Eliminating Mid-Spatial Frequency (MSF) Errors with VIBE Finishing

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June 8, 2010
NASA Mirror Technology Days
Outline

• Introduction
  – Mid-Spatial Frequency (MSF) Errors
  – VIBE Technology
• Characterization of MSF Errors
• MSF Error Removal with VIBE
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What is “mid-spatial frequency”?

Figure is the range of spatial frequencies addressable with a simple Zernike expansion.


Finish (a.k.a “gloss” or “roughness”) is typically less critical as it results in total transmission loss.

Mid-Spatial Frequency bandwidth limits help to define the MSF itself

\[ a = (\lambda \text{OPL}/10)^{1/2} \]

Example: Spoke and Spiral Errors

Unfiltered data

PV: 179.9nm
RMS: 28.6nm

PV: 152.8nm
RMS: 26.3nm

Low spatial frequency

PV: 41.9nm
RMS: 4.8nm

Mid-spatial frequency

PV: 17.1nm
RMS: 0.6nm

High spatial frequency

VIBE Process is a high-pressure, high-speed, full aperture polishing process.

Optic slowly oscillates while in contact with vibrating lap.

Full-aperture, conformal lap vibrates at high frequencies.
VIBE testing station provides platform for pad/slurry experimentation

- VIBE removal rate studies
- In-process testing of polishing pads
- Variable pressure and speed
Vibe linear motion with over-stroke

Animation speed and motion has been exaggerated for viewing purposes.
VIBE originally intended for pre-polishing glass spheres and aspheres

In just 10 minutes…

– Remove 10μm
– Improve surface figure
– Improve surface roughness by 100x
The role of VIBE in modern optical manufacturing processes

- **a) Traditional**
  - Conventional Grinding/Lapping
  - Conventional Pitch Polishing

- **b) CNC**
  - CNC Generate
  - Pre-polish using conventional polishing methods
  - Interferometric Measurement
  - Deterministic Figure Correction

- **c) CNC and VIBE**
  - CNC Generate
  - VIBE Pre-Polish
  - Interferometric Measurement
  - Deterministic Figure Correction
  - VIBE Finish
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Characterizing MSF Errors

• Implemented three different ways to visualize MSF errors

  – Power Spectral Density
  – Zernike Residual RMS
  – Slope Error
Power Spectral Density (PSD)

- Deviation from straight line
Power Spectral Density (PSD)

- Deviation from straight line

MSF errors occurring between 0.5 and 3mm periodicity due to sub-aperture polishing method.
Residual RMS and Slope data
Implemented for initial inspection

Pitch Polished Surface

Sub-aperture Rotationally Polished Surface
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Implementing VIBE to remove MSF errors

• Currently 4 months into Phase I

• Examining different compliant mediums to determine optimum polishing pad composition
  – Material
    • Borosilicate glass
    • Initial surface – sub-aperture figure correction of plano surface

• Only remove nanometers of material
  – VIBE finishing step completed in less than 60 seconds
We have examined many different types of compliant polishing pads with mixed results.
We have been able to reduce the appearance of MSF errors with VIBE.

Initial Sub-Aperture Polished Surface

Surface After 60-second VIBE Finishing
PSD data shows that VIBE finishing can reduce MSF errors.
Conclusions and Future Work

- VIBE finishing can reduce the appearance of MSF errors on flat rotationally polished surfaces

- Continued work on eliminating MSF errors
- Future work: extend technology to spheres, cylinders, aspheres and conformal optics
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INNOVATION

The Optimax VIBE process is a full-aperture, conformal polishing process incorporating high frequency and random motion to eliminate mid-spatial frequency (MSF) errors created by deterministic polishing in a VIBE finishing step while maintaining low spatial frequency form accuracy.

ACCOMPLISHMENTS

◆ Currently in Phase I SBIR – Development Stage
◆ VIBE finishing has been shown to reduce the severity of MSF errors
◆ We have incorporated repeatable interferometric methods to characterize MSF errors

COMMERCIALIZATION

◆ Optimax VIBE™ Technology
◆ U.S Patent Number 6942554 B1
◆ Primary target applications: Optical imaging systems where small angle scatter would reduce performance quality
◆ Optimax currently provides high precision optics to the aerospace, defense, medical and imaging markets, VIBE technology will enhance our capabilities
◆ Current customers are designing all spherical optical systems due to Asphere manufacturing limitations (MSF errors)
◆ MSF errors are formed during deterministic sub-aperture polishing processes. MSF errors cause small angle scatter and flare in optical systems.
  ◆ VIBE Finishing will eliminate these undesirable MSF errors

GOVERNMENT/SCIENCE APPLICATIONS

NASA:

◆ X-Ray Telescopes:
  ◆ IXO – slumping mandrels, produce surfaces less than 1.4nm rms between 2-20mm spatial frequency range.
◆ Exo-Planet Imaging Systems:
  ◆ Minimize scatter on primary and secondary mirrors, specifically less than 1nm rms in 4-50 cycles/aperture range

Non-NASA:

◆ High Energy Laser Systems, EUV Optics (Lithography), Imaging Systems and X-Ray Synchrotron Optics

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