MRF® developments & asphere metrology using VON™ Technology

presented to:
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June 7th to 9th, 2010
Boulder, CO

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Acknowledgements:
NASA: Scott Antonille, Dave Content, John Hraba, Phil Stahl, John West …
+ many DoD sponsors
Outline

- Asphere Stitching Interferometry (ASI™)
  - Variable Optical Null (VON™) Technology
- Large optic polishing with MRF®
- New aspheric representation
Asphere metrology typically requires dedicated – and costly – null lenses, which can often be the pacing element in optics manufacturing.

We are reporting here on a – NASA and DoD – SBIR success story in developing a metrology tool capable of:

- Measuring concave or convex surfaces
- Measuring flat, spheres and aspheres
  … *without* dedicated null lenses or tooling
- For both surface measurements and, in some cases, transmitted wavefronts (e.g. flat & dome TWF)
Asphere Stitching Interferometer (ASI™)

- Measure flats, spheres, and on-axis aspheres
  - Diameters up to 200 mm in all cases, up to 300 mm in most cases
  - Slopes up to 90 degrees, i.e. full hemispheres concave or convex

- Aspheric departures up to 1,000 waves (~630+ microns) from best-fit-sphere or more
  - Depends on profile and radius

- Automated part alignment and positioning

- ~1 meter of Z-axis travel for automated radius measurements (using cats-eye + stitching)

- High spatial resolution output maps
  - E.g. (500 x 500) pixels, (1K x 1K), (2K x 2K)...
  - Excellent lateral Frequencies capabilities
  - Important for metrology of Mid Spatial Frequencies, tight Edge Exclusion, quilting errors etc
Variable Optical Null (VON™)

- Counter-rotating optical wedges

- By varying the total wedge angle and tilt, the VON produces low-order aberrations:
  - Astigmatism, coma, trefoil
VON Configurations

No Tilt
No Wedge

Tilt only

Wedge only

Tilt and Wedge

small spherical

mostly astigmatism

mostly coma

coma and astigmatism

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Example: 1,000 Waves Asphere

- 118 mm CA
- 72 mm vertex radius
- 656 micron departure from best fit sphere
- High NA and aspheric departure make this asphere difficult to measure with other techniques
Variable Optical Null (VON) Device

See video…

- Only need to match the low-order aberrations of each subaperture, producing resolvable fringes over entire field
- Combine measurement of residuals with nominal wavefront of VON

Without VON

With VON

<table>
<thead>
<tr>
<th>R = 0 mm</th>
<th>R = 16 mm</th>
<th>R = 31 mm</th>
<th>R = 46 mm</th>
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</thead>
<tbody>
<tr>
<td><img src="1" alt="Image" /></td>
<td><img src="2" alt="Image" /></td>
<td><img src="3" alt="Image" /></td>
<td><img src="4" alt="Image" /></td>
</tr>
</tbody>
</table>
Measurement Results

- Measurement result using 6” F/2.2 transmission sphere
- ~40 subapertures
- ~15 minute measurement time
- Low mis-match error (3.6nm)

Measurement Lattice

rms = 147nm

Mis-match map: rms = 3.6nm
PTB Asphere: Measurement Reproducibility and Repeatability

PTB Asphere - Part Id 014542-725-00
Diameter: 52.2 mm
Departure: 59 µm (93 waves HeNe)
Base radius: 53.312 mm Convex

Comparison of measurement results between 6” F/2.2 and 6” F/3.2

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Std. Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV</td>
<td>1.812 µm</td>
<td>0.028 µm</td>
</tr>
<tr>
<td>rms</td>
<td>0.278 µm</td>
<td>0.008 µm</td>
</tr>
<tr>
<td>R0</td>
<td>53.303 mm</td>
<td>2.3 µm</td>
</tr>
</tbody>
</table>

6” F/2.2
PV = 1.790 µm
rms = 0.278 µm
R0 = 53.308 mm

6” F/3.2
PV = 1.789 µm
rms = 0.279 µm
R0 = 53.303 mm
High Resolution Stitching

2000 x 2000 pixel stitch result using 6” F/3.2
(36 Zernike terms removed to highlight mid-spatial frequencies)

15mm diameter area zoomed to show high resolution
Typical Measurement Times

- **Set-up times:**
  - Standard (known) lens: 1-2 minutes
  - Unknown lens: 4-8 minutes

- **Measurement times:**
  - Flats/spheres: 5-10 minutes
  - Mild aspheres: 10-20 minutes
  - Steep aspheres: 15-30 minutes
  - Depends largely on optimum transmission sphere availability
Current Limitations / Future work

- On-axis (rotationally symmetric) aspheres only
  - Not a fundamental limitation, only current software
  - Very mild off-axis aspheres can be measured now
- No aspheres with inflection points
  - Future versions of the ASI with different VON designs could possibly measure these
- Can measure aspheres with center holes, as long as the central subaperture “sees” some of the part
- Bigger size ASI…
The use of configurable null optics with subaperture stitching allows for:

- Large aspheric departure measurement capability (up to 1000λ)
- Shorter measurement times (fewer sub-apertures)

While maintaining all of the original benefits of subaperture stitching interferometry:

- Full aperture coverage
- Higher lateral resolution
- Increased accuracy
- Aspheric measurements without dedicated nulls
Shape: Hexagonal concave sphere
Material: Pyrex
Diameter: 870 mm
Wavefront specification: $\lambda/40$ rms
Initial wavefront error: $1.5 \lambda$ rms

See talk from John Hagopian and Jason Budinoff at NASA
Many issues with current representation:

- Significant digits?
- Accuracy?
- Difficult to constraint etc.

A more effective alternative ("Forbes Representation") has been developed with orthogonal polynomials. See www.qedmrf.com after 6/15/10 for details…
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