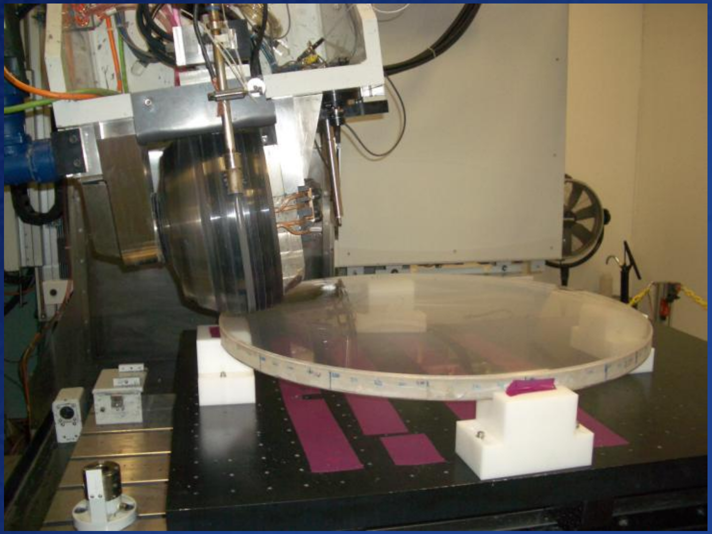


Recent Advances in MRF® Finishing of Large Optics

presented to:
Technology Days in the Government
Mirror Development
July 31-August 2 2007

Andrew Jones, James T. Mooney and Marc Tricard
QED Technologies®

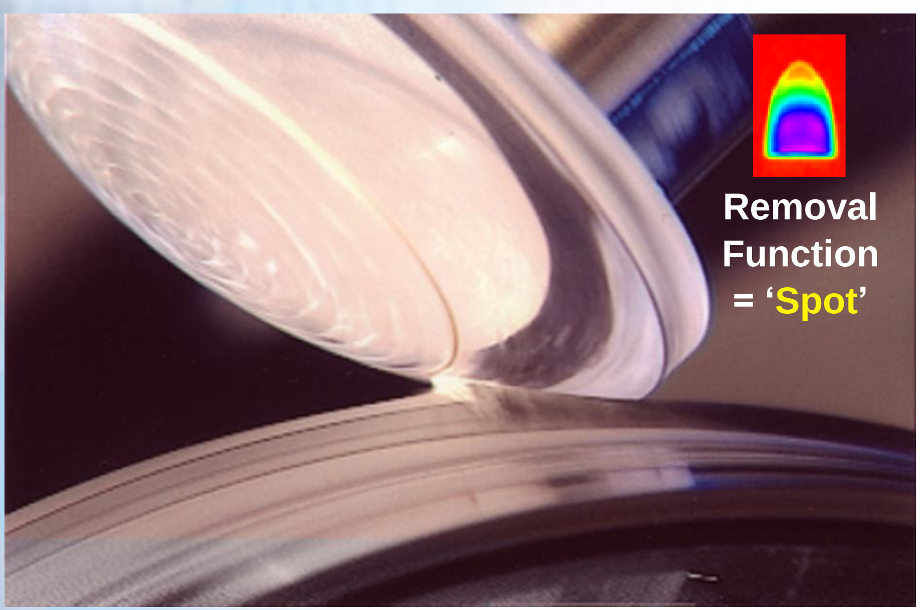
1040 University Avenue • Rochester, NY • USA
Tel: +1 (585) 256-6540 • Fax: +1 (585) 256-3211
mooney@qedmrf.com • www.qedmrf.com

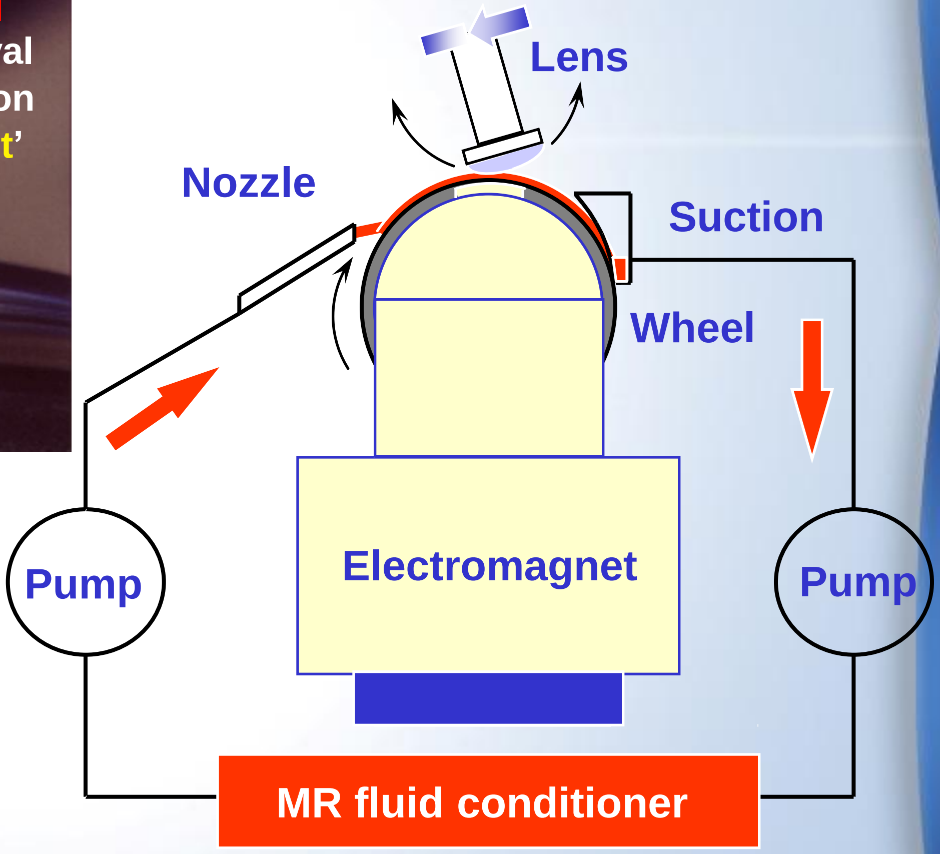
Acknowledgements:
John West, John Hraba
Dr. Philip Stahl
NASA SBIR 03-S2.05-7100

Outline

- Brief MRF® technology introduction
- Improved figure correction near edges of large segmented optics using MRF
- Freeform capabilities of large MRF platforms
- Implementation of “pre-polishing” on MRF platforms

Magnetorheological Finishing (MRF®) – How it works





MRF – Breakthrough Technology

The MRF polishing tool:

- never dulls or changes
- is interferometrically characterized
- is easily adjusted
- conforms to part shape - works on complex shapes (flat, sphere, asphere, cylinder, freeform…)
- has high removal rates
- removal based on shear stress so applies very low normal load on abrasive, improving surface integrity
- determinism leads to high convergence rate

These attributes lead to a production-oriented, deterministic, computer-controlled polishing and figuring technique.

Production proven: more than 100 machines worldwide

Polishing optics from 1mm to >1 meter

Family of QED Machines

- **Q22-XE – <100 mm in diameter.**
- **Q22-X - Up to 200 mm in diameter.**
- **Q22-Y - Raster tool path, up to 200 mm in size.**
- **Q22-400X - Up to 400 mm in diameter.**
- **Q22-750P2 - Plano optics up to 750 mm x 1,000 mm in size.**
- **Q22-950F – Freeform optics up to 950 x 1,250mm**
- **Q22-950F-PC– Freeform optics up to 950 x 1,250mm with pre-polishing capabilities**
- **Q22-2000F– Freeform optics up to 2+ meters**
- **SSI® -- Subaperture Stitching Interferometer (SSI) for high precision metrology.**
- **SSI-A® -- Subaperture Stitching Interferometer (SSI) for high precision asphere metrology.**

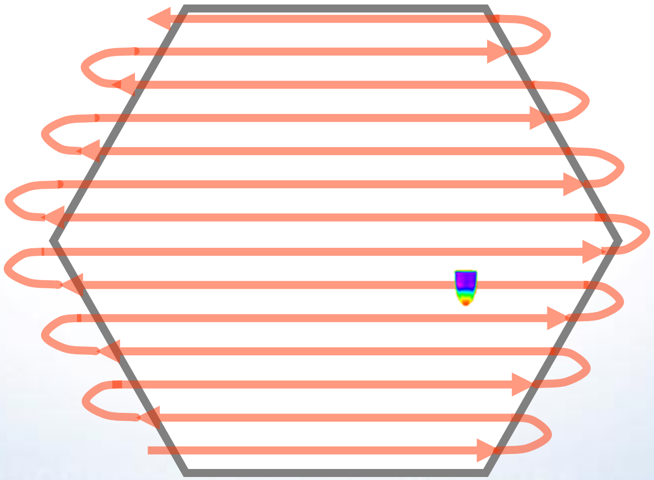
Fabricating Large Segmented Optics using MRF

Large segmented mirrors must have little or no edge exclusion

Standard MRF has demonstrated good performance at edges for a variety of aperture sizes and shapes.

Work reported is to improve edges even further.

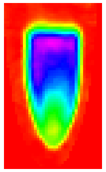
The primary goal of the SBIR is to understand process differences at the edge and to develop an approach to account for them.

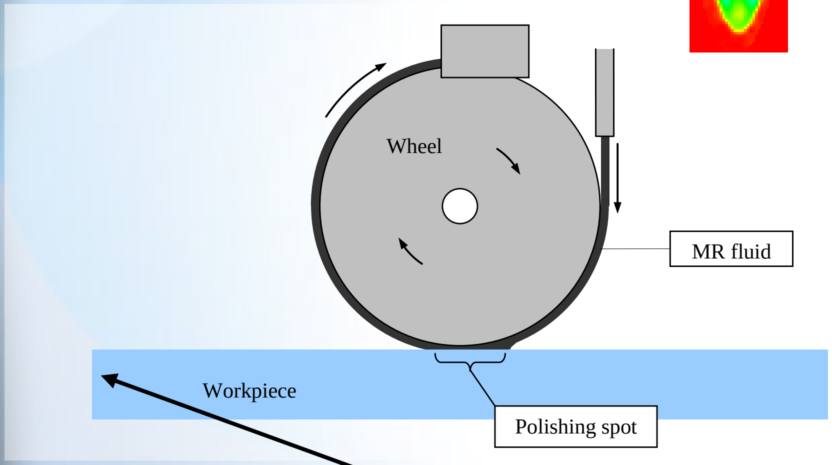


Causes of Edge Effects

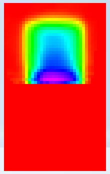
MR fluid flow over edges differs from flow over surface, leading to changes in the tool removal function ("spot").

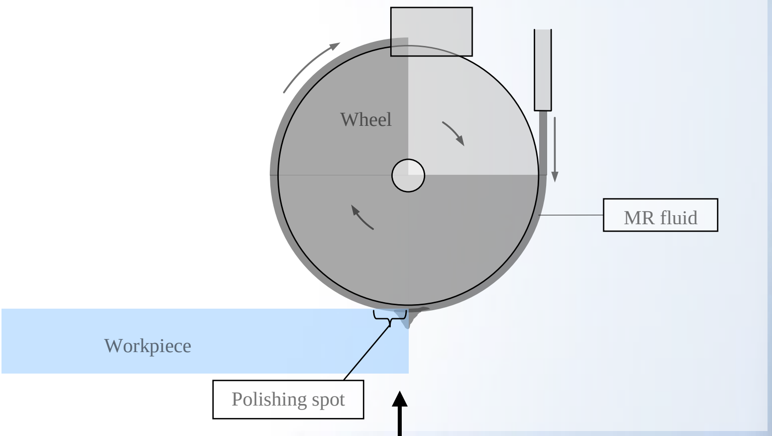
Polishing away from edges





Polishing at leading edge





Edge performance at *trailing edge*, superior to *leading edge* due to flow characteristics

Methods of Eliminating Edge Effects

QED Technologies

- **Removal map biasing: leave edge regions intentionally “high,” and correct with smaller spot**
  - Simplest to implement, but requires additional polishing iterations
- **Limited tool travel: start or end polishing inside leading or trailing edges, leaving edge regions intentionally “high”**
  - No edge effects at leading or trailing edge
  - Like removal map biasing, requires additional polishing
- **Variable plunge depth: use a smaller spot near edges**
  - More difficult to implement in software, but should provide best results – potentially in a single polishing iteration
  - Can start or end polishing closer to edges if using limited tool travel

Removal Map Biasing

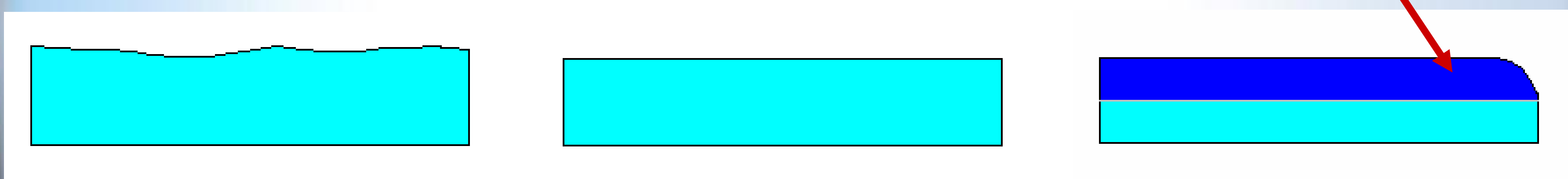
Where rolled edges are anticipated, remove less material so that edge regions are intentionally left "high"

- Minimizes amount of material that needs to be removed in subsequent runs

Correct edge regions with a smaller spot with subsequent iteration

Without removal biasing:

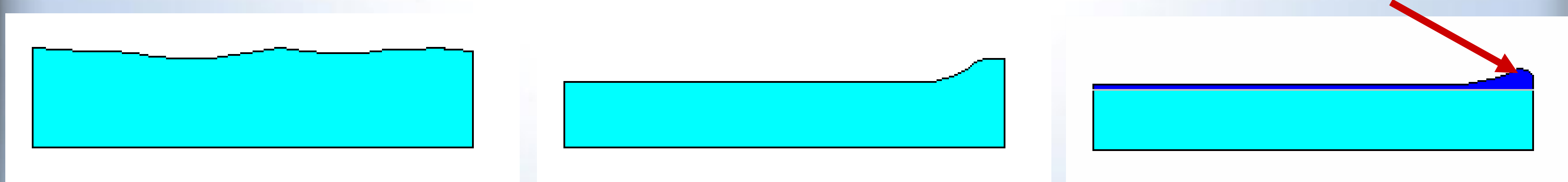
Residual to remove in second run



Before polishing | **Target figure** | **After polishing**

With removal biasing:

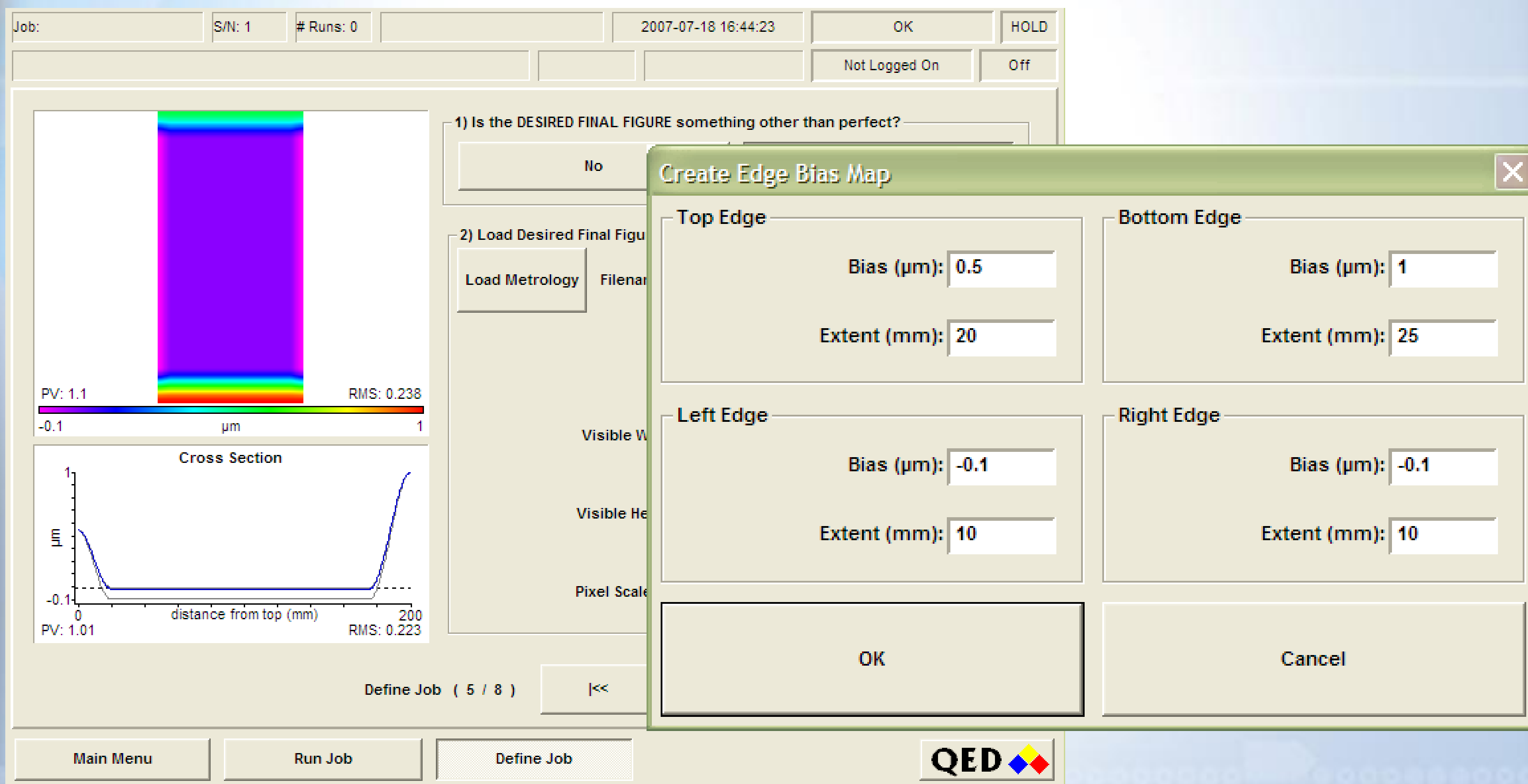
Residual to remove in second run



Before polishing | **Target figure** | **After polishing**

Automatic Edge Bias Map Creation

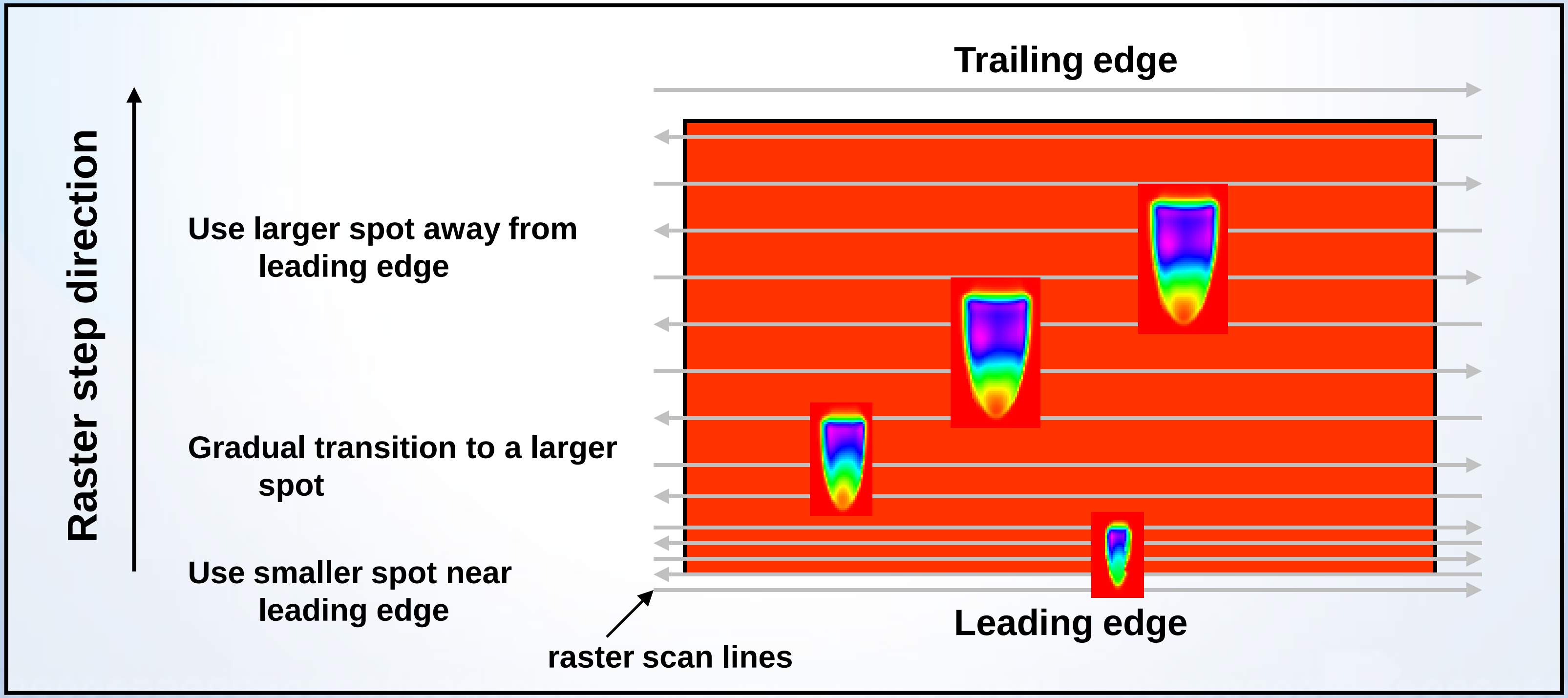
- A tool for creating edge bias maps has automatically been added to the MRF Control Software
- User can also generate customized bias maps



Variable Plunge Depth

- ❖ Extent of edge effect is proportional to spot size, but polishing time is (roughly) inversely proportional to spot size

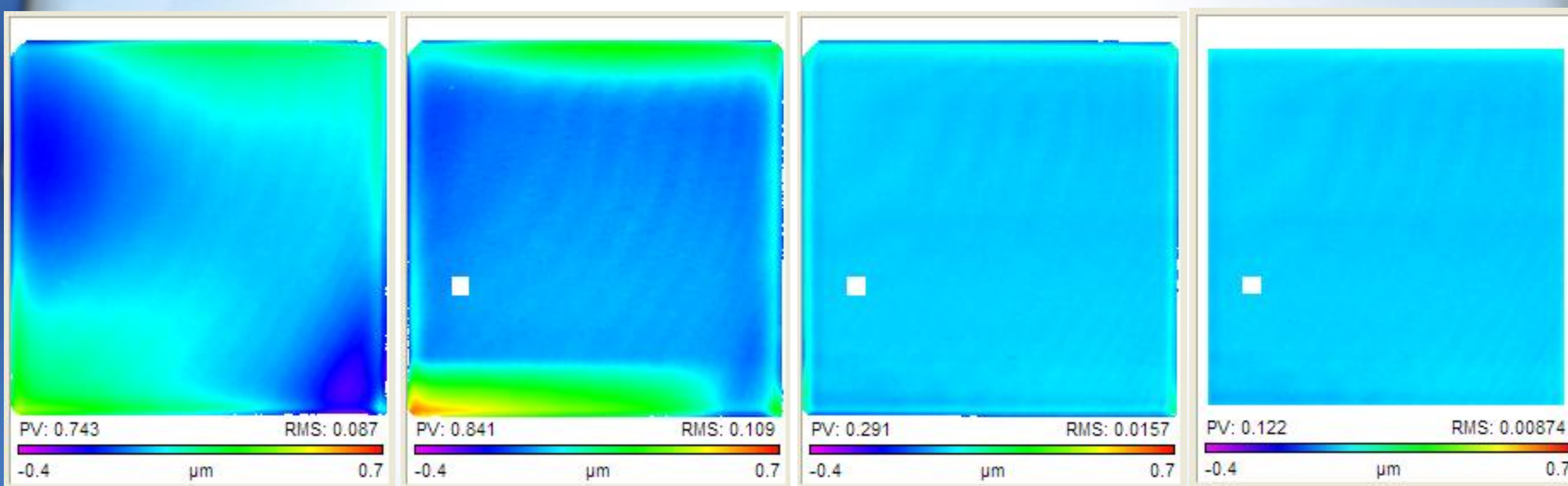
- ❖ Use smaller spot (lower plunge depth) near edges where edge effects are anticipated; use larger spot (higher plunge depth) away from edges to remove material quickly



Process Example

Two polishing runs on 74 x 74 mm CA part:

- Polishing using large MRF wheel (370 mm diameter used on meter-class platforms) to perform low-order correction
- Standard polishing run using small wheel (50 mm) to correct higher spatial frequency features



Initial surface

0.74 µm PV

0.087 µm RMS

After 370 mm wheel run

Corrected low-order figure away from edges

After 50 mm wheel run (full clear aperture)

0.29 µm PV

0.016 µm RMS

After 50 mm wheel run (2 mm edge exclusion)

0.13 µm PV

0.0087 µm RMS

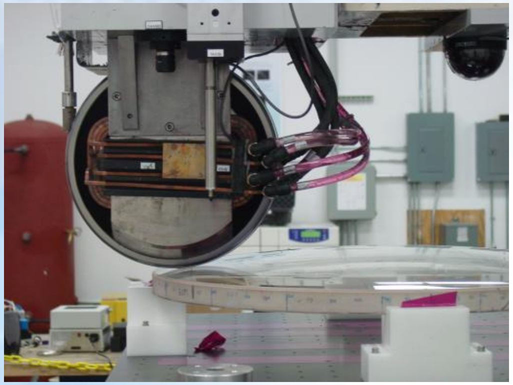
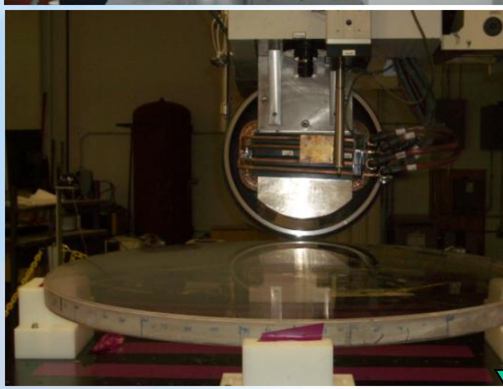
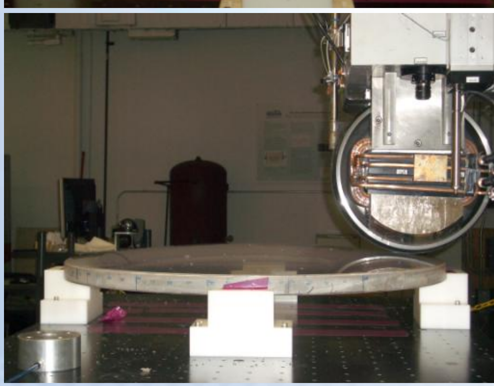
Polishing Cycle Time

- **For the multi-run polishing approach to be advantageous, the polishing cycle time must be significantly less than those of using a single small spot**

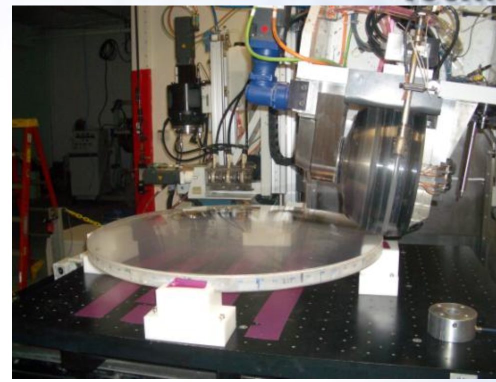
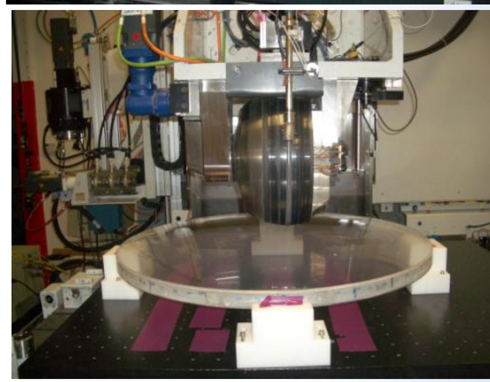
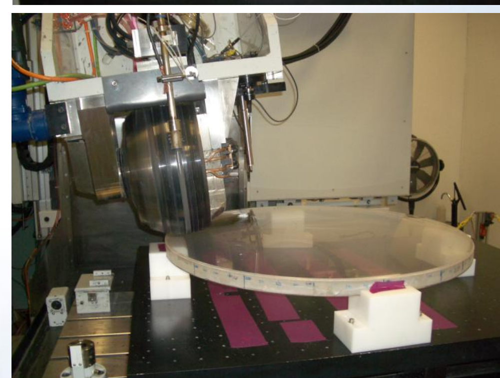
- **Estimated cycle time for polishing using 50 mm wheel only was 35% longer than using a multi-run approach.**

- ***Time savings are much greater for larger parts since a smaller fraction of the surface area is within one spot length or width of the edges***

Q22-950F Freeform Machine

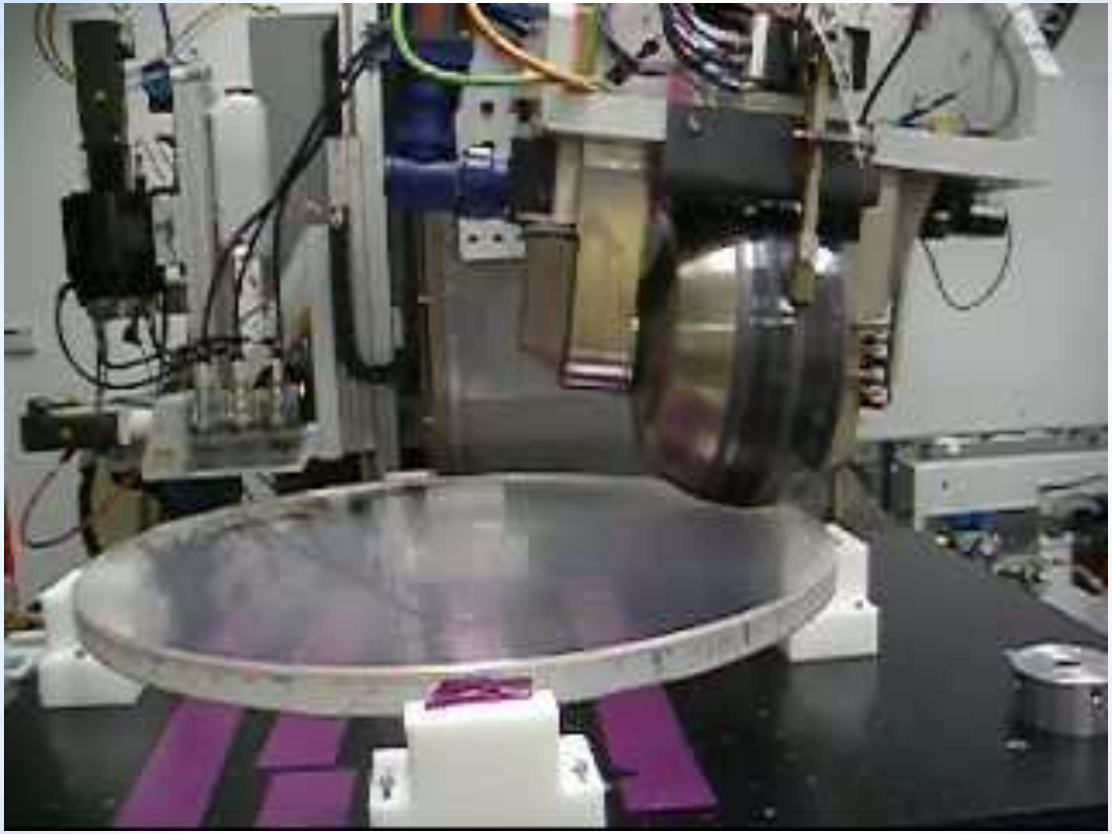




Polishing around the wheel

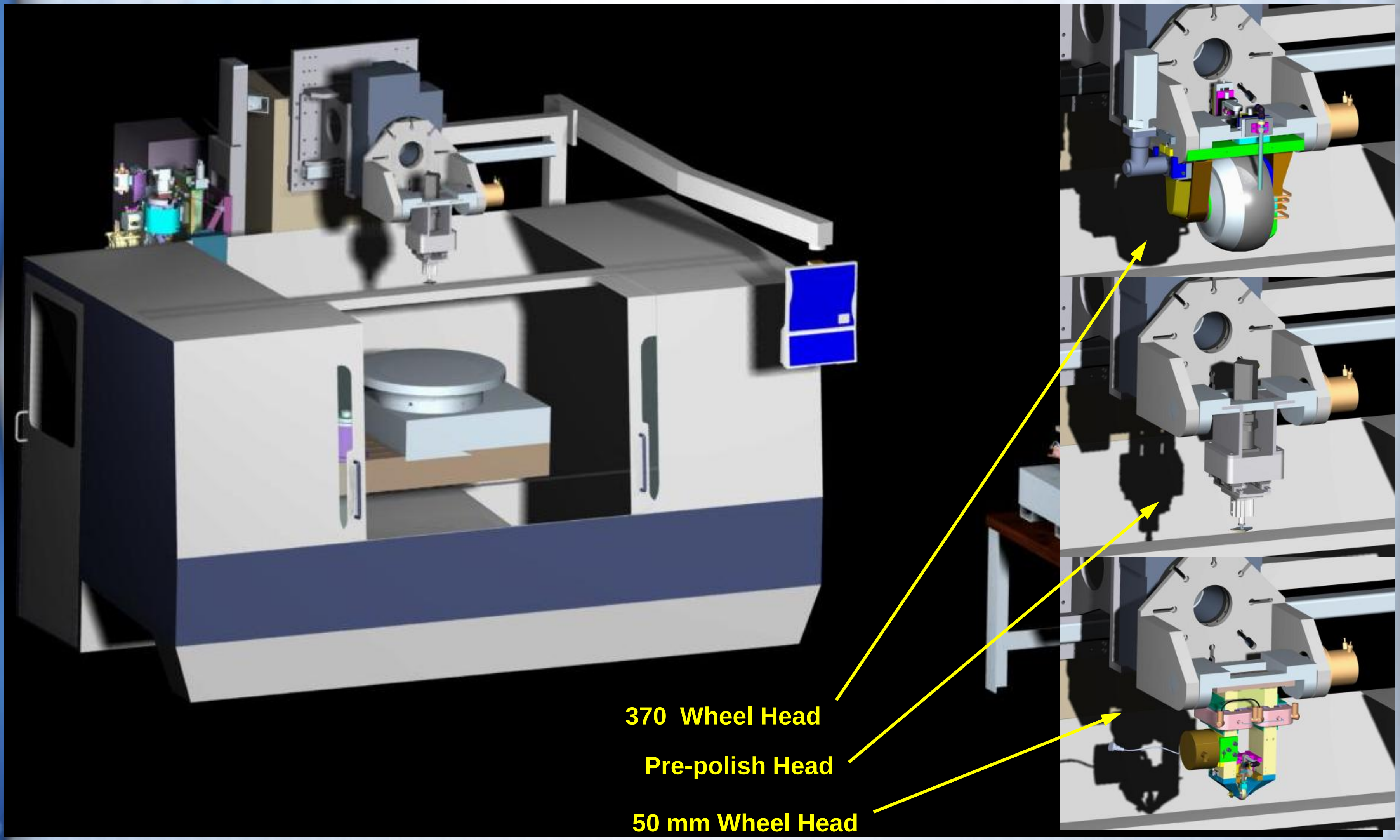
C-axis pivot

Raster Polishing Large Aperture Aspheres

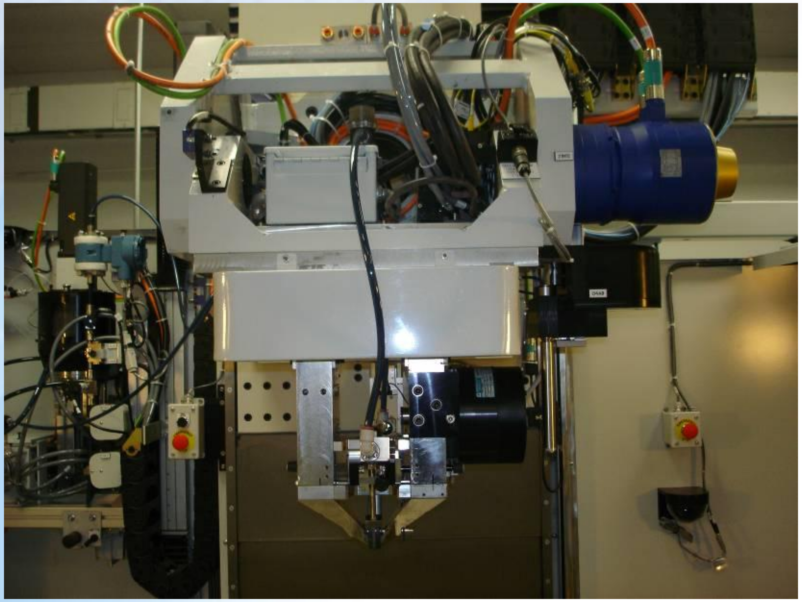


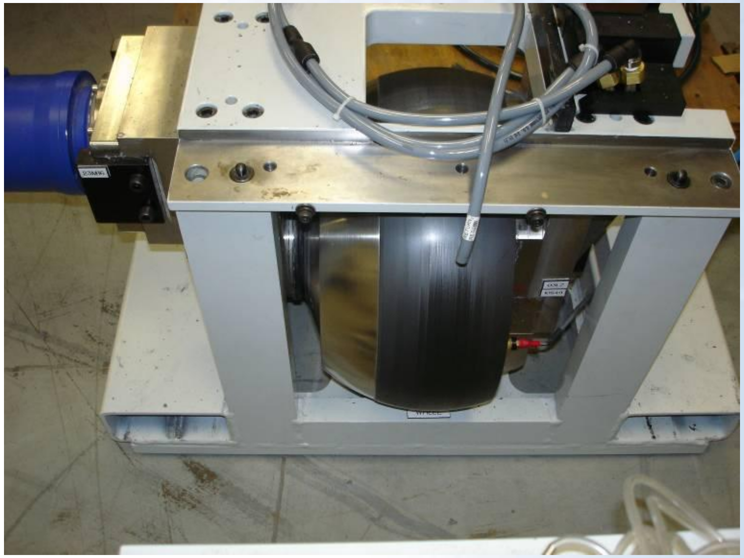
- ❖840 mm diameter
- ❖Fused silica
- ❖1.3 mm departure from best fit sphere

Q22-950F Polishing Center



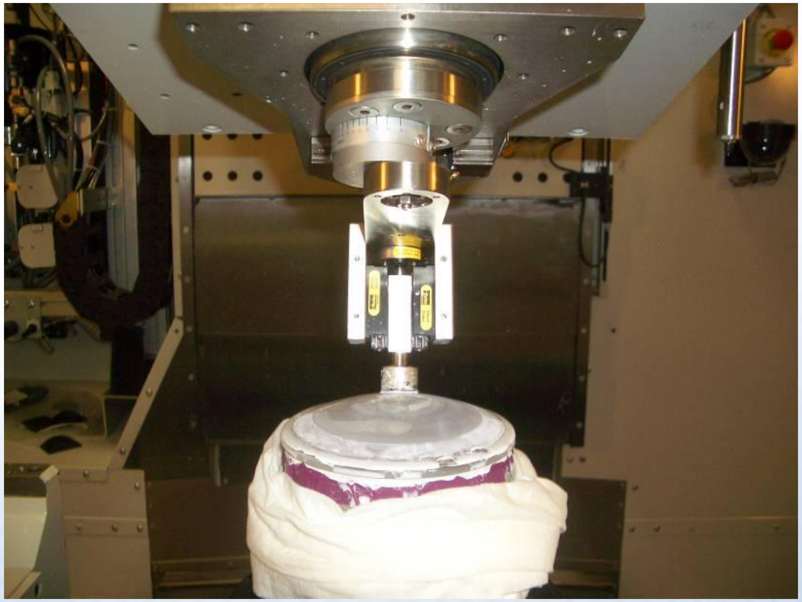
Three Heads





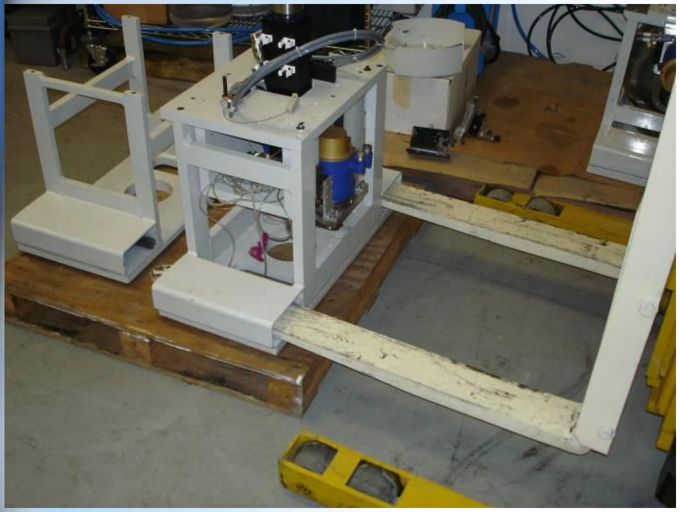
Ø50mm MRF

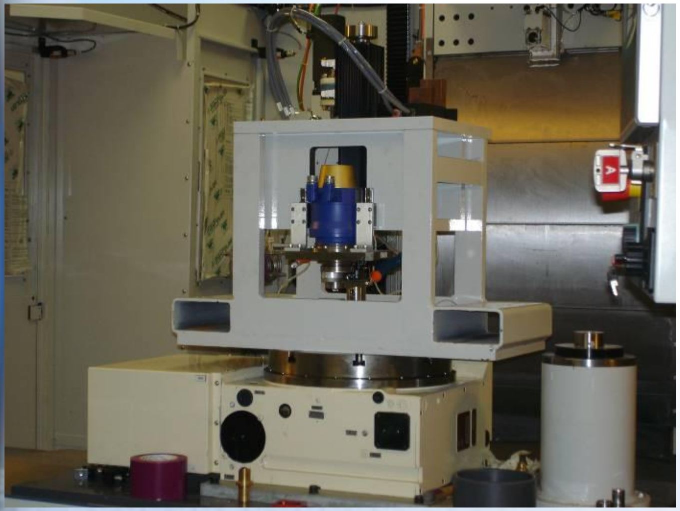
Ø370mm MRF

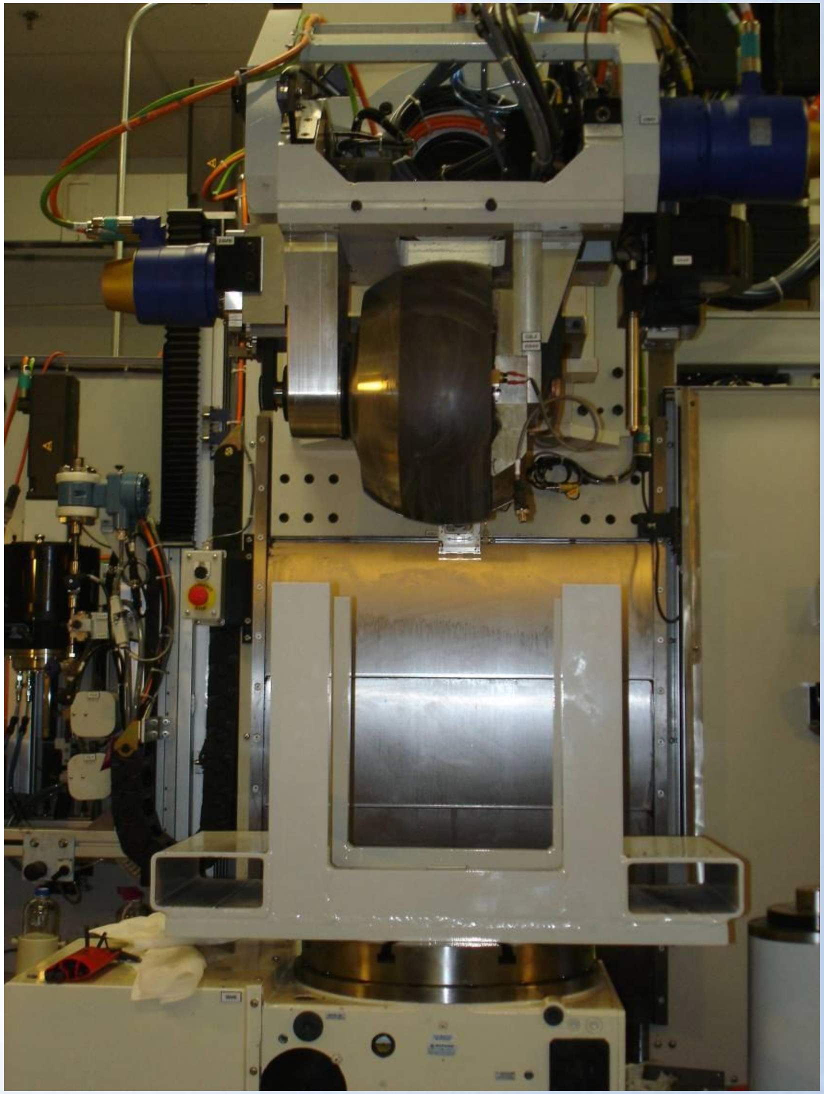


Pre-Polishing Head

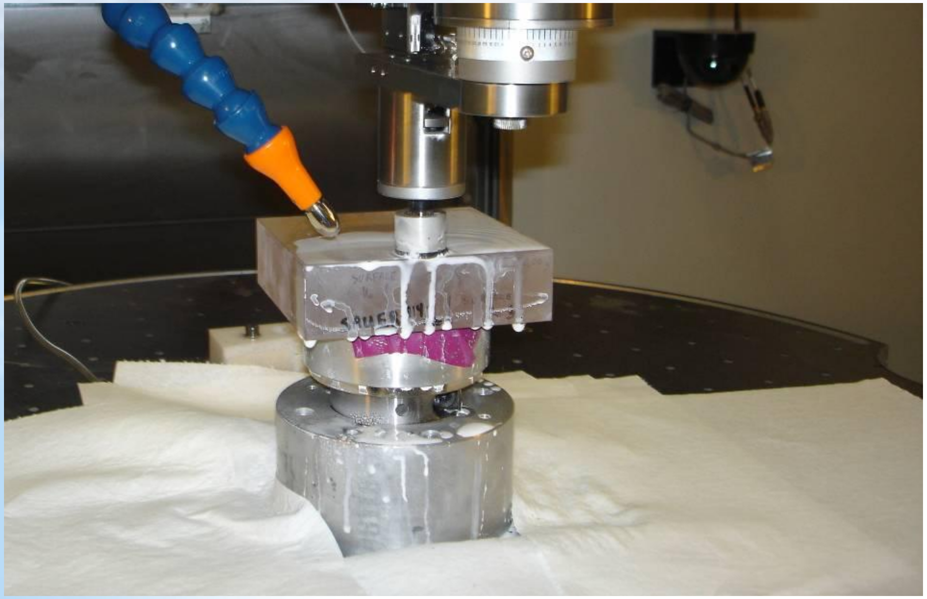
Changing Heads

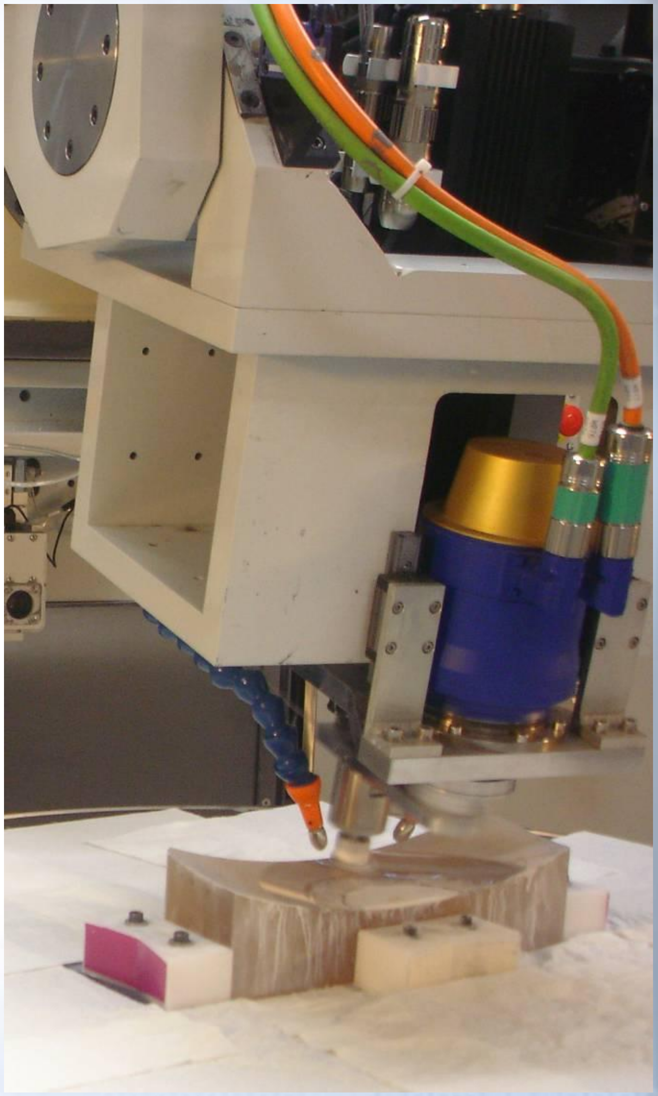




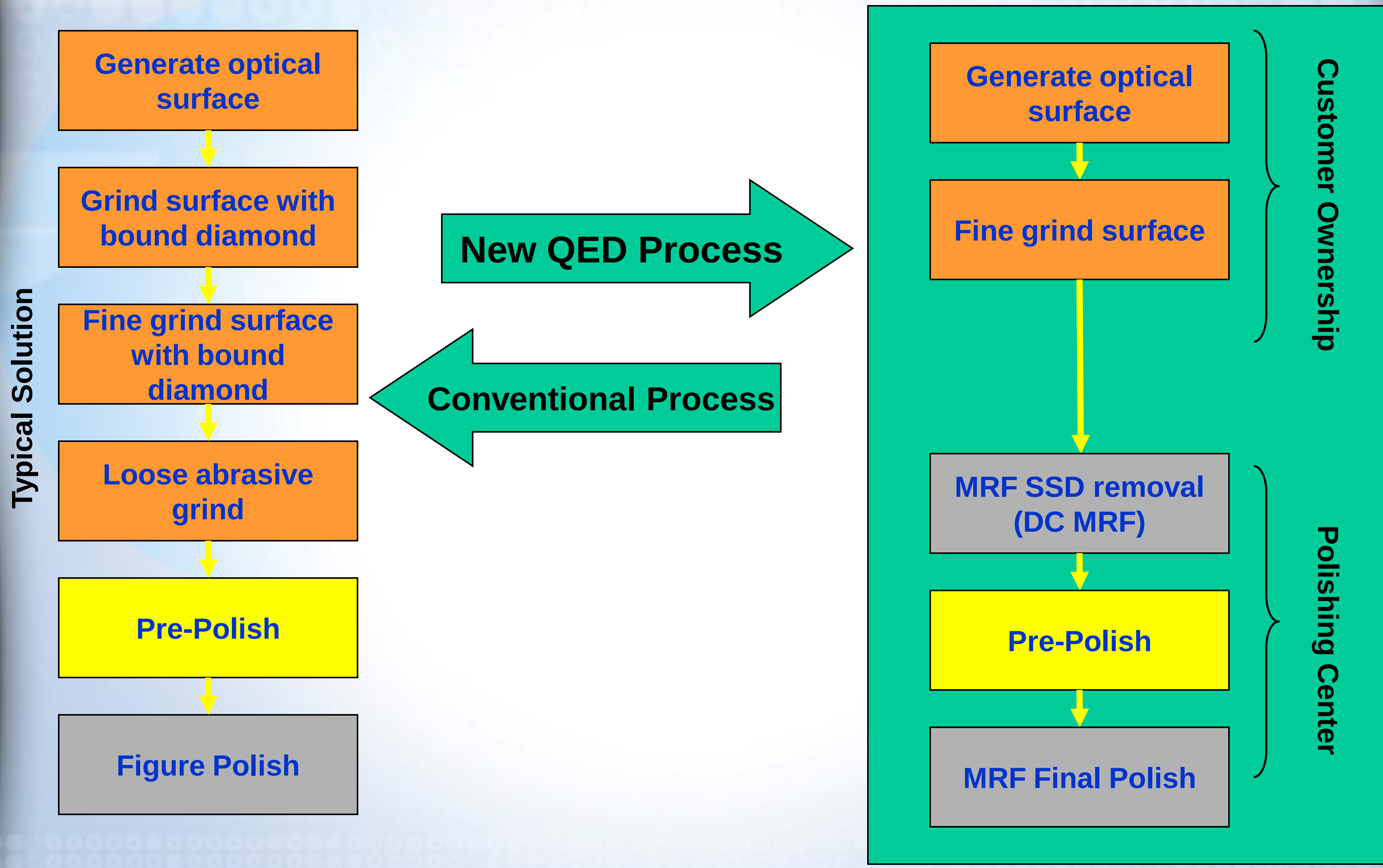


Pre-Polishing Head





Novel Process Flow

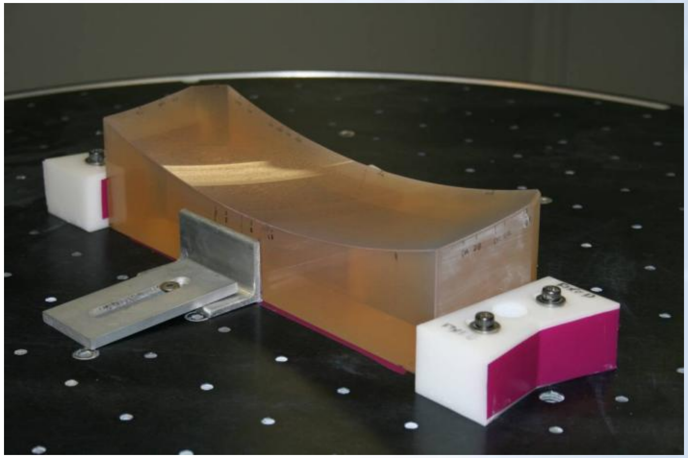


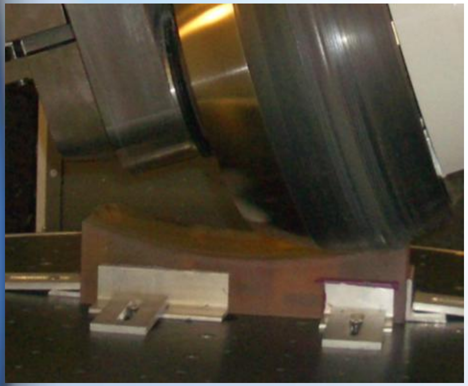
Example: Off-axis Component

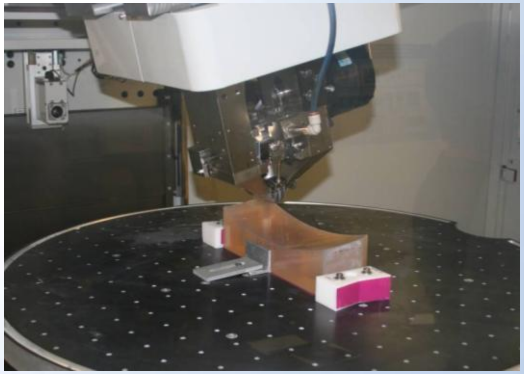
QED Technologies

~300 x 90 mm off-axis spherical section
~286 x 72 mm Clear Aperture
R = - 450 mm (cc)
Zerodur
Process on Q22-950 PC

- **MRF Damage Removal**
- **Smoothing (sub-ap pitch tool)**
- **MRF Figure Correction**





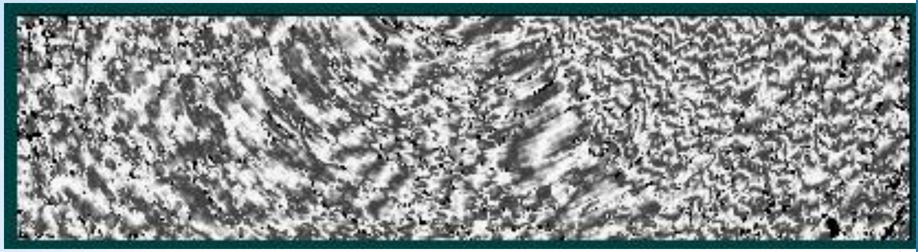


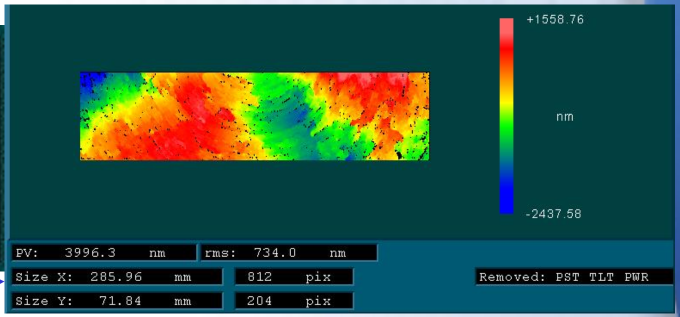
Off-axis process development Component

Initial Condition – Figure could not be measured at all until after MRF damage removal

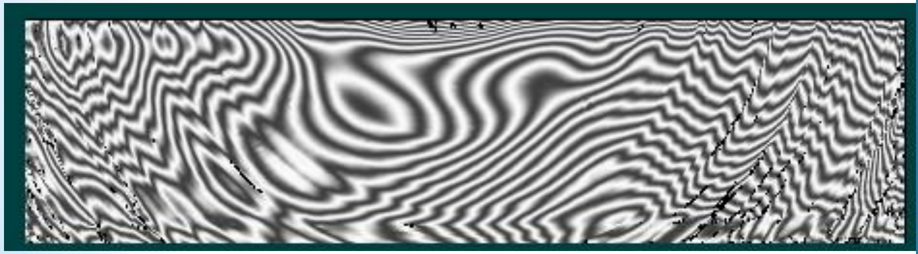
After MRF Damage Removal

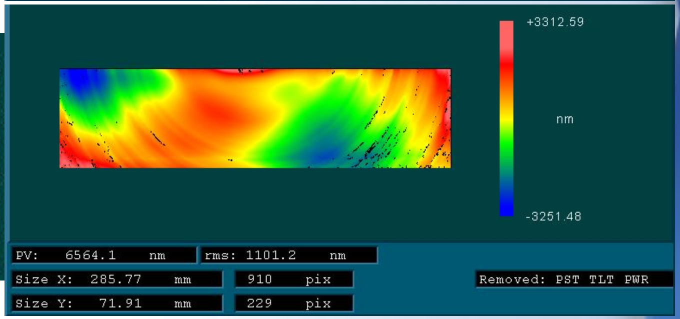
Uncertainty in PV & RMS is high because high slopes from grinding marks cause high fringe density



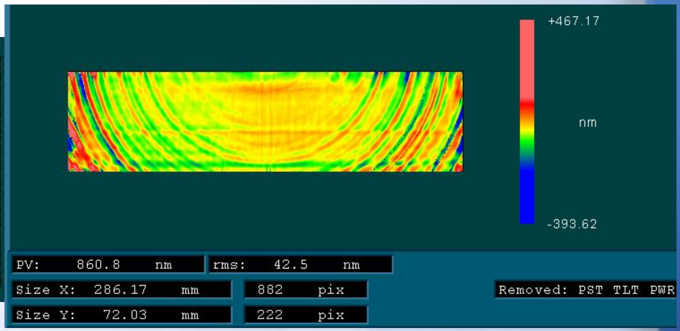


After Pad Polish





After MRF figure correction



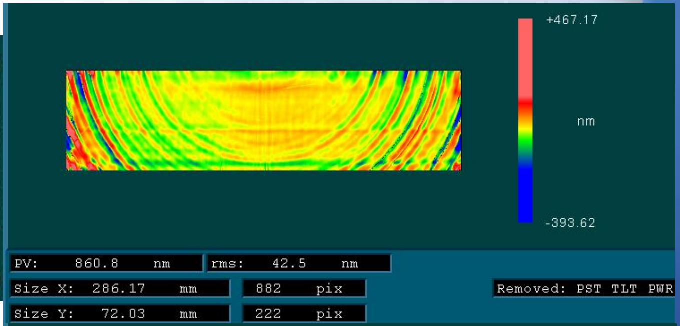
All Data shown over 286 x 72 mm CA

Off-axis process development Component

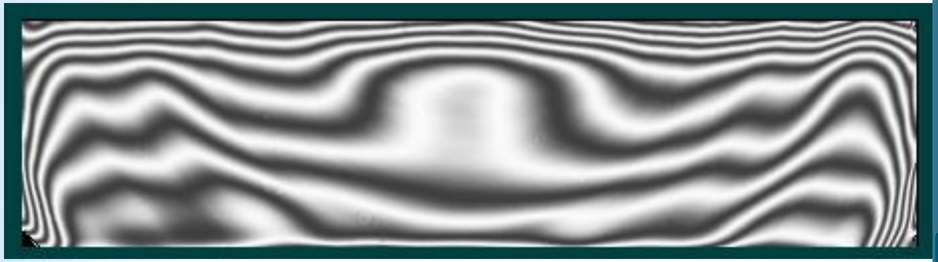
QED Technologies

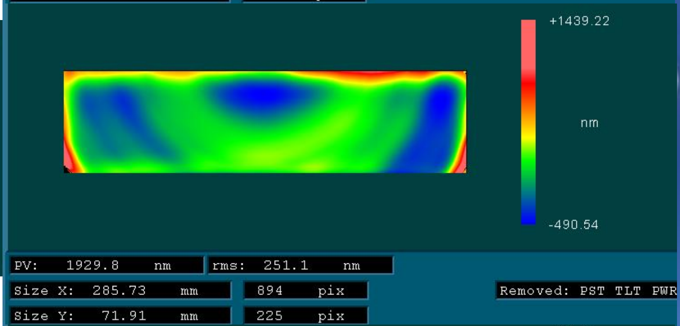
After 2nd Round of Pad/MRF

After 1st MRF FC

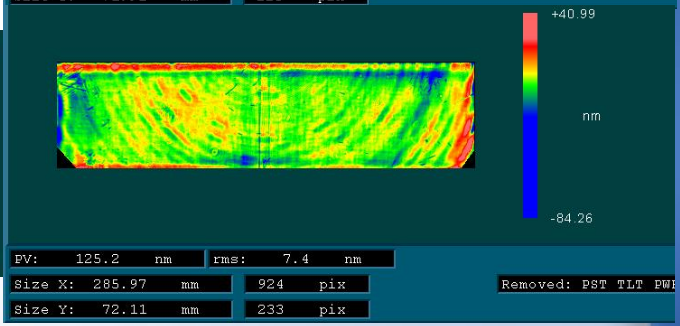


After Additional Pad Polish





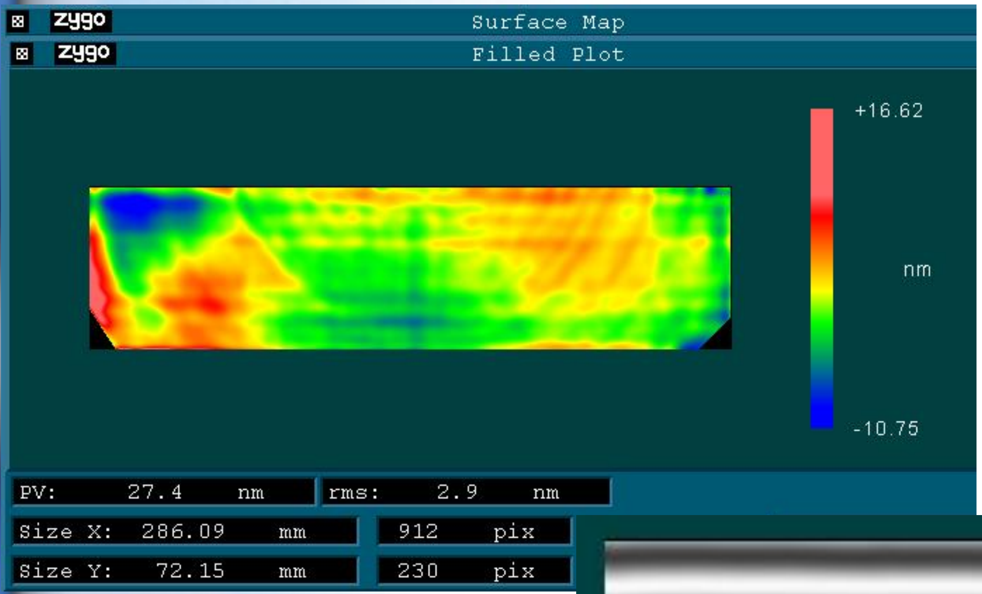
After 2nd MRF FC



Off-axis Component - Final Figure

Final Measurement

(Only Piston, Tilt & Power Removed)



PV = 27.4 nm
(λ/23)
RMS = 2.9 nm
(λ/218)

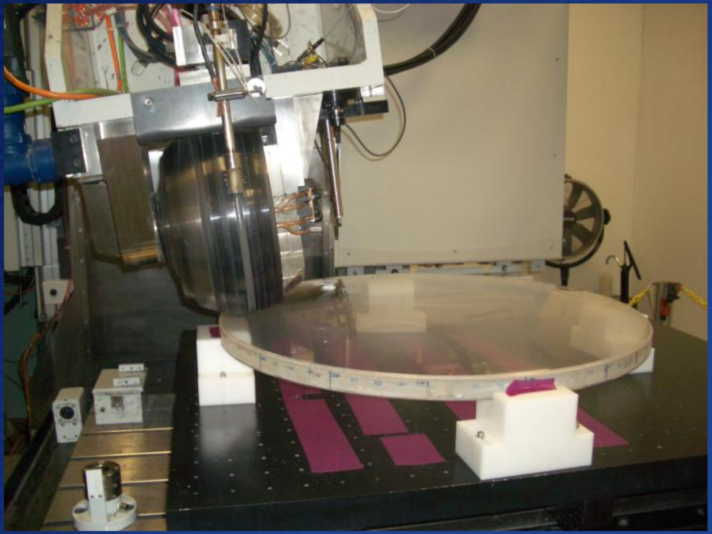
Synthetic Fringes

Summary

❖Methods have been demonstrated to improve the surface figure near edges of large segmented optics using MRF.

❖ MRF platforms have been developed that are capable of polishing 1 meter and larger apertures with freeform geometries.

❖ A pre-polishing process has been implemented on QED platforms to work in accord with the MRF process.



Recent Advances in MRF® Finishing of Large Optics

presented to:
Technology Days in the Government
Mirror Development
July 31-August 2 2007

Andrew Jones, James T. Mooney and Marc Tricard
QED Technologies®

Acknowledgements:
John West, John Hraba
Dr. Philip Stahl
NASA SBIR 03-S2.05-7100

1040 University Avenue • Rochester, NY • USA
Tel: +1 (585) 256-6540 • Fax: +1 (585) 256-3211
mooney@qedmrf.com • www.qedmrf.com

QED Technologies

THE CONFIDENCE FACTOR