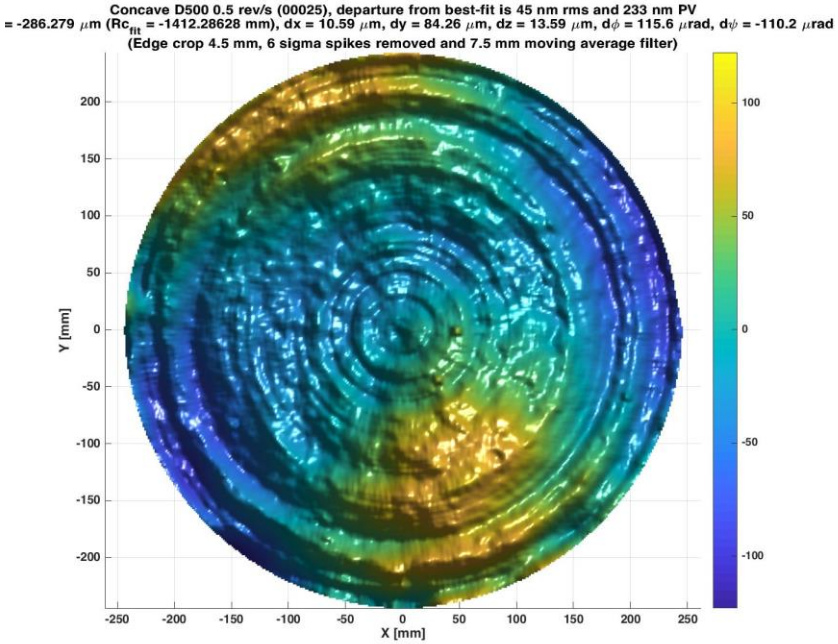
- ∅500 mm concave test surface (50 kg), radius of curvature -1.4 m
- Measured at 3 mm pointspacing at 0.25, 0.5 and 1 rev/s
- Measurement time 11 min (0.25 rev/s), 8:30 min (0.5 rev/s), 7 min (1 rev/s)
- Form error repeatability < 2 nm rms, radius < 5 um





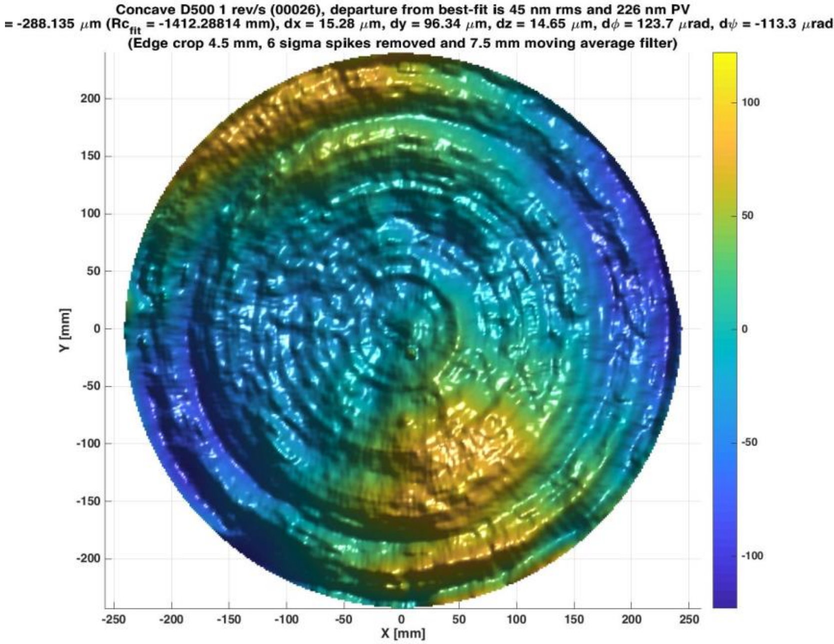
0.25 rev/s

RMS = 43.1 nm, PV = 243 nm, dRc = -283 um



0.5 rev/s

RMS = 45.0 nm, PV = 233 nm, dRc = -286 um

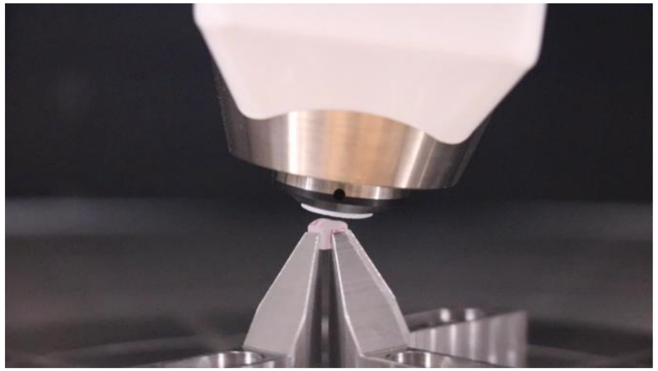


1 rev/s

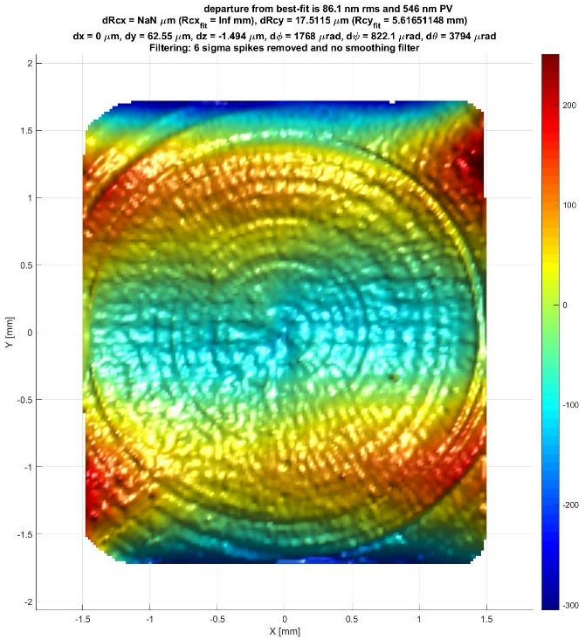
RMS = 45.0 nm, PV = 226 nm, dRc = -288 um

Measurement examples

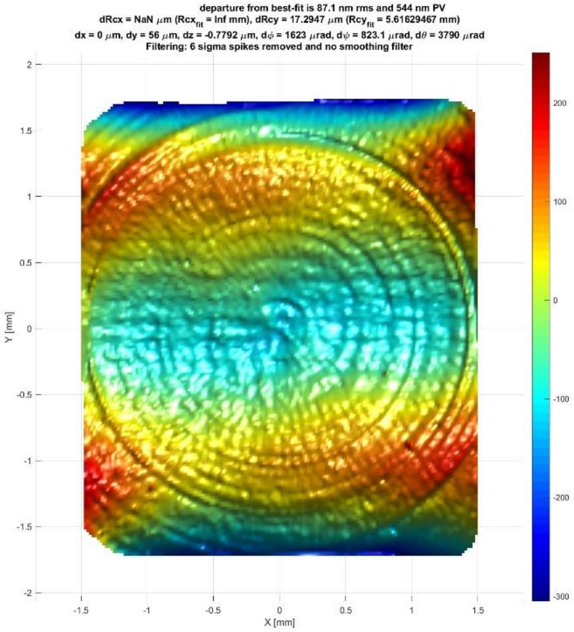
Small acylinder



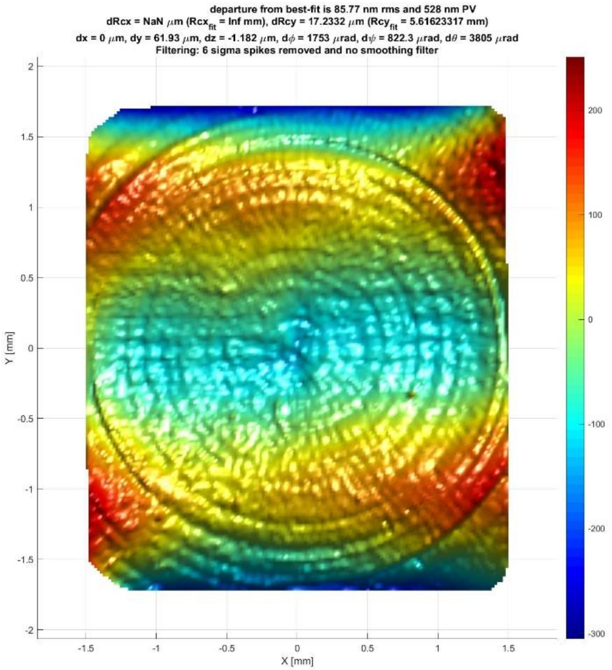
- Small acylinder (3 x 3.5 mm clear aperture)
- Fit position, tilt, rotation and best-fit-radius (ring structure is measurement artefact)
- Form error repeatability is < 1 nm rms, dRc repeatability is < 1 um



RMS = 86.1 nm
PV = 546 nm
dRc = +17.5 um



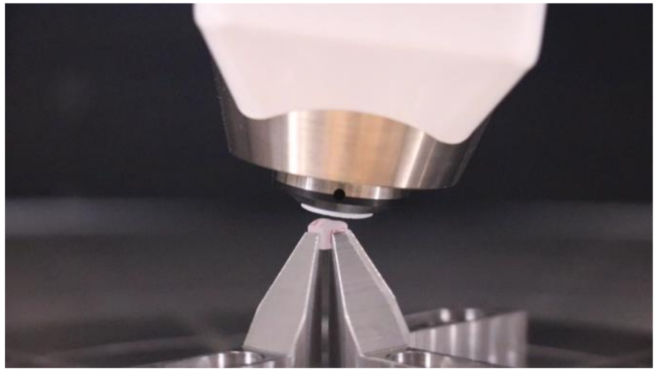
RMS = 87.1 nm
PV = 544 nm
dRc = +17.3 um



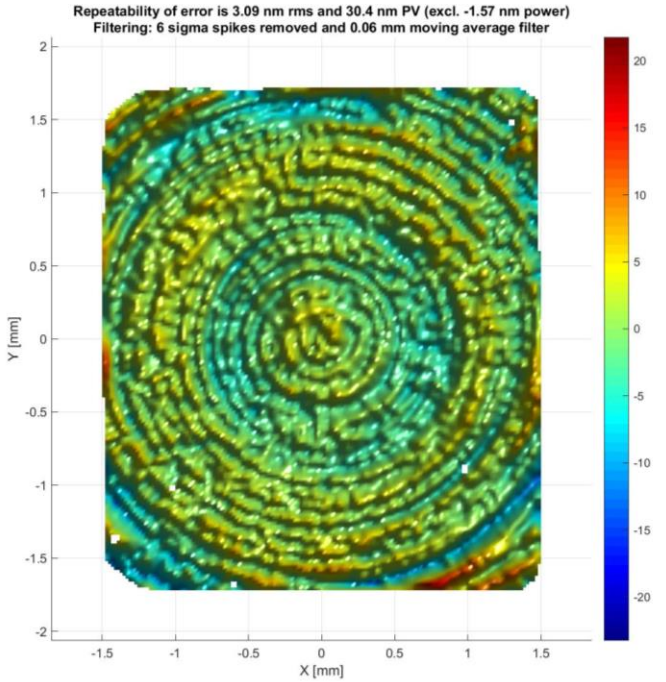
RMS = 85.8 nm
PV = 528 nm
dRc = +17.2 um

Measurement examples

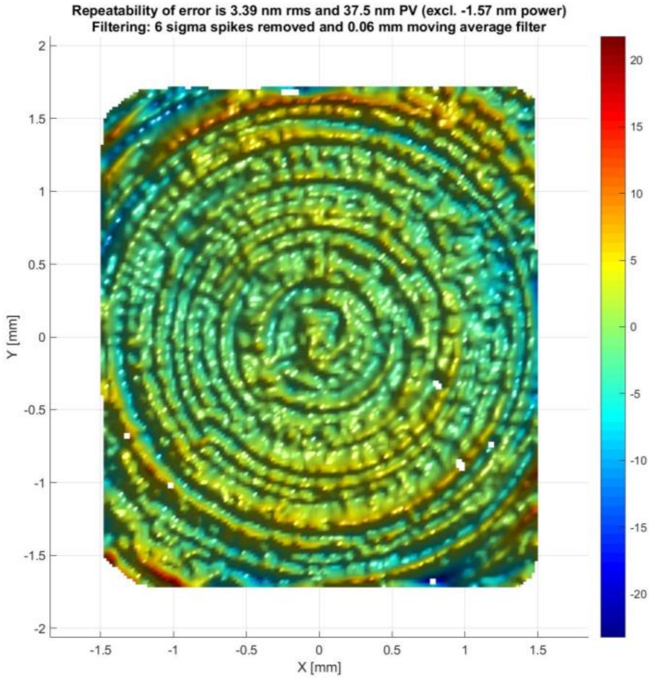
Small acylinder



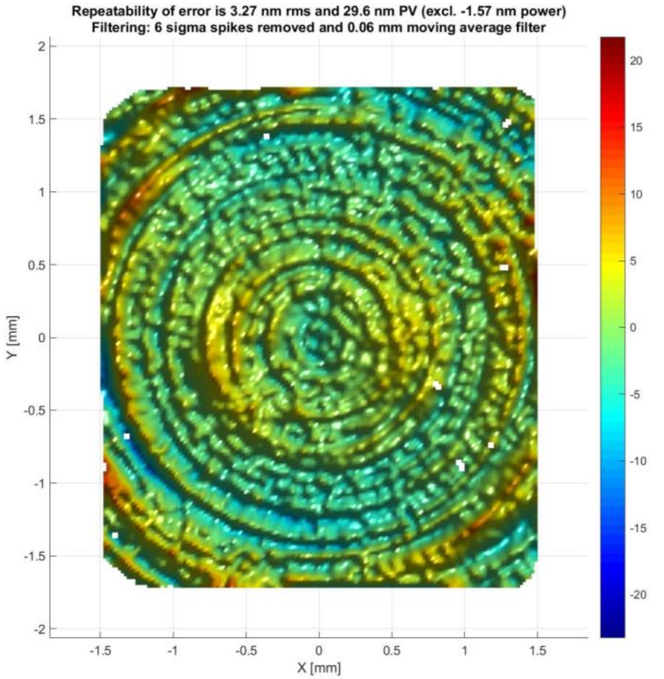
- Small acylinder (3 x 3.5 mm clear aperture)
- Fit position, tilt, rotation and best-fit-radius (ring structure is measurement artefact)
- Form error repeatability is < 1 nm rms, dRc repeatability is < 1 um
- Average point-by-point repeatability is 3.3 nm rms



RMS = 3.1 nm
PV = 30.4 nm



RMS = 3.4 nm
PV = 37.5 nm

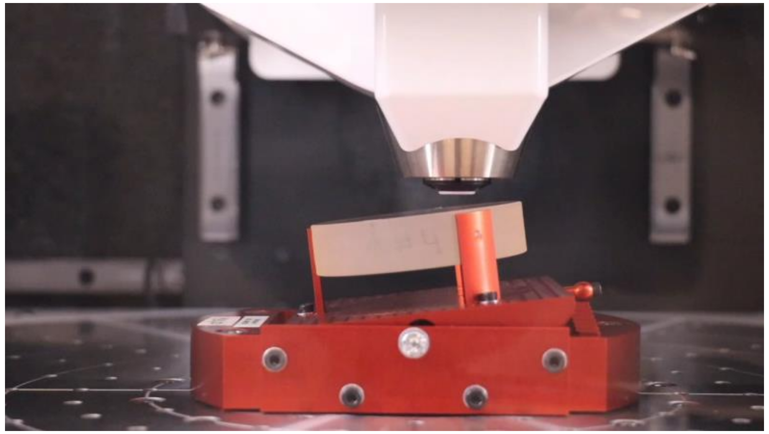


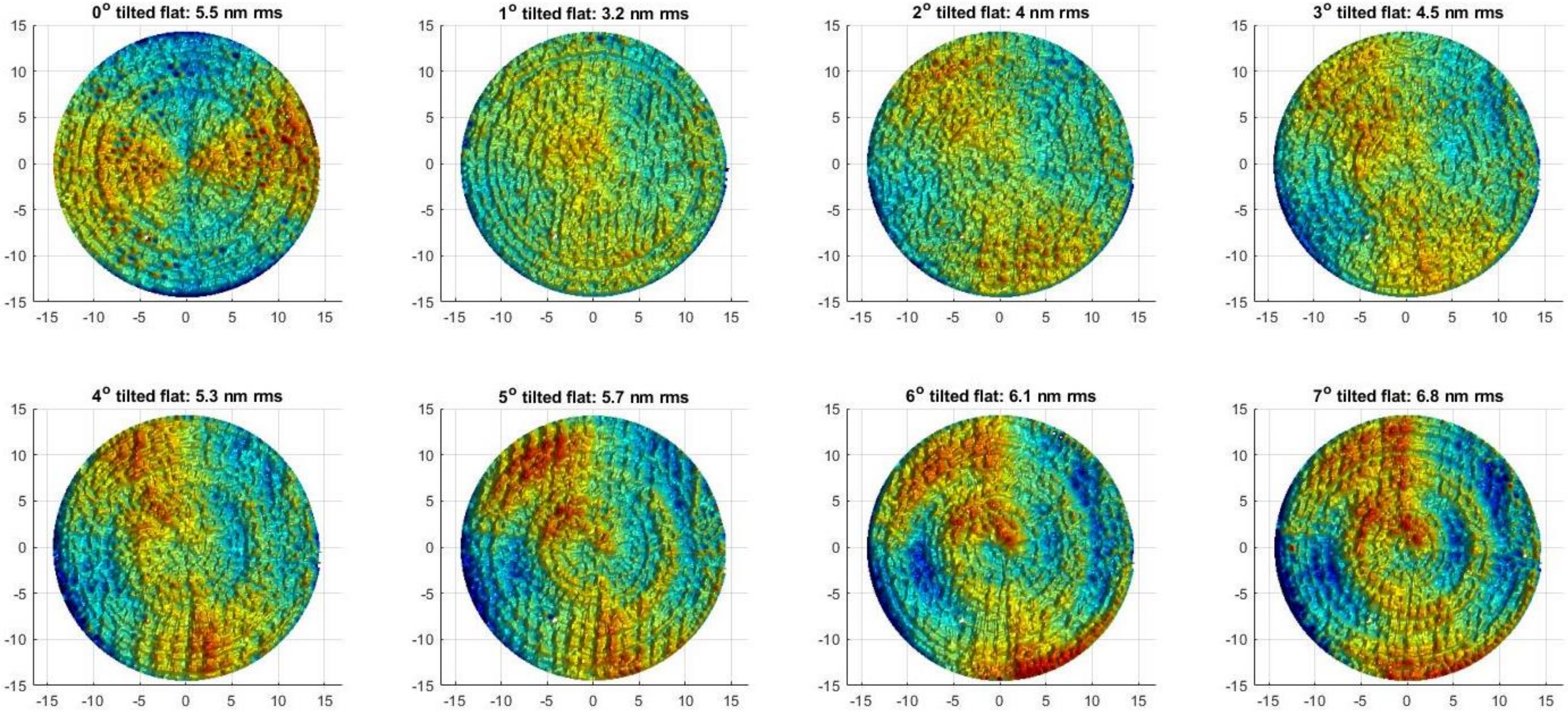
RMS = 3.3 nm
PV = 29.6 nm

Measurement examples

Tilted flat 0°-7°

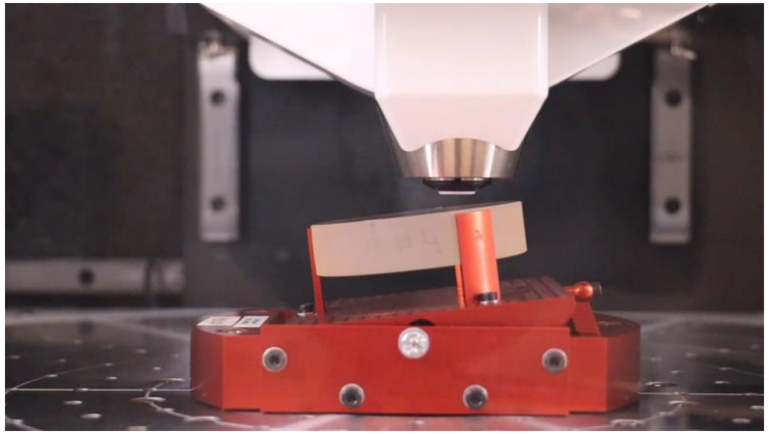
- λ/20 Zerodur flat, ∅30 mm aperture, max 2.5 mm PV
- Fit tilt only (no power removed)
- Flatness error < 7 nm rms for 0-7° using calibrated artefact



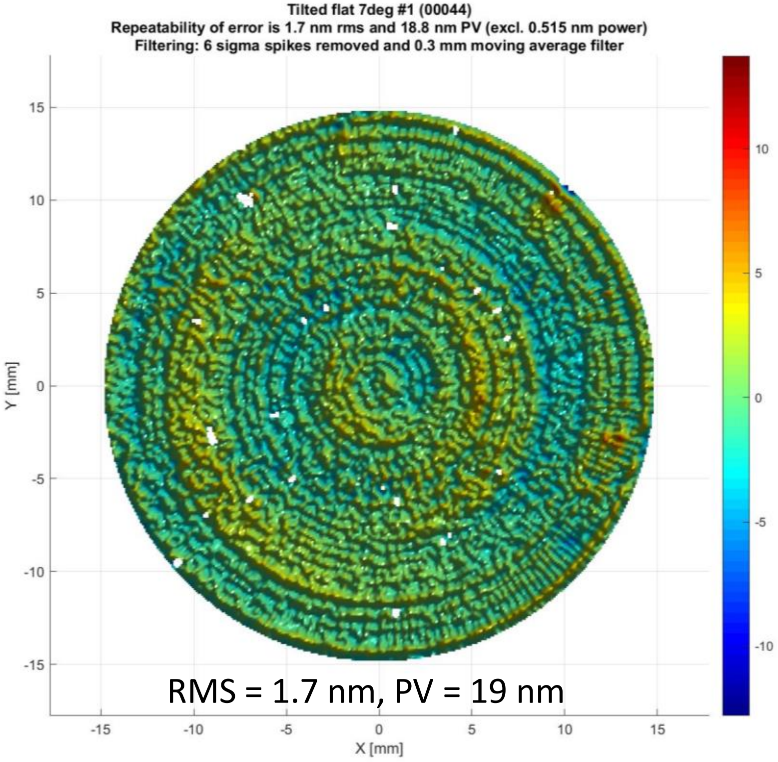


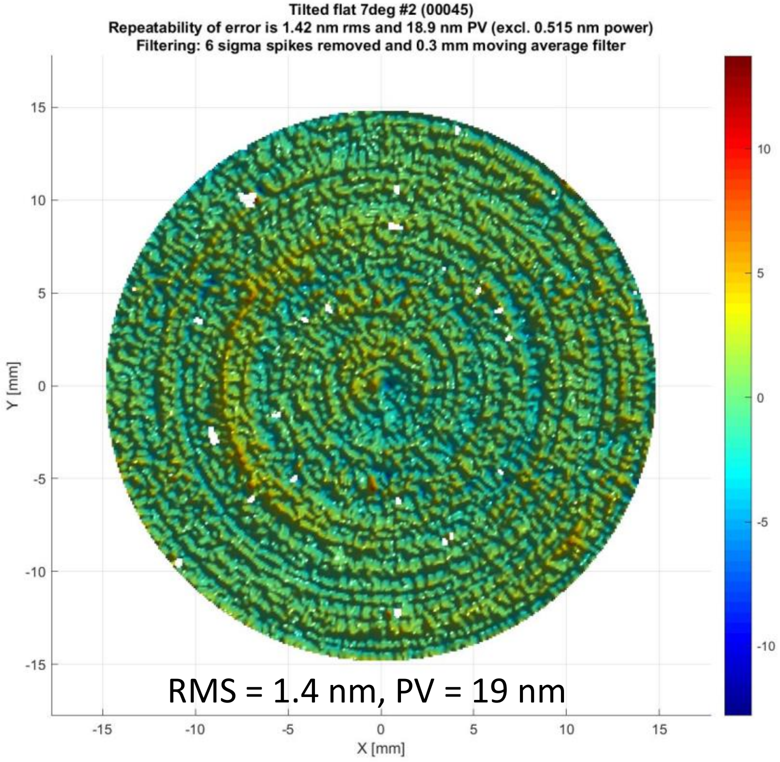
Measurement examples

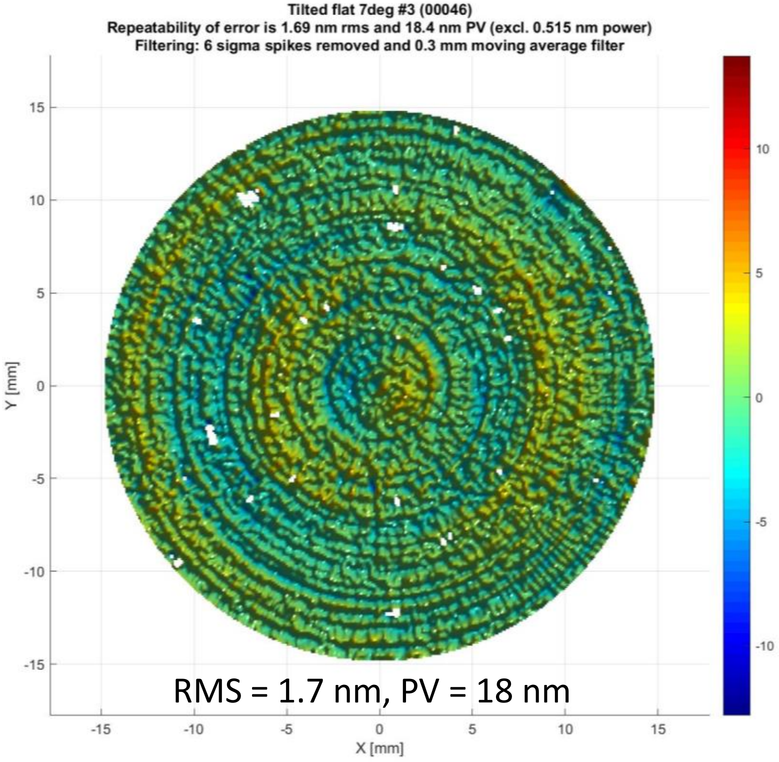
Tilted flat @ 7°



- λ/20 Zerodur flat, ∅30 mm aperture, max 2.5 mm PV
- Fit tilt only (no power removed)
- Point-by-point repeatability 3x at 7° is 1.5 nm rms

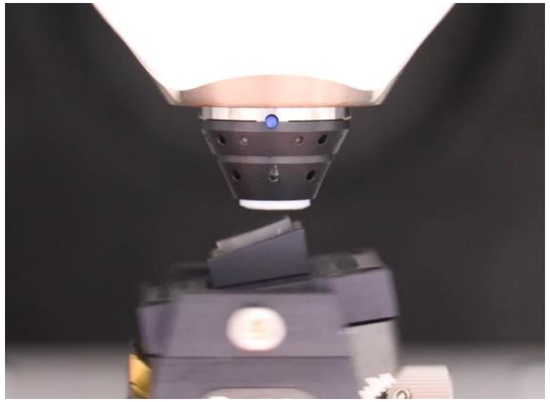




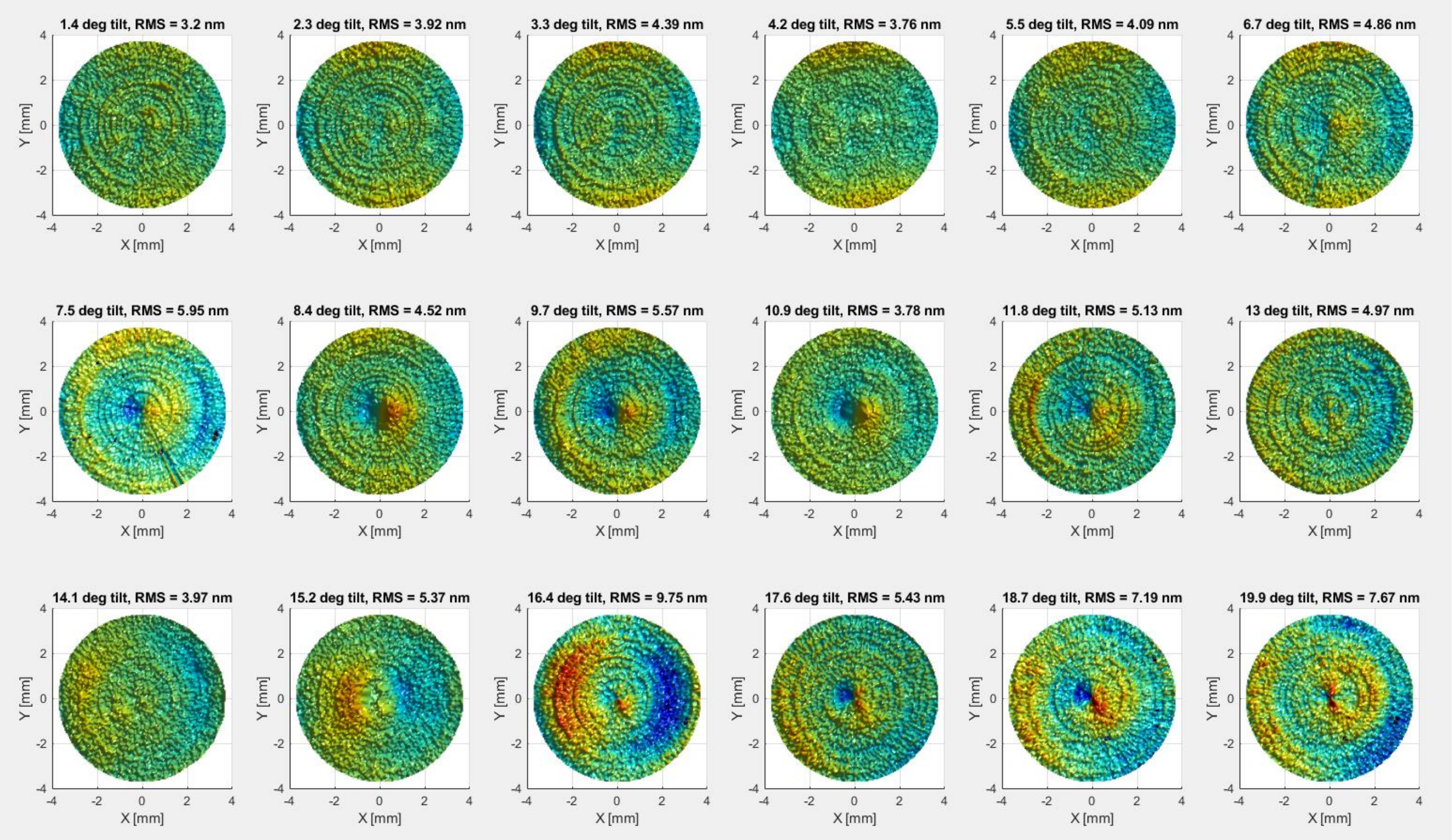


Measurement examples

Tilted flat 0°-20°

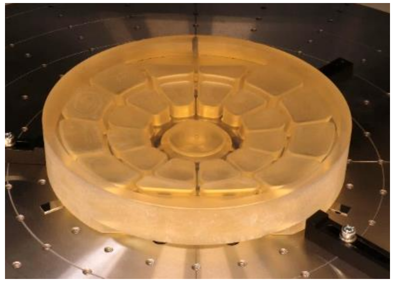


- ∅7.5 mm tilted flat from 0-20° all < 10 nm rms

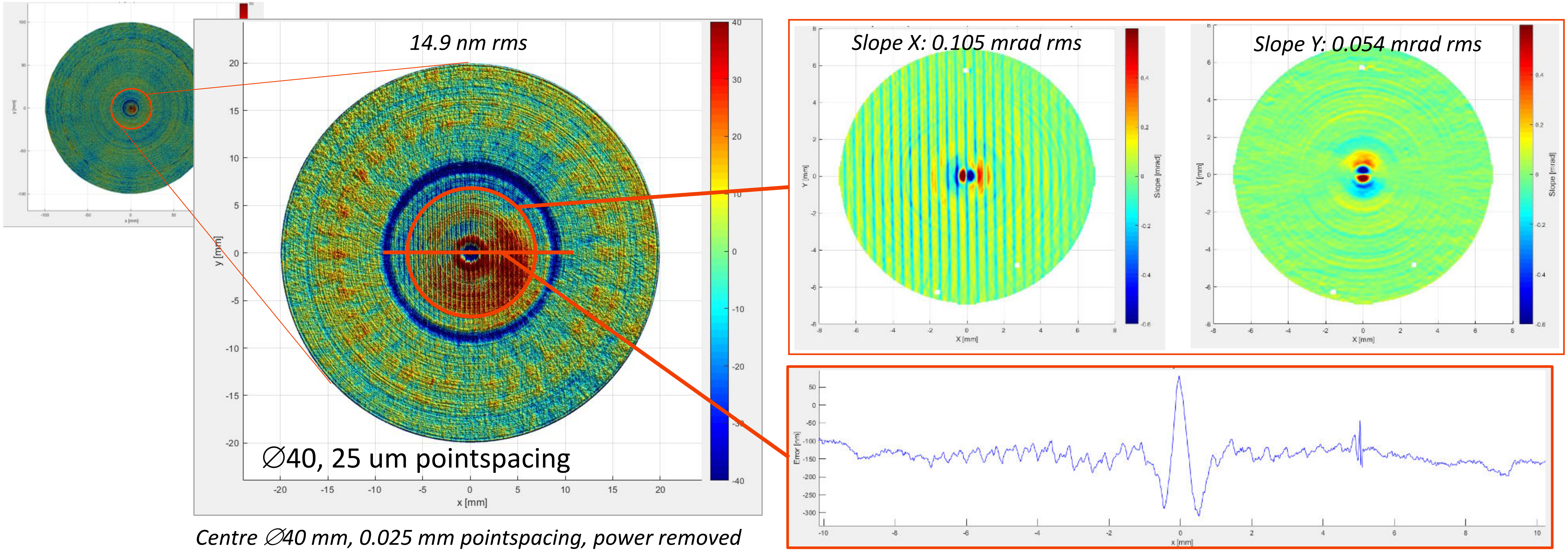


Measurement examples

Mid-spatials characterization of polished mirror



- Polished aspherical mirror blank (center was to be removed)
- Measured full ∅200 mm at 0.1 mm (2k x 2k points), and zoomed on central ∅40 mm at 0.025 mm (1.6k x 1.6k points)
- Radial linescans show centre defect dimensions in high detail

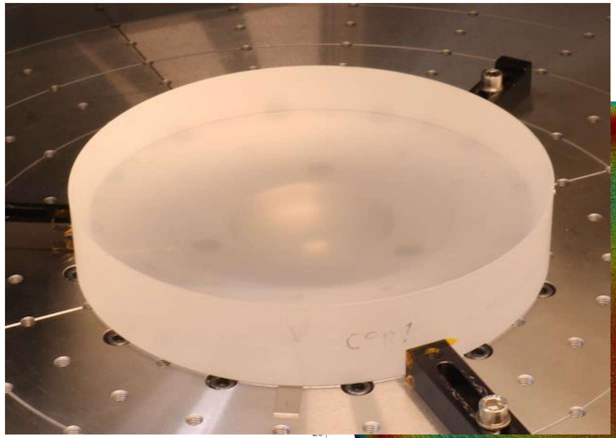


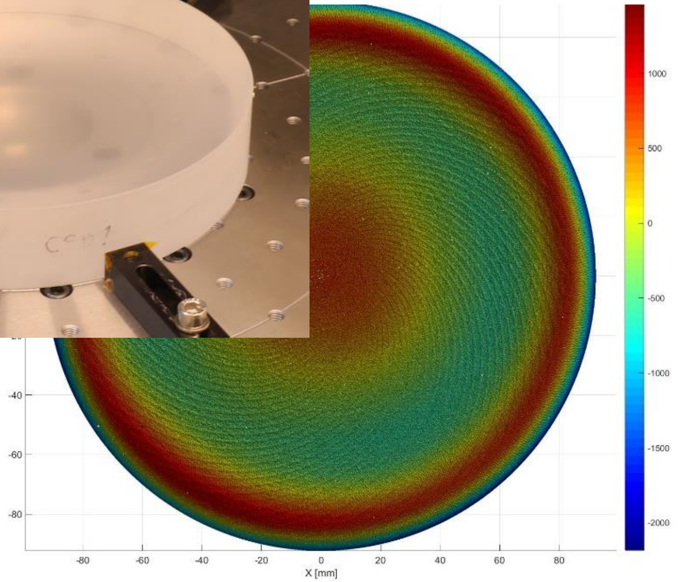
Centre ∅40 mm, 0.025 mm pointspacing, power removed

Measurement examples

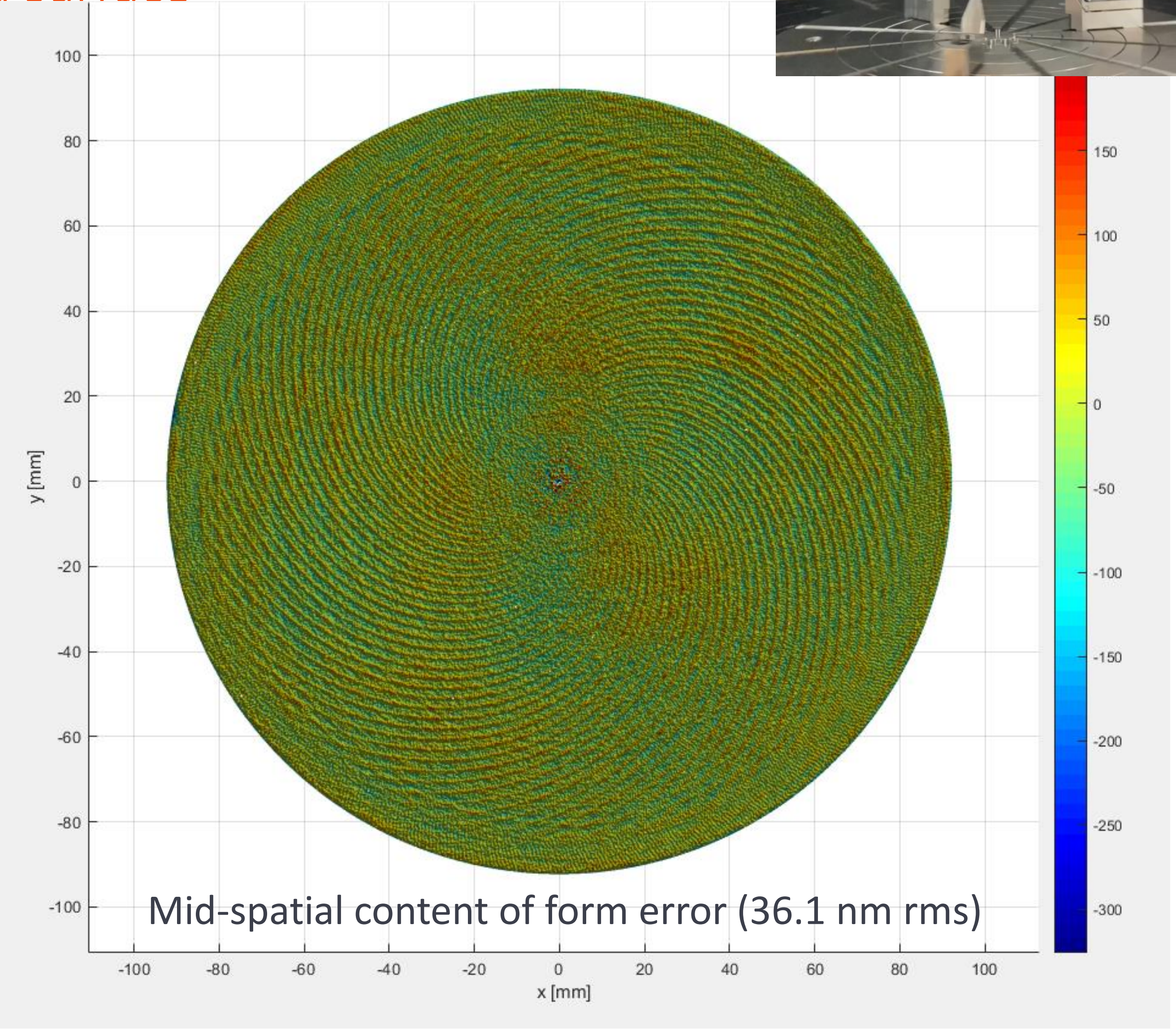
Mid-spatials characterization of ground surface

- Concave ground surface with mid-spatials
- Valuable to know before starting polishing
- Grinding process optimization
- Up to 5 um Ra tilted flat (diffusor)





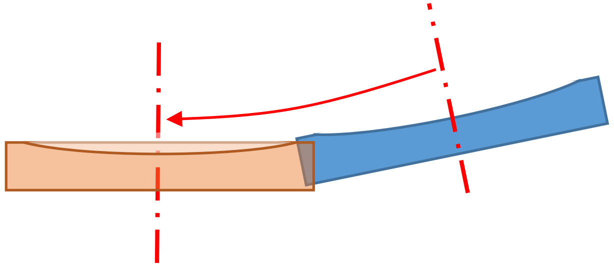
Measured form error



Mid-spatial content of form error (36.1 nm rms)

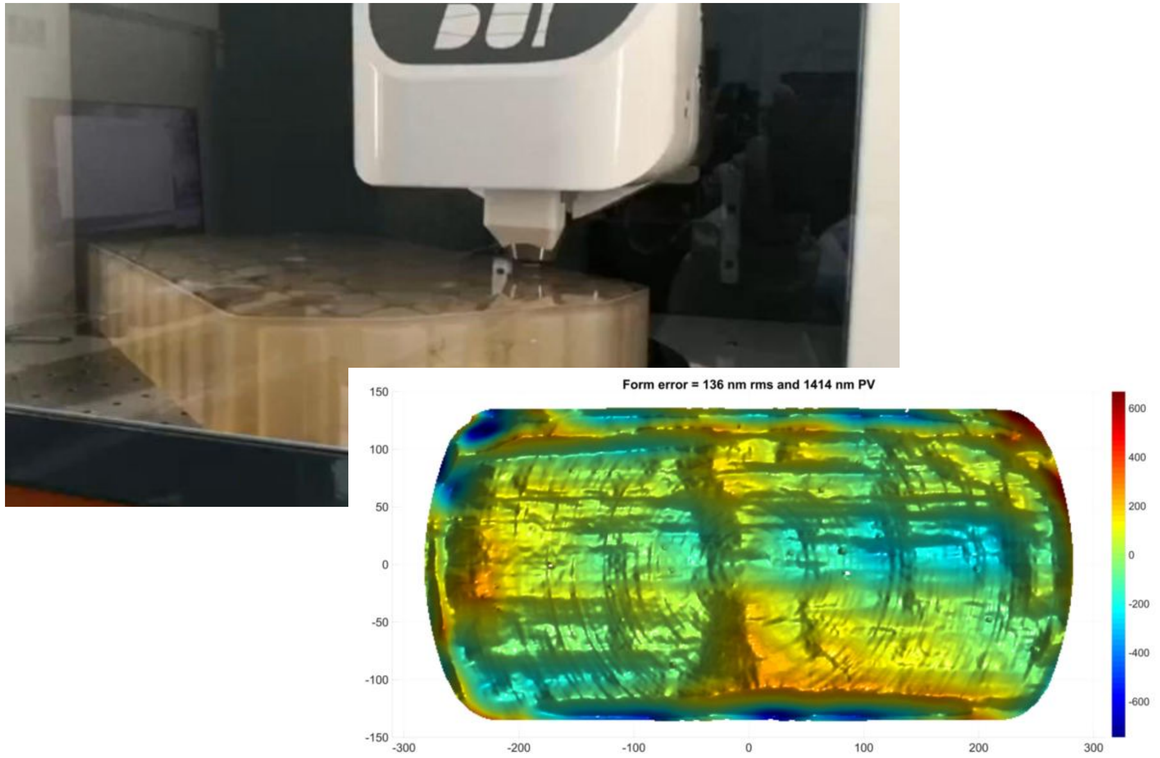
Measurement examples

Off-axis optics

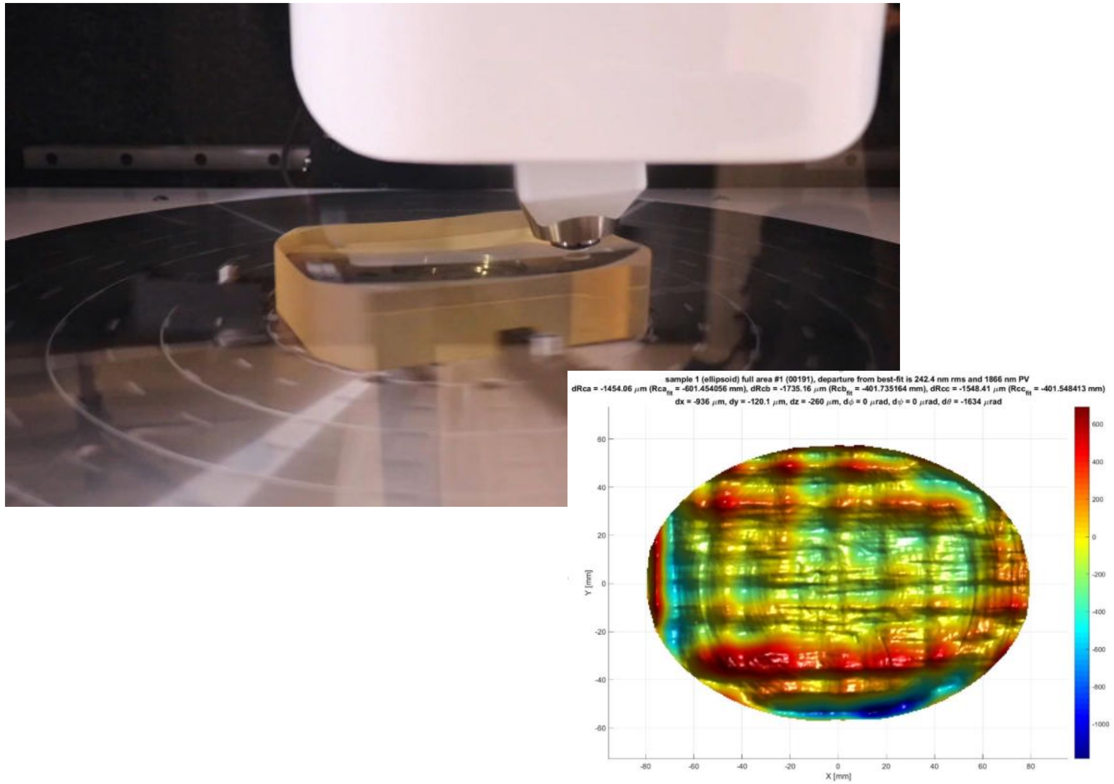


- Off-axis pieces < ∅600 mm can be measured at their off-axis position
- Pieces > ∅600 mm can be measured centred on the table (e.g. off-axis asphere becomes centred freeform)
- Software automatically does all coordinate transformations

550 x 260 mm aperture, off-axis ***convex*** *asphere with radius of 75 m (!)*



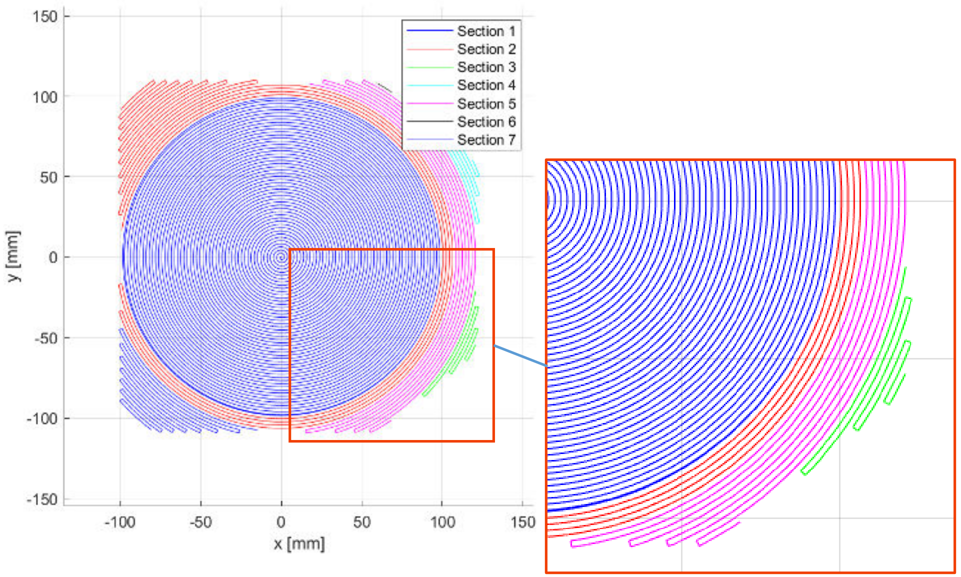
160 mm elliptical aperture, off-axis ellipsoid with 3 mm freeform departure

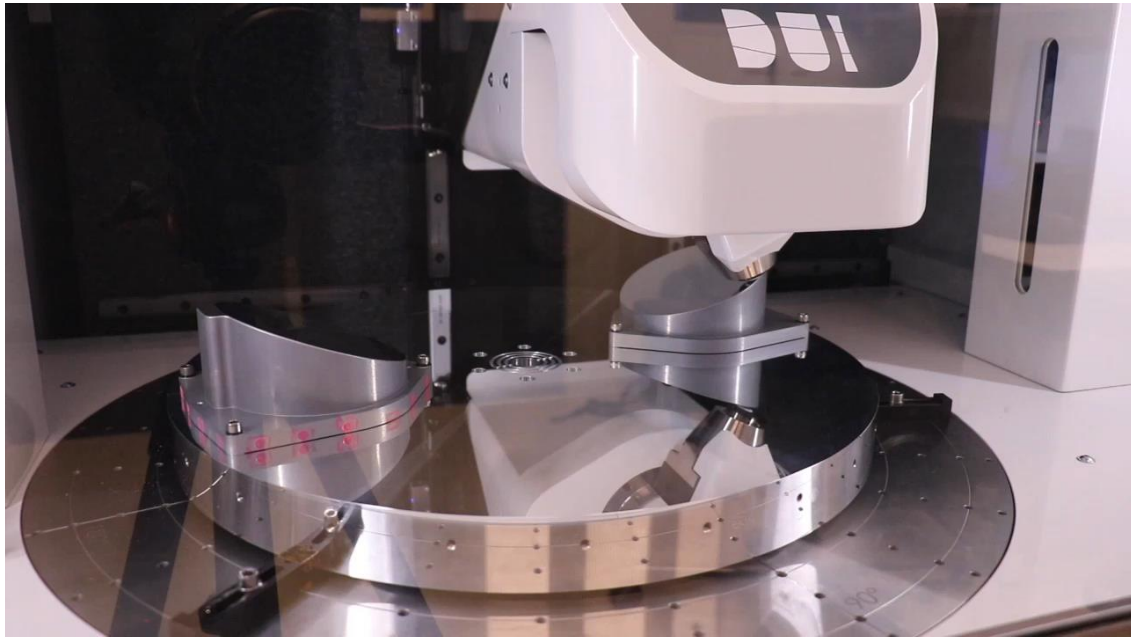


Measurement examples

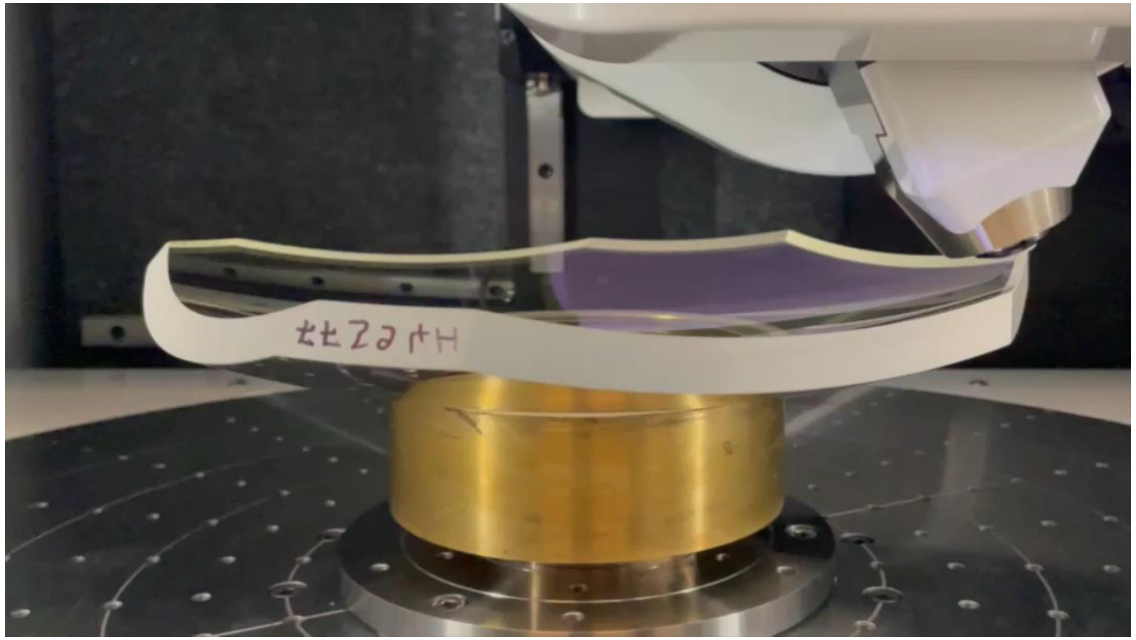
Non-circular apertures

- Probe must keep lock on surface
- Table makes zig-zag motion
- Enter surface contour using shape or polygon
- Software automatically calculates trajectory





Off-axis asphere measured de-centred



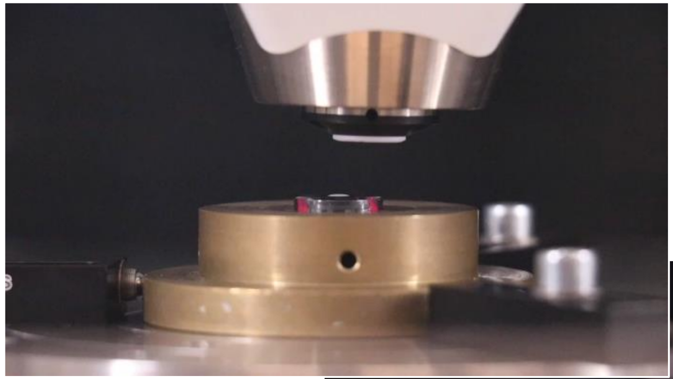
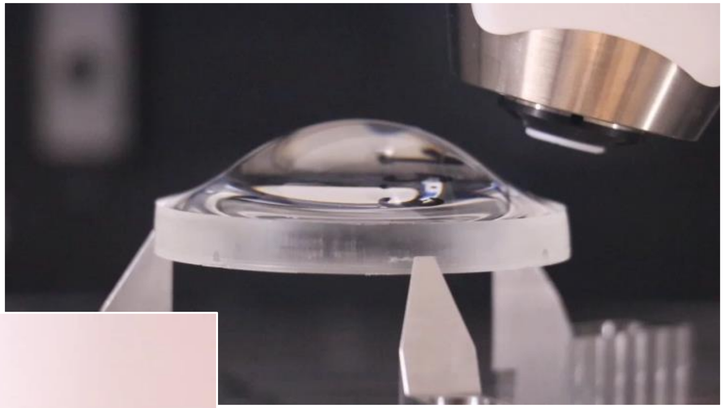
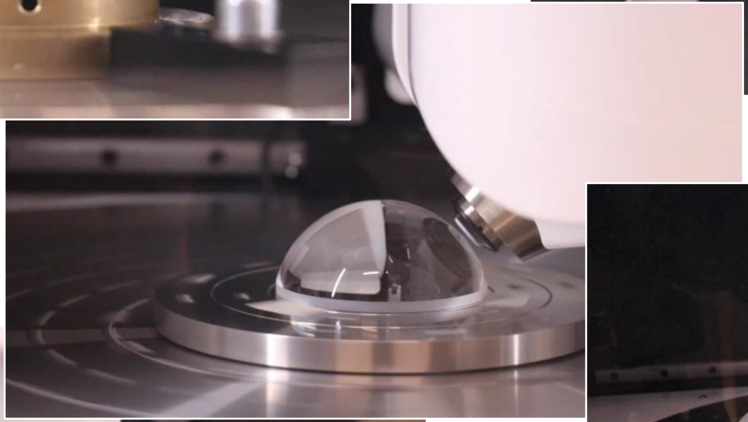
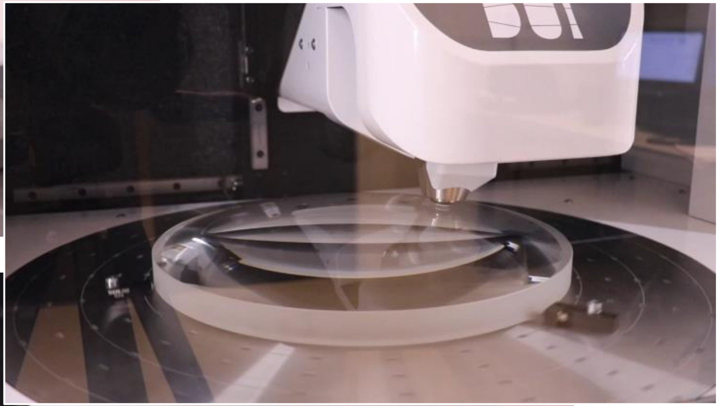
Off-axis non-circular freeform measured centred

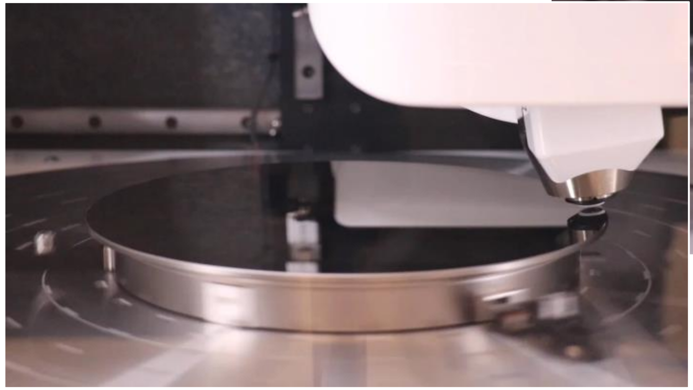
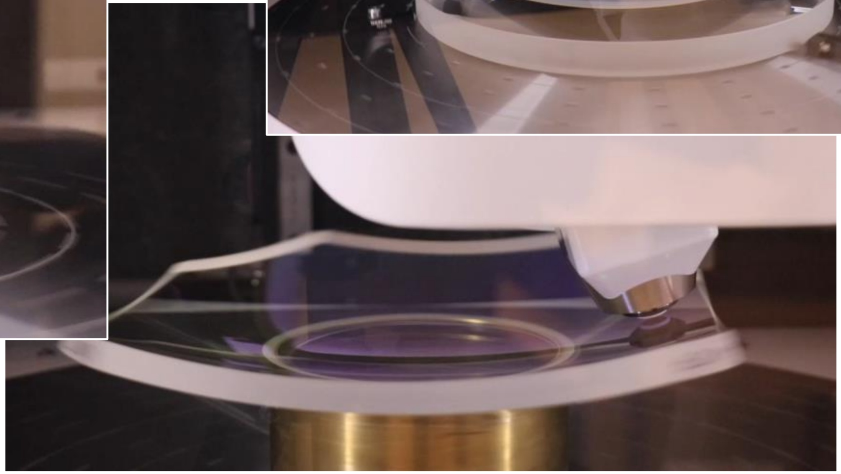
Measurement examples

Versatility

All movies are at actual speed

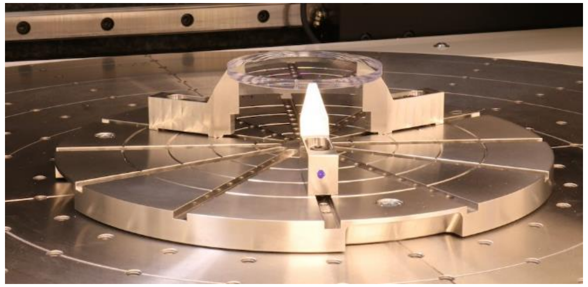
- IR lens (coated)
- Lens with curvature change
- Hemisphere
- Wild freeform
- Large non-circular freeform (coated)
- Large convex asphere
- Concave aspherical mirror
- ....

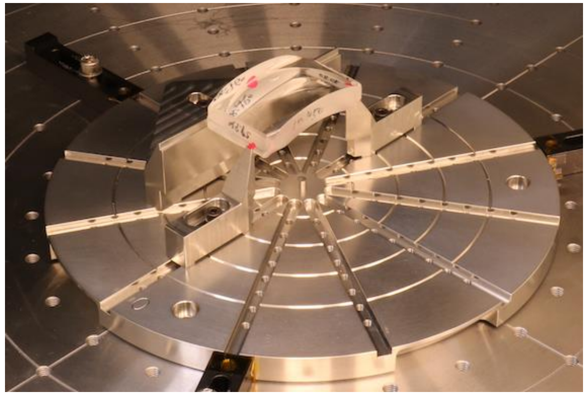





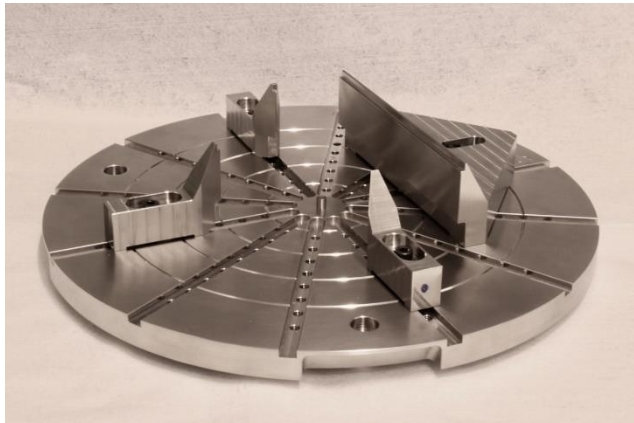



Mounting Kit

- Standard clamp for ∅25 mm or ∅40 mm standard chuck
- Universal mount
  - For circular, rectangular and off-axis optics
  - Simple precision alignment / centering functionality
  - Can be prepared outside machine
  - No further alignment in machine necessary
- Multi-purpose interface plate
- Software to easily configure safety contour for used mount



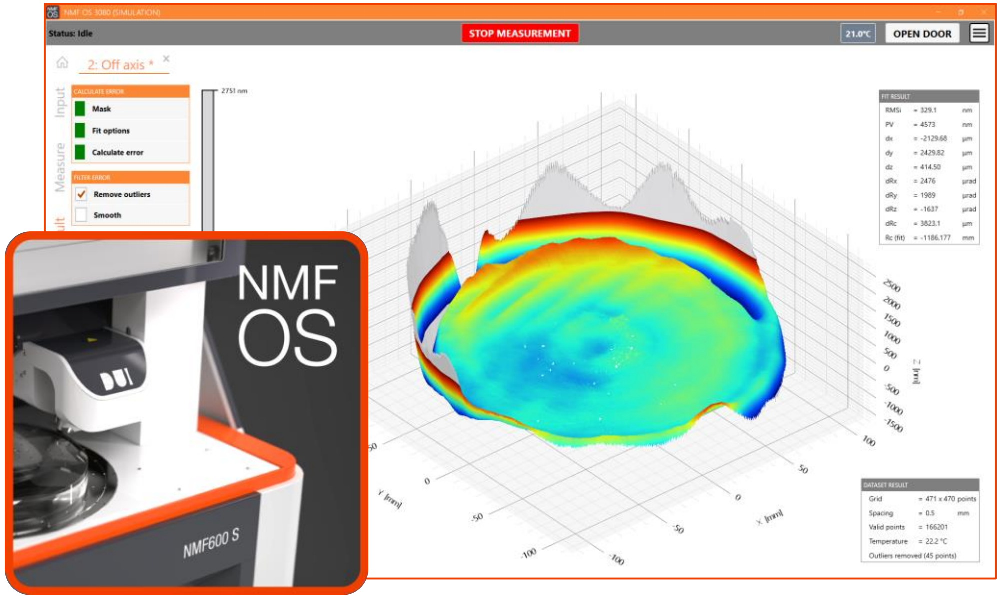




NMF OS software

- Workflow based software guides user through the process
- Database to store and manage all measurements
- Three simple steps to do a measurement
    1. Input surface formula, outside contour and desired measurement area; then software calculates trajectory
    2. Press ‘Start’ to detect surface height and to perform measurement
    3. Automatically best-fit design to xyz data to calculate error map, and mask / filter / analyze result as desired
- Zernike and slope analysis
- Export data in all common formats
- Automatically generate pdf report
- Remote assistance in case of questions/problems

- Usually half a day training is sufficient to comfortably operate the machine
- Machine has various crash prevention measures constantly monitoring safe operation

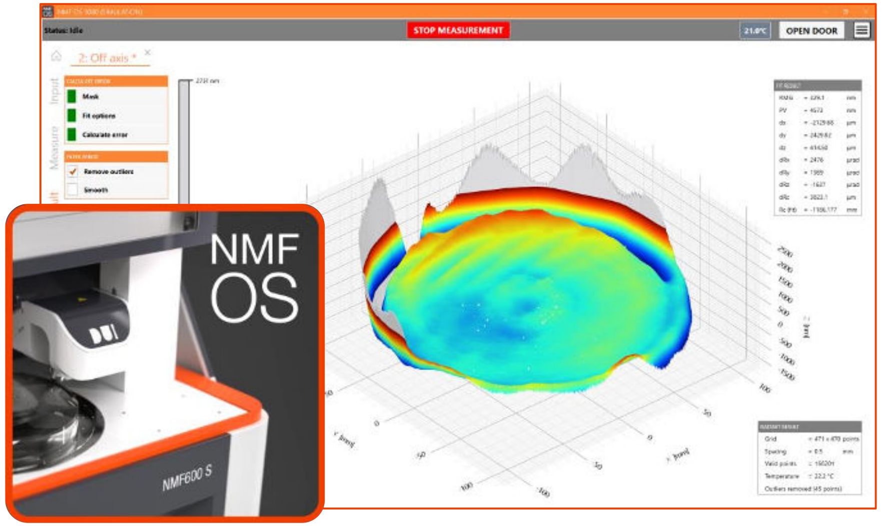


NMF benefits

- "Interferometer accuracy with
  coordinate measurement machine versatility"

- Enable new and better products for your customers
  - Aspheres, freeforms, off-axis, non-circular apertures
  - Highest accuracy, traceable calibration and simple sanity checks
- Lower production cost and time
  - Optimize process control
    Mid-spatial measurement, less iterations
  - Improve yield / reduce polishing time
    Measure after grinding, better starting conditions for polishing
  - Higher measurement throughput
    Measure many mixed shapes with minimal setup time
  - No measurement setup cost
  - Easy to use, fully automated fast measurement

- **Contact us to perform sample measurements for you!**



Thank you!

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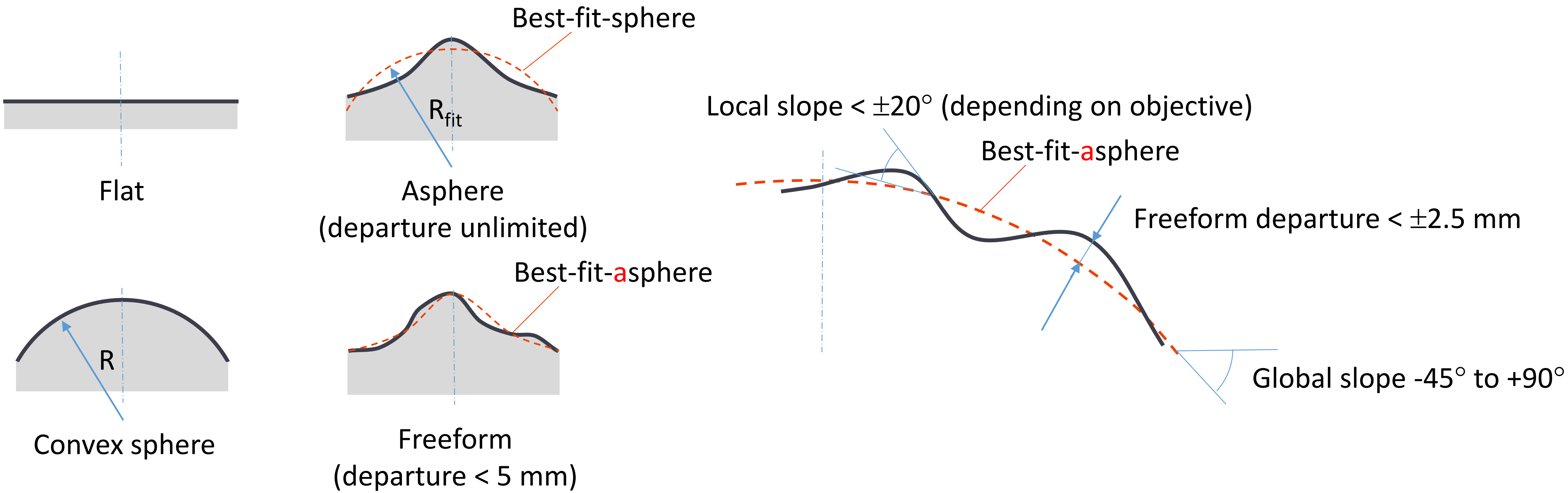
Dutch United Instruments

Appendix: Definitions for surface form

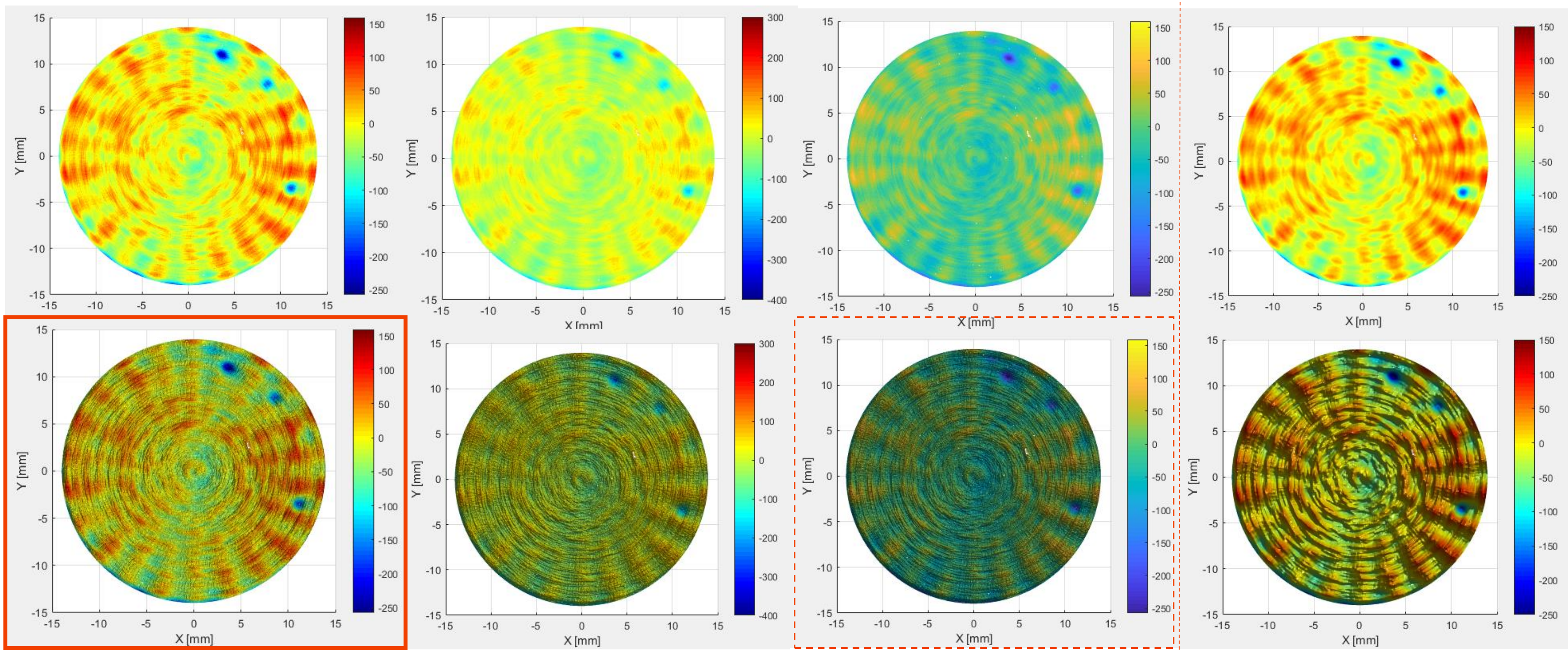
- Surface form (flat to freeform)
- Departure from best-fit-sphere & best-fit-asphere
- Global and local slope



Appendix: Surface data visualization

Original data | Larger color range | Colormap | Smoothed

Shading off / Shading on



Note: Some older data still has Parula colormap