3-D Metrology and Correction of Aspheric Diffractive Optics

ASPE Annual Meeting
Denver
November 17, 2011

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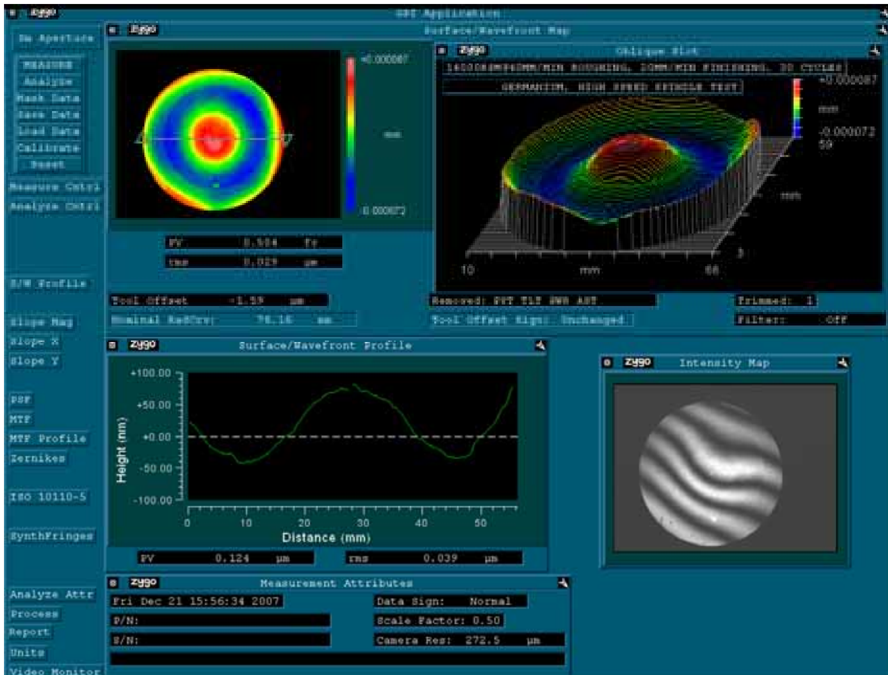
Precitech

Demand for large, thin IR lenses

2-axes diamond turning w/ vacuum chucks



Demand for Large Diffractive Surfaces

Nanoform® 250 Ultra

2-axes up to 4-axes X, Z, C, B

Control Design Features

- **QNX real time operating system**
  - Allow real time process monitoring during part cutting
  - Industry leading 0.01 nm programming resolution
- **Linear holographic glass scales**
  - Industry leading 16 picometer feedback resolution
  - Mounted at the center line of the scale to reduce thermal errors
- **Linear motors coupled to true analog linear amplifiers**
- **On-machine work piece balancing system**

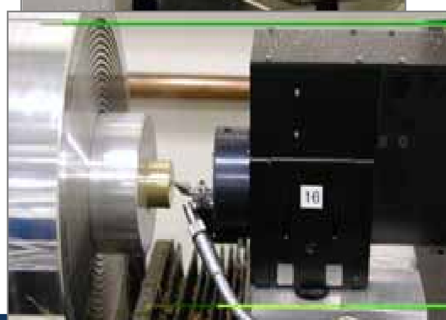
Machine Design Features

- Sealed natural granite base providing exceptionally long term machine tool stability
- FEA optimized dual sub-frames for the ultimate in environmental isolation
- Hydrostatic oil bearing slideways with optimized stiffness and dampening characteristics
- Liquid cooled slides and spindles for thermal stability
- Two standard spindle options to optimize performance for your application

Nanoform® 250 ultra Specifications

Slide Travel X & Z	220 mm	Load Capacity	SP-150 85 kg HS-75 27 kg
Max Feedrate	4000 mm/min	Spindle Speed	SP-150 7,000 rpm HS-75 18,000 rpm
Swing Capacity	250 mm 222 mm optional B-axis	Position Accuracy C-axis Rotary B-axis	+/- 2 arc-sec +/- 1 arc-sec
X&Z Straightness	0.2 µm full travel 0.05 µm/ 25 mm	Max Speed C-axis Rotary B-axis	3000 rpm 50 rpm intermittent

3D Error Compensation using a Fast Tool Servo

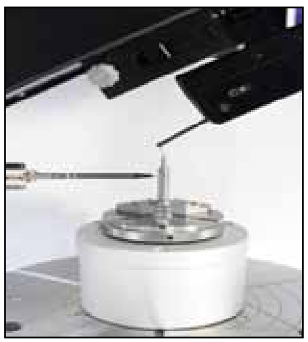


The **Fast Tool Servo** systems enables the diamond turning of surface structures such as *micro prisms, lens arrays, torics and off-axis aspheres with departures up to 1000 microns*

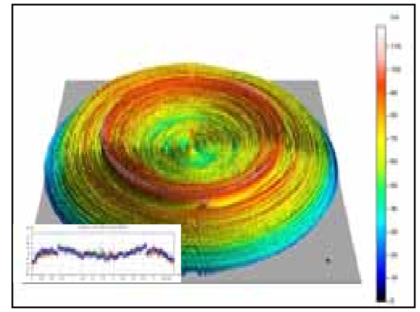
	FTS 1000	FTS500	FTS70
Travel	1000µm ≈119hz 250µm ≈238hz	500µm ≈168hz 250µm ≈238hz 625µm ≈470hz	70µm ≈ 100hz
Maximum Acceleration	278m/sec^2	278m/sec^2	300m/sec^2
Typical Form	<0.6 µm PV	<0.3 µm PV	<0.3µm PV
Typical Finish	<9 nm Ra	<5 nm Ra	<3 nm Ra

Versatile metrology for a large range of optical components

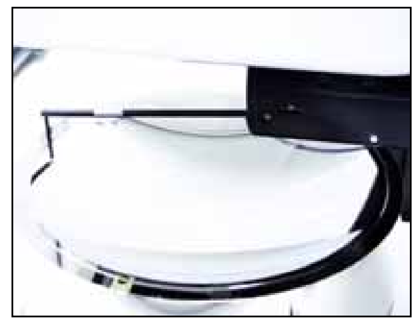
Steep Spheres
& Aspheres



Roundness & Runout



Highly Aspheric
Gullwings



Large Diameter
Asphero-Diffractive

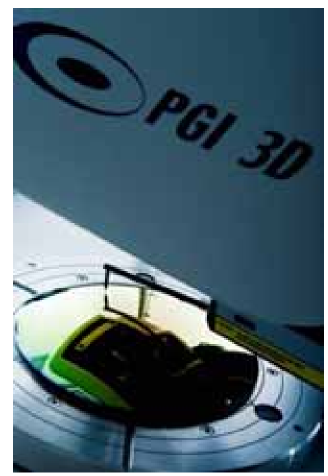
Designed specifically for Optics Manufacturers

Introducing the PGI Dimension range

- The PGI Dimension is the latest in dynamic, flexible, aspheric metrology
- A modular, high accuracy measurement platform
  - adaptable to differing budgets and technical needs
  - Add technology as markets and requirements evolve
- Based on two of Taylor Hobson's core technologies
  - Aspheric profilometry and high accuracy roundness

3D Measurement Capabilities

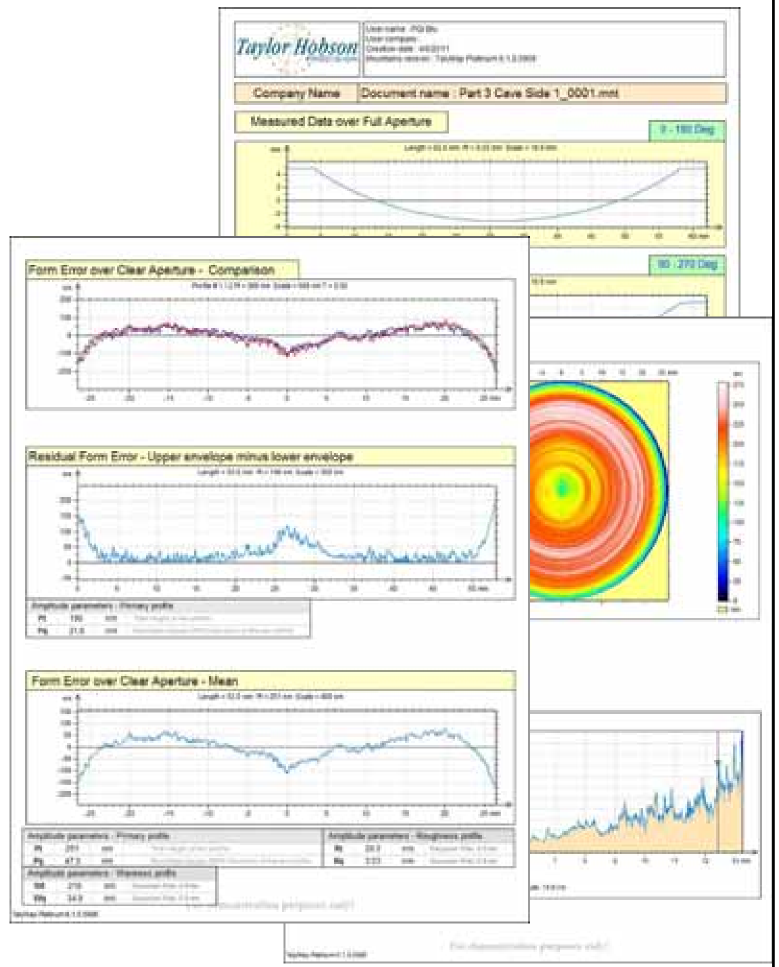
- Accurate measurement of a large range of diameters, sag’s and shapes
- Fast measurement, rapid set up
  - Designed to fit within manufacturing cycle times
- Fully automated operation and simplified user interface
  - Easy to use, reduces operator dependency
- 3D measurement and analysis
  - 3D data feedback for manufacturing process control
- Unique data analysis tools
  - Including Diffractive Zone Analysis
  - Reverse engineering functions



Key Specifications

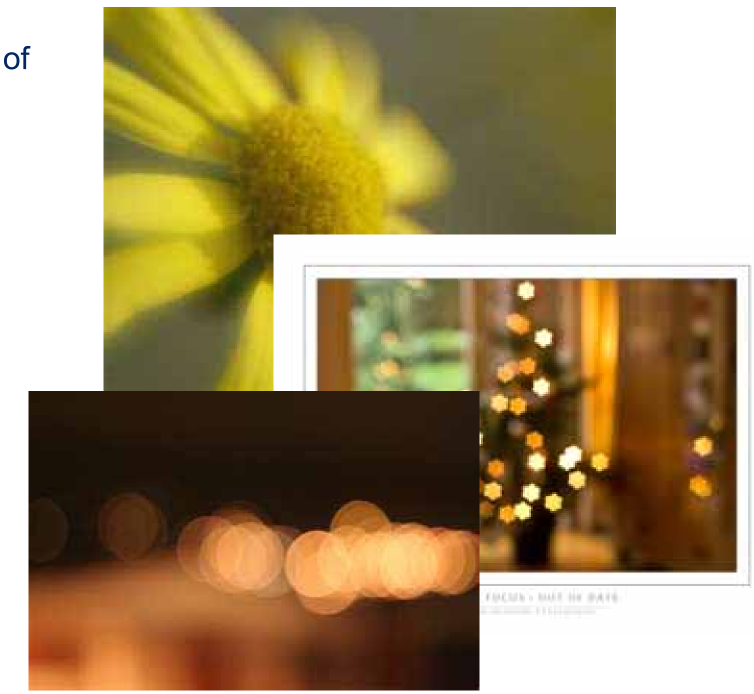
- Measure and analyze a wide range of shapes, sags, slopes and frequencies
  - Slope angles up to 85 deg!
  - Up to 300 mm diameter
  - Sags of up to 50 mm
  - Spatial frequencies from 125nm to 10's of mm's
  - Form repeatability typically <50nm, better than λ/10
  - Extremely low total system noise <3nm RMS
    - Including Gauge noise <1nm RMS
  - Fully automatic alignment of aspheric axis to spindle axis
    - <0.3um of de-centre
    - <0.008 Deg of tilt
  - Fast measurement speed with minimal loss of accuracy

- Advanced analysis tools enable comprehensive parameter reports
  - All form, finish and waviness spectra
  - ISO compliant output



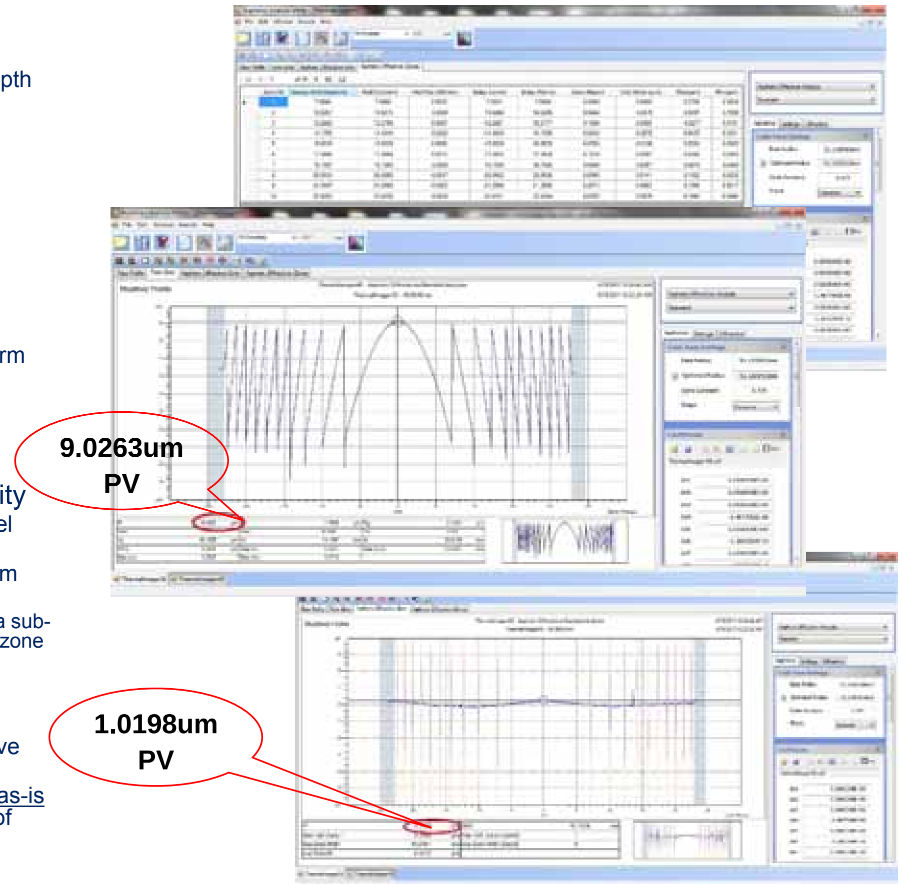
PGI Dimension improves Image Quality

- PGI Dimension can improve the performance of your imaging system
  - Reduces form error, waviness and roughness
  - Low Spatial Frequency (Form Error):
    - Poor focus quality (inadequate correction of spherical aberration)
    - Focal length and position error
    - Field of View and Magnification error
    - Distortion
    - Reduction in MTF (Resolution)
  - Mid Spatial Frequency (Waviness):
    - Directed (narrow angle) scatter
    - Intensity distribution errors
    - Reduction in MTF (Resolution)
    - Halo and ghost effects
  - High Spatial Frequency (Roughness):
    - Diffuse (wide angle) scatter
    - Reduced transmission
    - Background noise



New Analytical Tools

- PGI Dimension and the AAU
  - Ensures the quality of aspheres
  - Save time with instant analysis of form error, zone depth and spacing
  - Closes the loop to the manufacturing process
    - Correction and improvement of form error
- Advanced Asphere Analysis Utility (AAU)
  - Aspheric and diffractive base radius and form error
  - Astigmatism analysis with multiple traces
  - Peak and rms slope error
  - Sag calculator for quick verification of equation
  - Sag table results to show theoretical vs. measured form and slope error
  - Variable filtering and spike removal
  - Optimized radius option
- Unique Diffractive lens form measurement capability
  - Unique patented technology from TH delivers nm level residual form error analysis
  - Diffractive zone depths are usually larger than the form error specifications
    - Taylor Hobson's advanced algorithms can extract a sub-micron lens form error from much larger diffractive zone depth variations
- Derived co-efficient functions
  - Enables reverse engineering of aspheric and diffractive components
  - Feedback to designers an equation representing the as-is manufactured lens (with error) to enable adjustment of critical design systems and improve performance

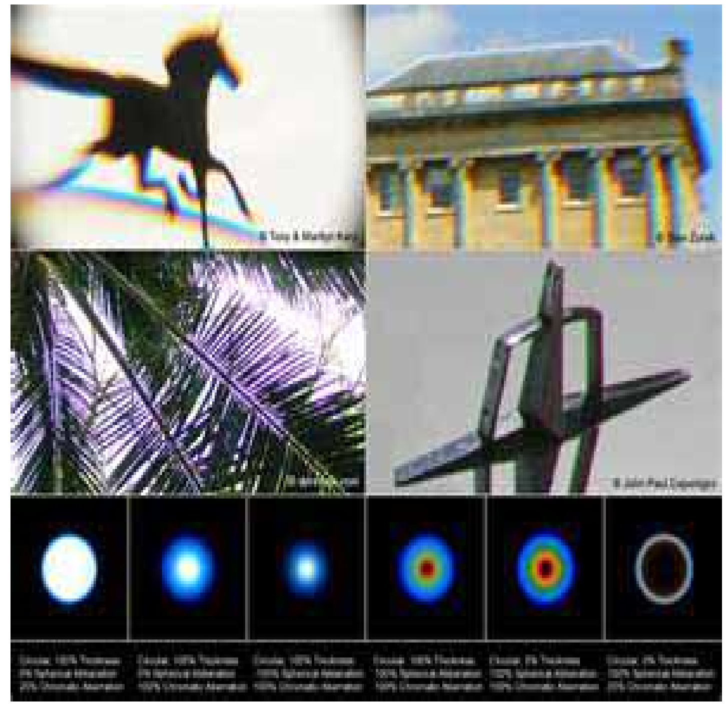


PGI Dimension enables high quality Diffractives

- Reduces Zone Height Errors
  - Transmission losses

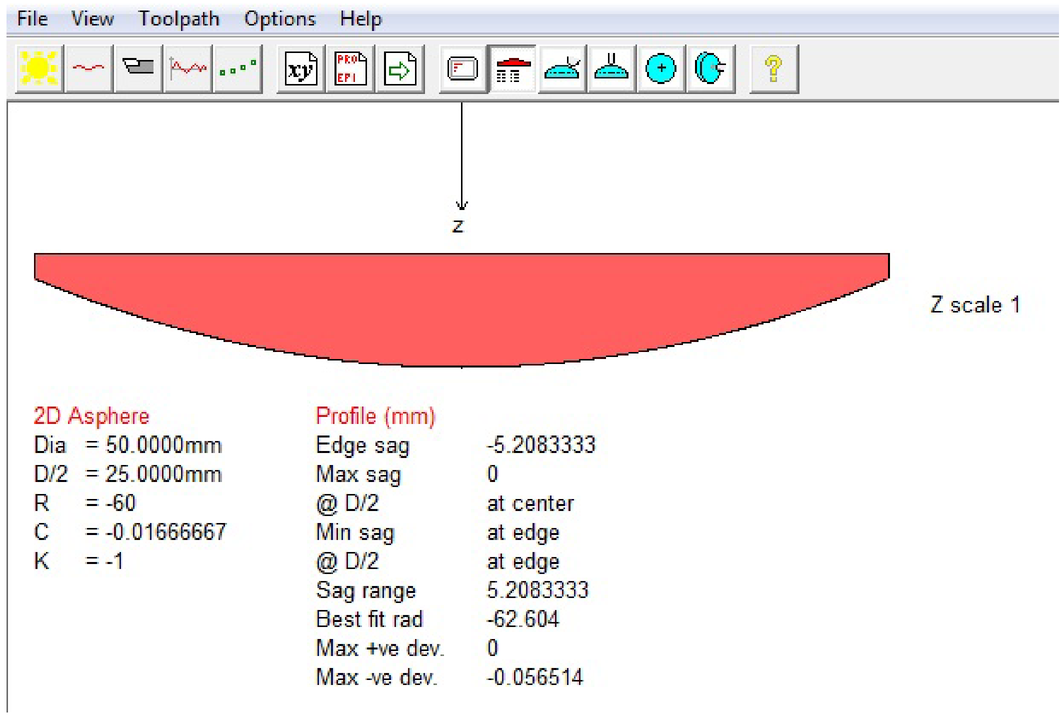
- Reduces Zone Spacing Errors
  - Blurred Focus
  - Band-pass shift
  - Chromatic Aberration

- Improves Zone Sharpness (Shadowing)
  - Transmission losses



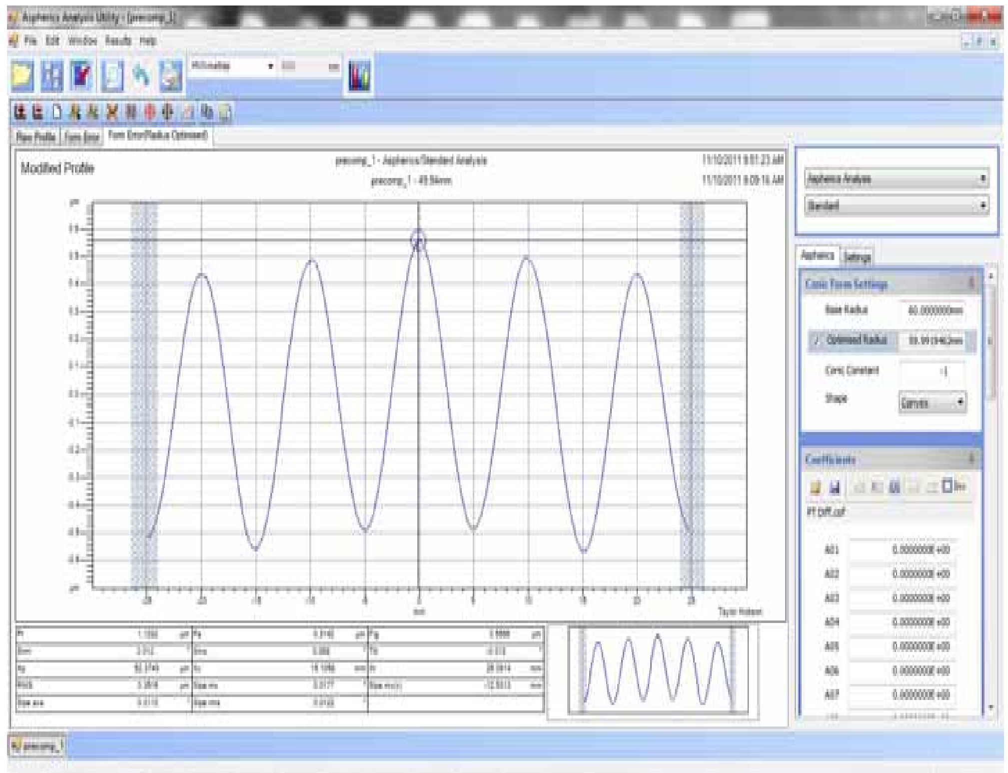
First test case: Axisymmetric CuNi asphere

- 50mm Diameter
- 60mm radius
- K= -1
- .057mm Departure from BFS
- 22.62 Deg of slope



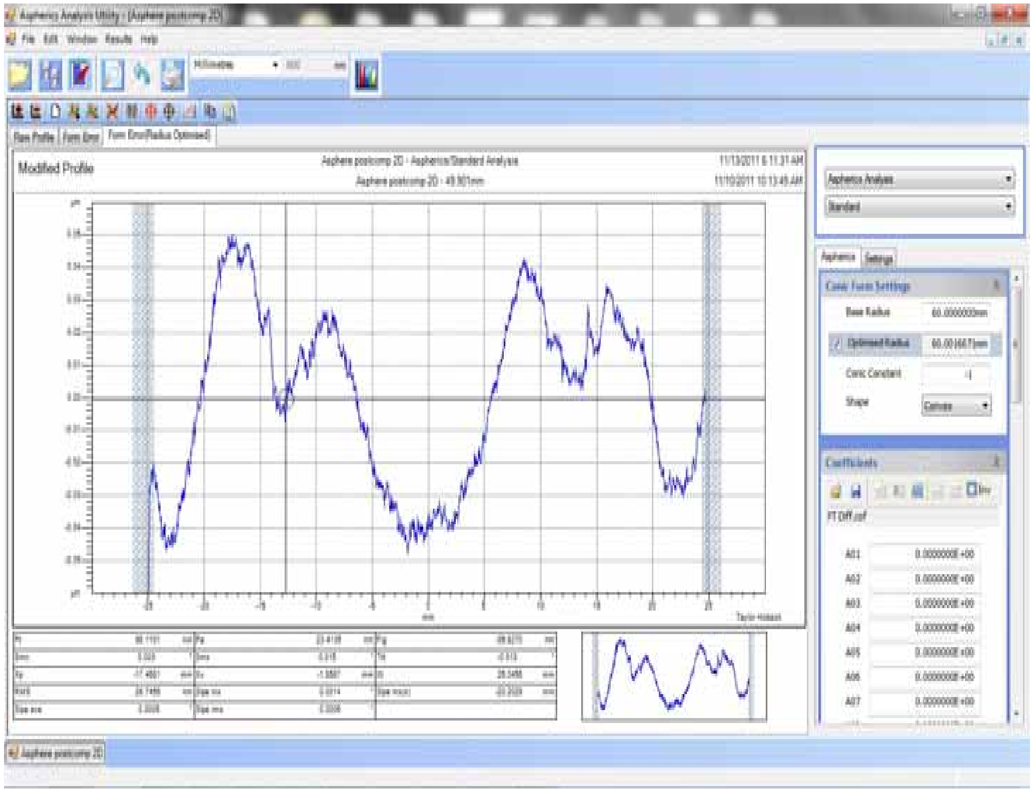
Measurement result of the Asphere

- Form error typical of a wavy tool
- Single PGI trace
- Deviation from ideal asphere
- Pt=1.128um
- rms= .352um
- 80um LP filter was applied



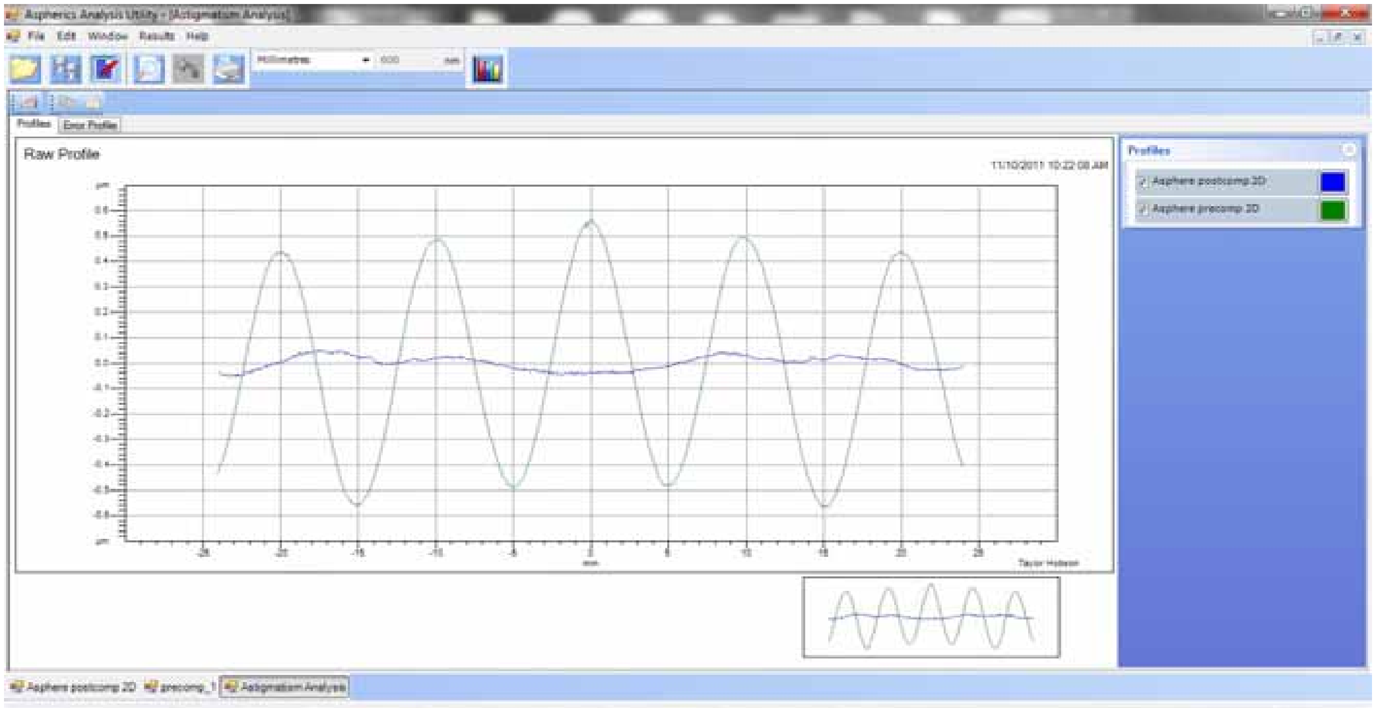
Asphere error post compensation

- Pt=.098um
- rms= .027um
- 48 mm CA



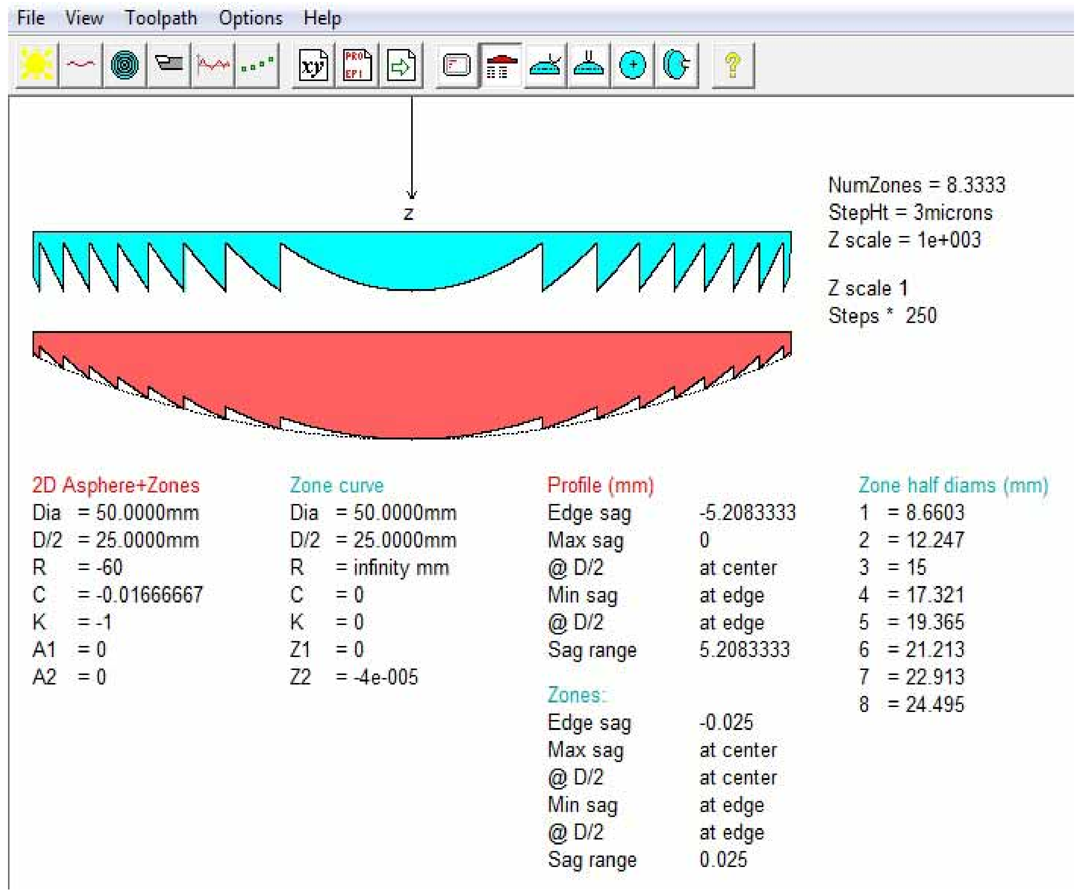
Asphere form error comparison

- Over 10x improvement in form error



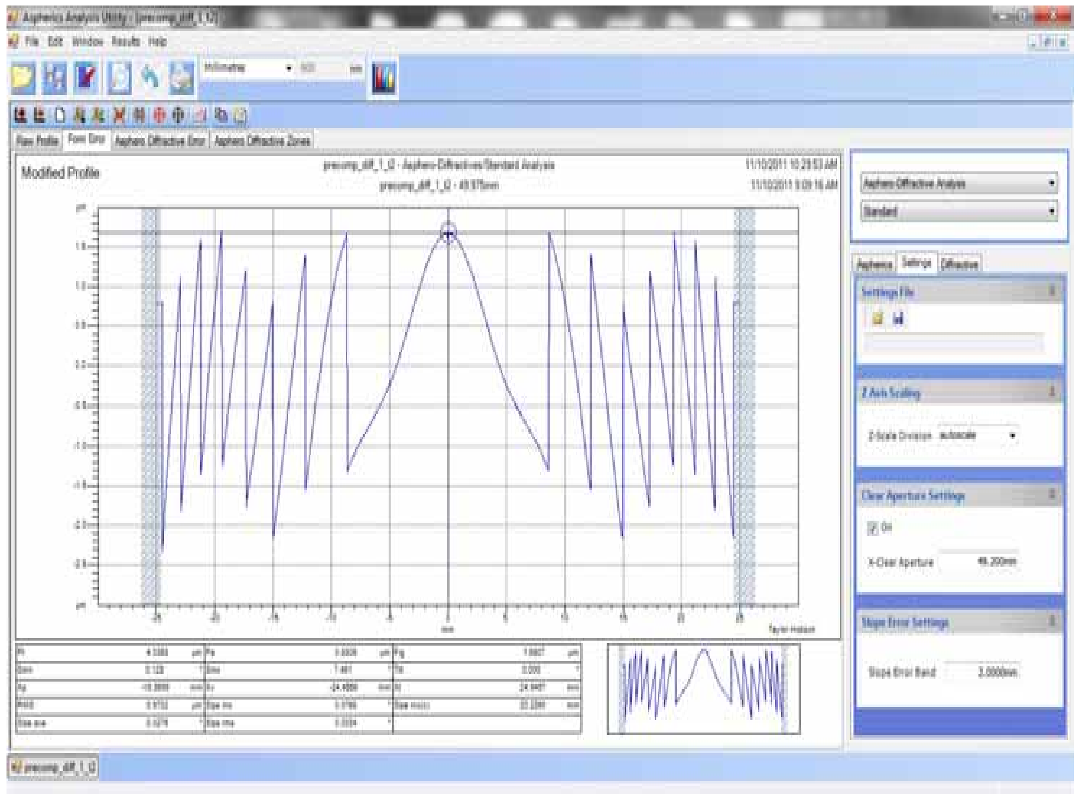
Second test case: Axismmetric Diffractive

- 60mm convex radius
- K= -1
- Diffractive coefficient -4e-5
- 3um Step Size
- Programmed using DIFFSYS



2D Diffractive Measurement

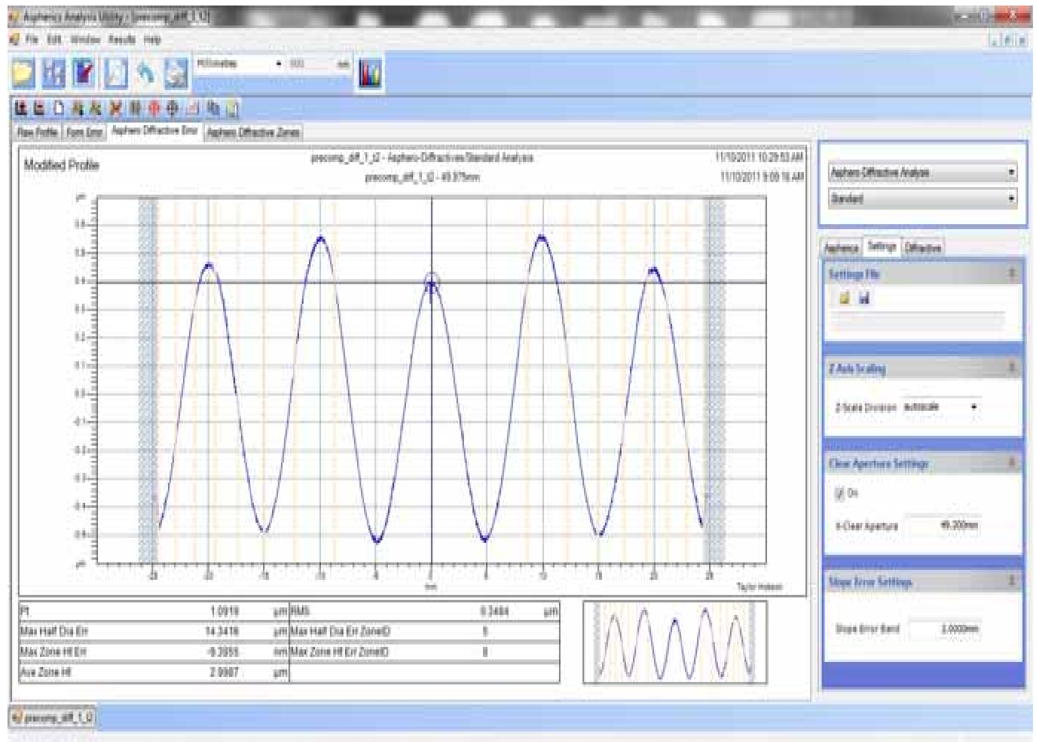
- Single PGI trace
- 1micron sine wave super imposed on the base asphere
- Residual error from base asphere



Diffractive Residual Form Error

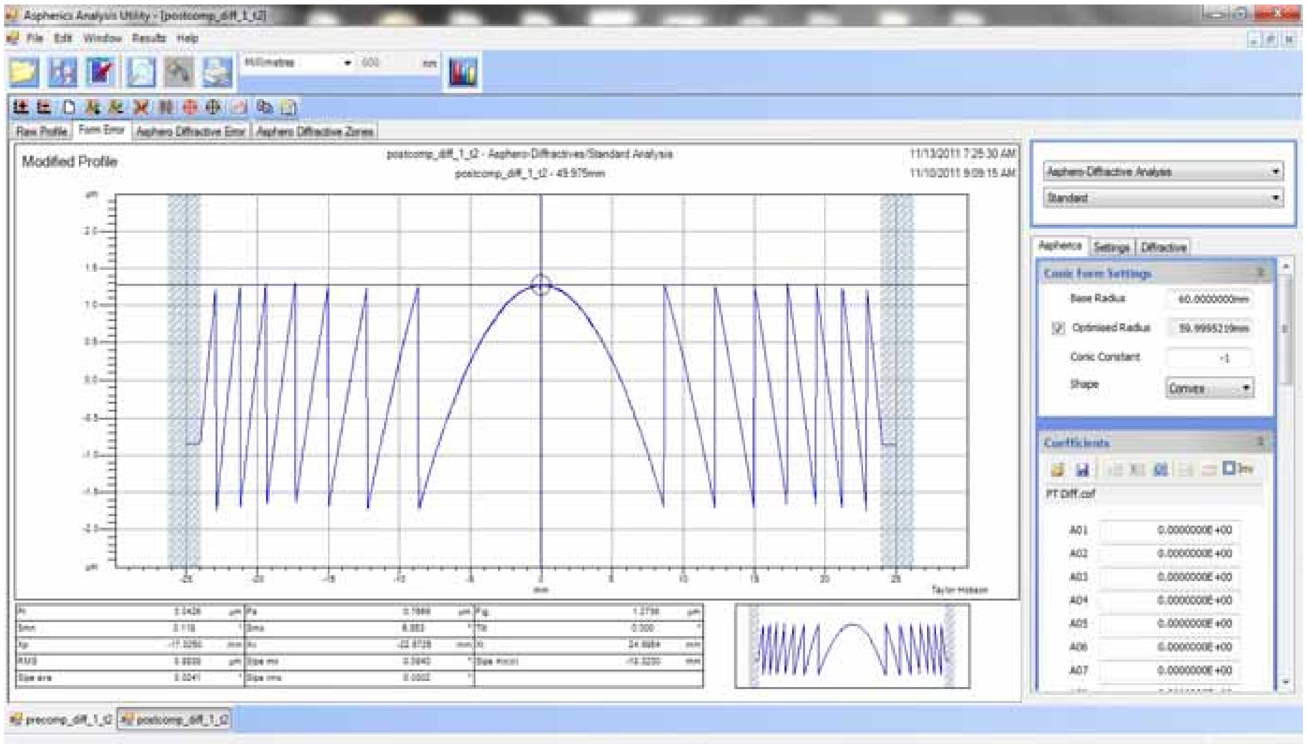
- Residual error from base asphere and diffractive of 1 micron

- Tool showed roughly a 200nm zone in center



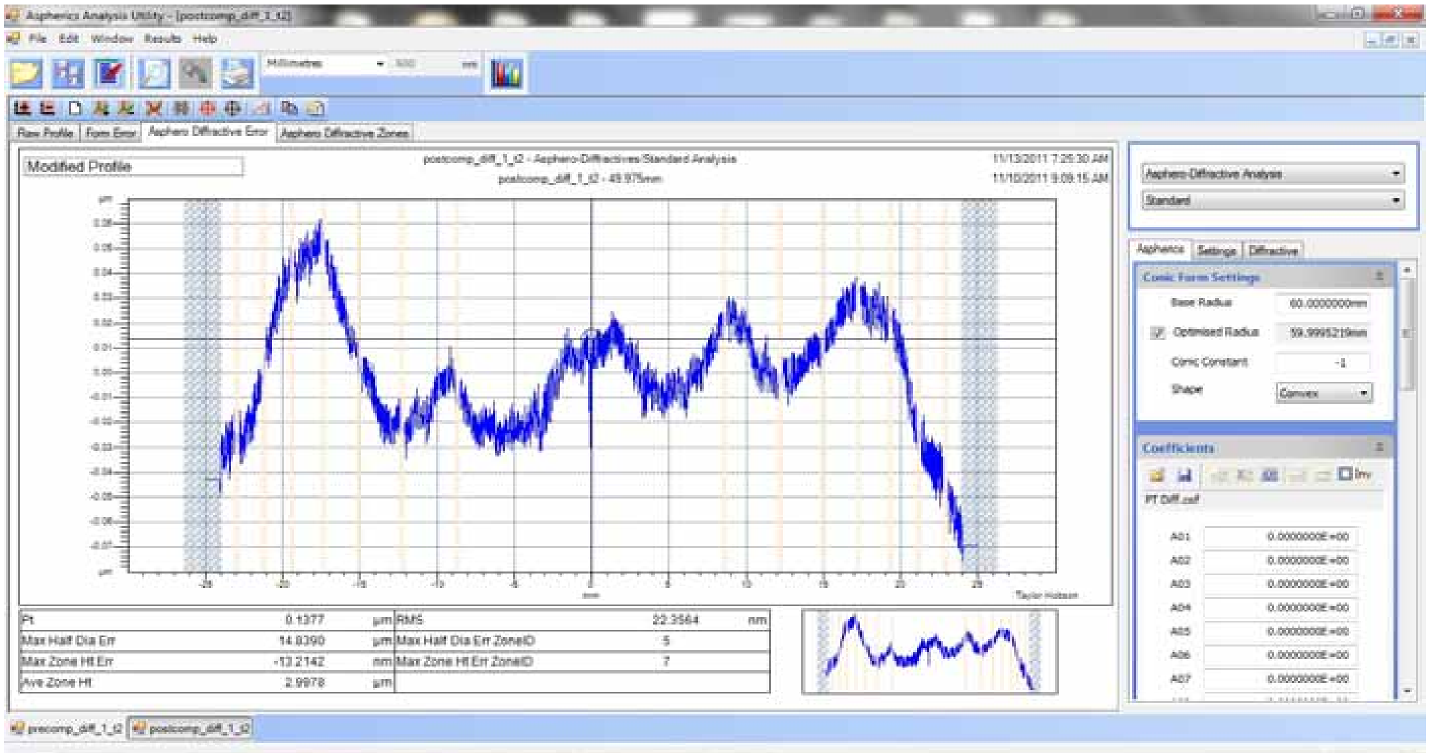
Diffractive Post Compensation with Asphere Removed

Pt = 3.043 microns. Nominal step height is 3 micron.

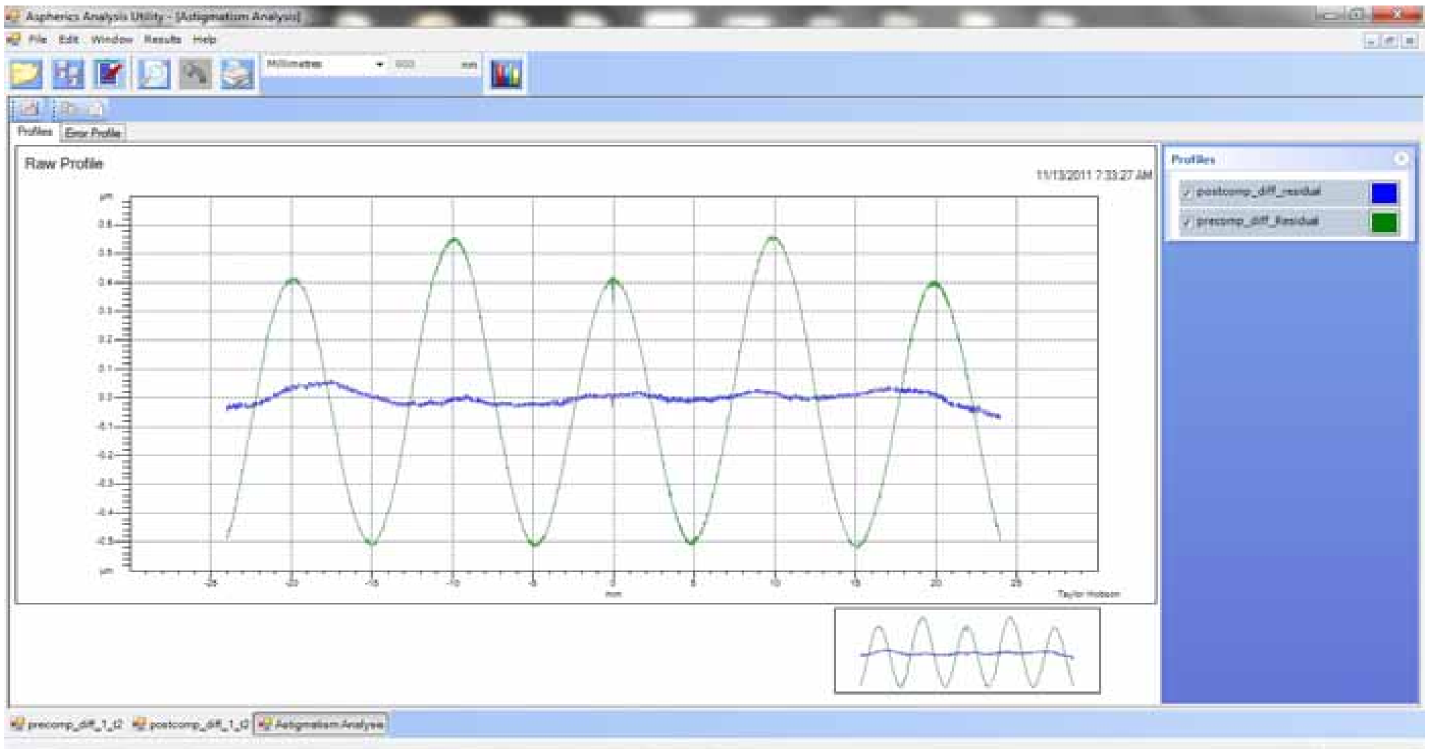


Diffractive Post Compensation Residual Error

- 8x improvement in form error without any filtering

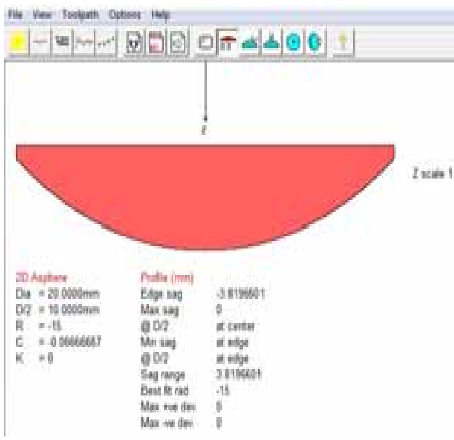


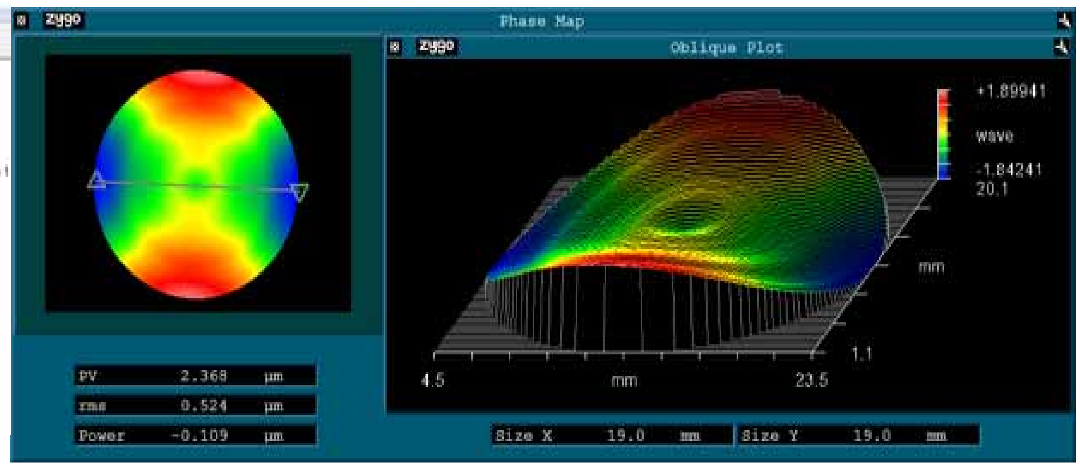
DIffractive Pre-compensation versus Post Compensation



Third test case: Sphere with Astigmatism

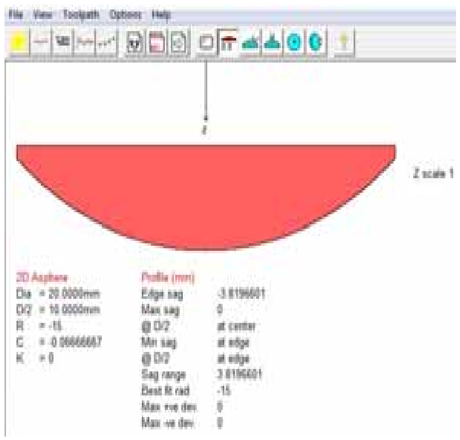
- 20 mm diameter convex brass sphere w/ 15mm radius
- Max slope of 42 Deg
- Cut with Fast Tool Servo at 3000 RPM
- Pt= 2.368 microns
- Measured with an interferometer
- Lateral calibration assumed fringes continued to the diameter
- Camera resolution of 320 X 240





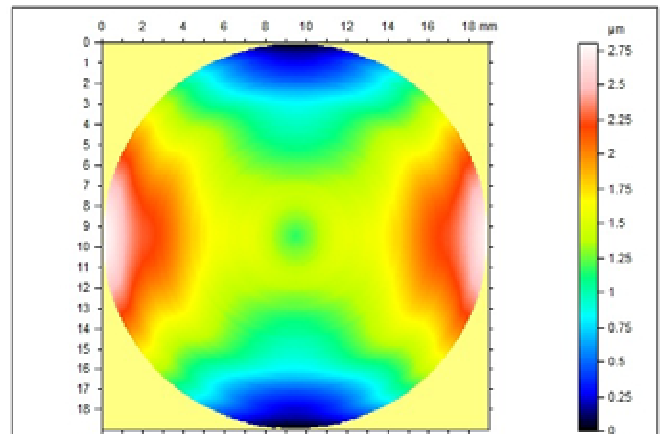
PGI 3D Measurement of Sphere (Radial and Sag)

- Traces taken every 45 Deg
- 19mm CA used with 80 um LP filter
- P-V from PGI 3D (Radial/ Surface normal) matches Zygo within 24nm
- It is important to note that the measurement error analysis should be relative to the machine axis



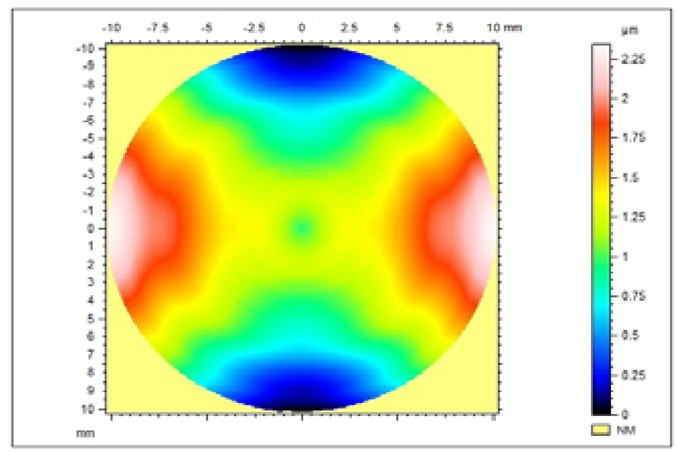
3D Astigmatism

ISO 25178		
Height Parameters		
Sz	2.799	µm
Sq	0.543	µm



3D Astigmatism

ISO 25178		
Height Parameters		
Sz	2.344	µm
Sq	0.507	µm

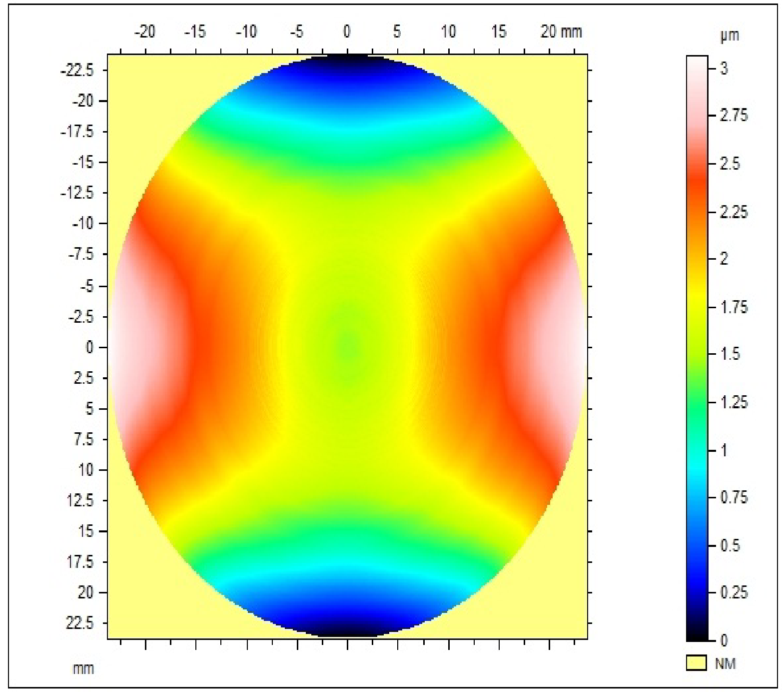


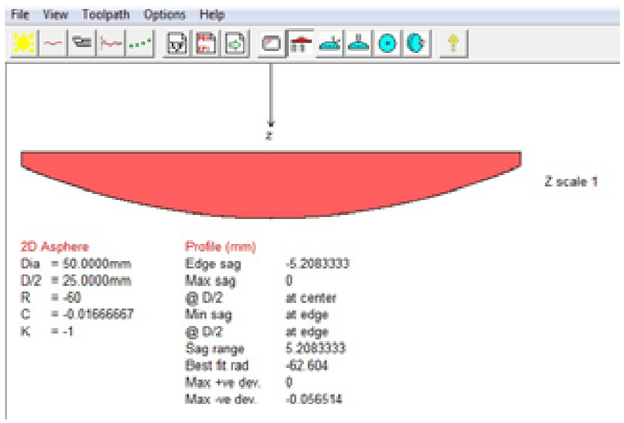
Fourth test case: Asphere with Astigmatism

- PGI 3D measurement Asphere Pre-compensation
- Case 1 asphere with 3 microns of astigmatism
- Astigmatism was cut with Fast-tool servo using DIFFSYS and FastCom software.
- Traces taken every 45 Deg

3D Astigmatism

ISO 25178		
Height Parameters		
Sz	3.066000	µm
Sq	0.629611	µm



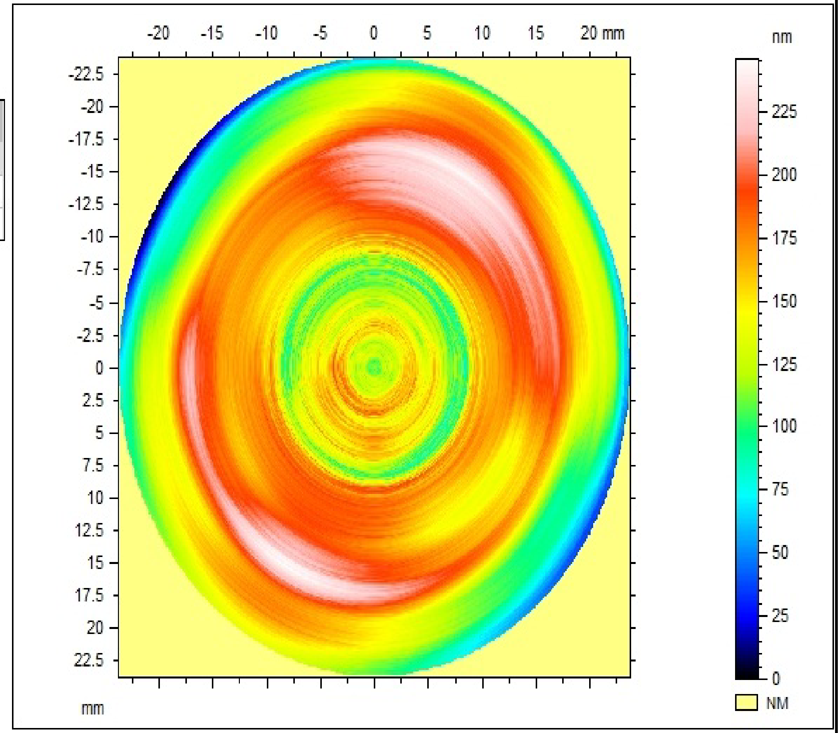


Asphere Correction Results

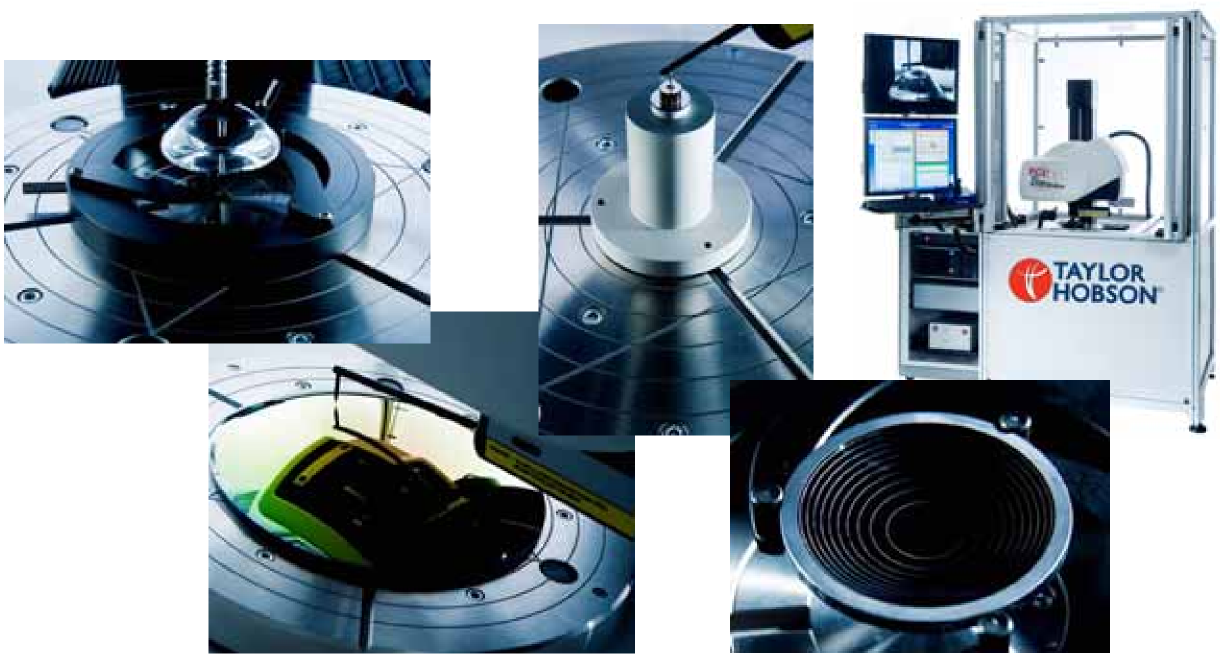
3D Astigmatism

ISO 25178		
Height Parameters		
Sz	245.999999	nm
Sq	41.411050	nm

- PGI 3D error map was feed back into FastCom software to create correction program
- 12x improvement in Form-error on the first attempt!!!



PGI Dimension



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