6-AXIS ULTRAFORM FINISHING PLATFORM
A-AXIS CONFIGURATION

Mirror Technology Days 2016
Greenbelt, Maryland

OptiPro Systems, LLC
Ontario, NY 14519

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Presented by: David Mohring
NASA SBIR Contracts

NASA Contract Number: NNX16CM33P– Phase I
Title: UFF Mandrel Fabrication Enhancement
COTR: Roy Young @ MSFC
Fabrication of Freeform Conic Mirrors and Mandrels

OptiPro Systems, LLC
Ontario, NY

INNOVATION

The UltraForm Finishing (6-Axis UFF) and the UltraSurf platforms developed by OptiPro Systems deterministically polish and measure complex aerodynamic and conformal mirror shapes made of difficult to manufacture glass, crystal and ceramic materials.

ACCOMPLISHMENTS

◆ 2008 OSA – Paul Forman “Excellence in Engineering Award” for first affordable Computer Controlled Optical Machining Center.

◆ Optical fabrication companies and prime contractor suppliers are embracing the new technology to cost effectively manufacture axisymmetric domes and optics for newly designed defense systems. The technologies developed under the SBIR contracts have provided a cost effective manufacturing solution for DoE, DoD, MDA and NASA components.

◆ The integration of the UFF (CNC controlled finishing platform) and the UltraSurf (Automated non-contact measurement device) provides a deterministic fabrication solution for a wide range of newly developed windows, domes and mirrors.

COMMERCIALIZATION

◆ UltraForm Finishing (UFF) : Asphere, Axisymmetric Dome, Freeform Polisher
  • Private Sector installations at Universities, Material manufacturers and Precision optical component manufacturers

◆ UltraSurf : Non-Contact Asphere, Axisymmetric Dome measurement platform
  • Private Sector Asphere and Dome Measurement System for production

◆ Primary market focus is on companies engaging in the optical fabrication and measurement of spherical domes, aspheres, parabolic mirrors, torics and conformal/freeform shapes.

◆ Private sector investment into the UFF and UltraSurf platforms has been through Beta site partners and production level machine purchases.

◆ OptiPro Systems, LLC has alliances with material manufacturing firms who require new manufacturing techniques to test and enhance their prototype components and determine the pathway to production level quantities.

GOVERNMENT/SCIENCE APPLICATIONS

◆ NASA Contract Numbers NNX12CF49P, NNX14CM21P

◆ NASA NNX13CM02C (SBIR 2011-II) (MSFC)

◆ DOD Contract Numbers W31P4Q-05-C-R048 and W31P4Q-04-C-R101 awarded by the Defense Advanced Research Projects Agency (DARPA); and Contract Numbers N41756-05-M-1390, N68936-06-C-0010 and N68936-09-C-0079 awarded by the Navy Engineering Logistics Office and NAVAIR.

◆ Toric, Acylinder and other freeform geometric shapes made from Si and SiC.

◆ Freeform reflective mirror applications for the Department of Energy

◆ Materials Include : Spinel, ALON™, CeraLumina™, Si, SiC, ceramics, Fused Quartz & standard optical glasses
Outline

- Optical Surface Definition
- Grinding / Diamond Turning
- UltraForm Finishing
- UltraSmooth Finishing
- Software Tools
- Polishing Process
- Surface Metrology
- Nickel Plated Surface Finishing
Complex Optical Surfaces

- Off-Axis Aspheres
- Torics
- Aspheric Cylinders
- Parabolics
- Freeforms and Conformal Optics
Surface Definition

- **Mathematical Equation**
  - Basis functions
  - Zernike polynomial
  - Q Polynomial

- **Wireframe model**

- **Solid model**

- **Cloud of points**

- **Mandrel definition ...**

\[
\begin{align*}
r &= \sqrt{h_0^2 + 2k y - py^2} \\
z &= \sqrt{r^2 - x^2}
\end{align*}
\]

\(r\) is the radius of the surface at any given \(y\) coordinate, \(h_0\) is a constant equal to 425 mm, \(k\) is a constant equal to -3.844346977 mm, \(p\) is a constant equal to -3.0810743x10\(^{-04}\)
Manufacturing Tools

- Deterministic Grinding (DMG)
- UltraForm Finishing (UFF)
- UltraSmooth Finishing (USF)
• OptiSonic 3X: 3-axis ultrasonic machining
• OptiSonic 5X: 5-axis ultrasonic machining
UFF Features

- Wheel size range 6 to 100 mm in diameter
- Wheel nominal hardness range from 30-80 Shore A
- Bound/fixed abrasives or commercial polyurethane belts with slurry
- Capable of finishing a wide range of materials from optical glass to hard ceramics to sub-micron form tolerances
Measure Removal Function

- Integrated STIL pen
- Onboard metrology

Input Initial Figure Error

- Zygo Interferometer Input
- Profilometer Input

Optimize Polishing Tool Path

- Reduce figure error
- Fine control of polishing path

UFF
USF

- Prepare part for UFF correction
  - Lower stock removal will leave less signature
- Smooth MSF post UFF

  - Tool design allows for high compression in vertical direction and possesses great torsion stiffness
  - Tooling's compliant layer can be configured with different stiffness materials.
  - Ideal tool design for USF high-pressure, high-speed polishing setup
6-Axis UFF @ MSFC

- X,Y,Z linear axis
- A,B,C Rotary Axis
- Tool Rotation motion control
- Work Piece motion control
- Freeform capabilities
- Tool normal -> Surface
- Full CNC Control
- Optical Fabrication software
- Bound and loose abrasives
- Deterministic / corrective
UFF 300 Platform @ MSFC

The initial platform design was configured with an axis orientation required to polish a rectangular 250 mm x 250mm fused quartz mandrel. The current setup of the 6-axis machine has the A and B axes both on the head with the tool. The useable travel on the x-axis is roughly 430 mm and the usable travel on the y-axis is roughly 315 mm.
New 160A(sphere) vs. Triumph
Tasks

1. Design table mounted precision CNC rotary A-Axis.
2. Rotary Axis and work holding fixture component manufacture and purchase.
3. A-Axis Assembly and Test with calibration standards and measuring equipment.
4. UFF UltraWheel toolpath development incorporating the varied axis configurations.
5. A-Axis Motion Control / Orientation optimization on the CNC test platform at OptiPro.
7. UFF Tooling & Fixture Setup and Design of experiments (DOE) detailed.
8. Nickel Plated Aluminum Mandrel Polishing Test with required measurements as detailed in DOE.
9. MSFC Group A ART-XC Mandrels approximate dimensions of 2 inch diameter and 27 inch long.
### Work schedule, milestones, and deliverables

**Detailed Phase I work schedule, milestones, and deliverables**

**Phase I June 10, 2016 to December 9, 2016**

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<th>Task #</th>
<th>Description</th>
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Table Mounted Rotary Axis
XZ Orientation “A-Axis”
YZ Orientation “B’-Axis”

The 2 Rotary axis orientations (Along X-axis and then Along Y-axis). The resultant mandrel surface will be measured and analyzed for form errors and mid spatial frequency errors. Process parameter requirements determined.
Aluminum Mandrel Test Piece

Actual mandrel lengths can extend to 630 mm in length with an average diameter of 100mm.

Proposed work piece size for initial tests shown below....

The x-ray optics module alignment station used for the FOXSI project
A-Axis Motor

- Outer Labyrinth
- Inner Labyrinth
- Motor Mount Plate
- Aerotech ADRT
- Top Plate
- Precision Ground Angle
- A-Axis Mount Plate
A-Axis Bearing/Integral Motor Assembly
Part Mounting
Part Mounting

- The part fixture is trammed with the A-Axis motor top plate.
- Shoulder bolts are threaded through the part fixture and into the mandrel to lock rotation.
- The tailstock is then positioned so that the live center puts pressure on the mandrel, securing it in place using tapered features on both ends.
Nickel Plated Mandrel
Ni Plating USF Initial Results

- Silica, Alumina, Diamond Abrasives
- Polish Tool pad materials: Polyurethane, Suba, Felt
- Initial Zygo NewView Surface roughness:
  - PV: 769 nm  RMS: 347 Angstroms
Ni Plating USF Latest Results
APOMA
American Precision Optics Manufactures Association

TUCSON TECH WORKSHOP
NOVEMBER 10th-11th

Don’t miss your chance to:

- Learn new technologies and manufacturing tips
- Hear the latest industry insights
- Connect with leaders of the optics community

BONUS: Attendee’s will be able to tour the University of Arizona Richard F. Caris Mirror Laboratory
There are many challenges to manufacturing acylinder and freeform optical components, but Don’t Panic!

- OptiPro continues to develop technologies in Grinding, UFF, UltraSurf, and ProSurf to deterministically fabricate precise complex optical surfaces.