Overview of full-shell approach

Optics for X-ray Surveyor workshop, March 2016
Outline

• Error Allocation
• Process flow
• Replication
• Direct Fabrication
• Pros and Cons
• Zeeko experiments
• Post-fabrication correction
• Mounting and Alignment
## Error Allocation

<table>
<thead>
<tr>
<th>Requirement</th>
<th>0.5</th>
<th>0.20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Margin</td>
<td>0.66</td>
<td>0.20</td>
</tr>
<tr>
<td>Pointing jitter</td>
<td>0.28</td>
<td>0.14</td>
</tr>
<tr>
<td>Vibrational Effects</td>
<td>0.13</td>
<td>0.07</td>
</tr>
<tr>
<td>Defocus error</td>
<td>0.01</td>
<td>0.007</td>
</tr>
<tr>
<td>Launch shifts</td>
<td>0.13</td>
<td>0.07</td>
</tr>
<tr>
<td>Thermal effects</td>
<td>0.15</td>
<td>0.075</td>
</tr>
<tr>
<td>Gravity release</td>
<td>0.1</td>
<td>0.05</td>
</tr>
<tr>
<td>Epoxy effects</td>
<td>0.13</td>
<td>0.07</td>
</tr>
<tr>
<td>Shell-to-shell misalignment</td>
<td>0.24</td>
<td>0.12</td>
</tr>
<tr>
<td>Installation errors</td>
<td>0.24</td>
<td>0.12</td>
</tr>
<tr>
<td>Reflector pair</td>
<td>0.70</td>
<td>0.38</td>
</tr>
<tr>
<td>Surface slope error</td>
<td>0.18</td>
<td>0.10</td>
</tr>
</tbody>
</table>
Replication
Pros and Cons

**Replication**

**Pros:**
- One mandrel for multiple shells (if multiple modules)

**Cons:**
- Simplified alignment, especially if the shell has monolithic structure
- Relatively stiff – less complicated support structure, less obscuration, less weight for support
- Less susceptible to residual stresses (if any) in coating based corrections

**Direct fabrication**

**Pros:**
- Low density
- Chandra-like resolution is doable
- If metal - Taylor the alloy to match CTE, the telescope structure can be done from the same material – simplifying thermal design, less epoxy

**Cons:**
- Nickel – higher density
- Replication process – need for stress

**Limit on diameter ~ 2 meters**
Direct Fabrication
Technique is pioneered by the Astronomical Observatory of Brera, Italy

Coarse and Fine Grinding → Figuring → Super-polishing → Ion Figuring

X-ray test at PANTER:
- low-frequency errors: 6”
- mid-frequency errors: 13”
- out-of-roundness error: 5.3”
- the optical axis tilt between segments: 8.9”

Potential
Direct Fabrication

- Diamond turning
- Figuring
- Super-polishing
- Differential Deposition

Whiffle tree station with an aluminum shell supported at 12 points.

A metrology fixture to support the mirror shell during the skip test.
Direct Fabrication Post-fabrication Correction methods

Coating stress and magnetic materials
Melville P. Ulmer (Northwestern University)

Differential Deposition
Kiranmayee Kilaru (USRA, MSFC)
David Windt (Reflective X-ray Optics, LLC)

Ion Figuring (Brera Observatory, Italy)
### Mechanical Properties of Potential Mirror Substrate Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Density (g/cm³)</th>
<th>CTE (10⁻⁶ / K⁻¹)</th>
<th>Elastic Modulus (GPa)</th>
<th>Yield Strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fused Silica</td>
<td>2.2</td>
<td>0.5</td>
<td>72</td>
<td>48*</td>
</tr>
<tr>
<td>Beryllium</td>
<td>1.8</td>
<td>12</td>
<td>318</td>
<td>240</td>
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<tr>
<td>BeAL-162MET</td>
<td>2.1</td>
<td>24</td>
<td>69</td>
<td>276</td>
</tr>
<tr>
<td>AlSi</td>
<td>2.8</td>
<td>13.9</td>
<td>193</td>
<td>314</td>
</tr>
<tr>
<td>Duralcan F35.30S AlSi+SiC(30% by vol)</td>
<td>2.8</td>
<td>14.6</td>
<td>120</td>
<td>210</td>
</tr>
</tbody>
</table>

*Maximal achievable value. The ‘working’ value is typically much less and depends on the surface/subsurface condition.

Ideally, the mirror shell has low density, low coefficient of expansion (CTE), high modulus of elasticity and high yield strength. It should also be a material that is not too difficult to figure and polish.

- Be + NiP (CATS-ISS telescope)
- BeAl +NiP
- AlSi + NiP

**Direct Fabrication**

Additional Benefits of metal substrate:
- Less joints – less epoxy error
- Thermal design could be simplified
Zeeko machine

- The machine utilizes a “bonnet” technique in which an inflated rubber hemispherical diaphragm supports the polishing medium.
- There are different “bonnet” sizes (20 mm, 40 mm and 80 mm radii of curvature)
- This computer-controlled deterministic polishing processes leads to a high convergence rate.

<table>
<thead>
<tr>
<th></th>
<th>before</th>
<th>after</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure error (St. Dev.)</td>
<td>500 nm</td>
<td>10.7 nm</td>
</tr>
<tr>
<td>Slope error (&gt; 2 cm) cm(RMS)</td>
<td>6.32 arcsec</td>
<td>0.30 arcsec</td>
</tr>
<tr>
<td>Low frequency (&gt; 7 cm) slope error (RMS)</td>
<td>2.66 arcsec</td>
<td>0.09 arcsec</td>
</tr>
<tr>
<td>Mid frequency (2-7 cm) slope error (RMS)</td>
<td>5.73 arcsec</td>
<td>0.29 arcsec</td>
</tr>
</tbody>
</table>
Alignment

Shell can be supported from one end

The use of the clips (FOXSI – 2007) minimizes the distortions due to epoxy shrinking

There is a “sweet spot” the influence on the angular resolution performance is minimal

Strings approach – XMM

Equalizing the strings tension in azimuthal direction

CDA or UV
Conclusions

• To meet the stringent angular resolution requirements for the X-Ray Surveyor Mission all the error contributors should be addressed;

• Full shell approach could be viable option for inner mirrors of the X-ray Surveyor;

• Direct fabrication technique has potential to meet the angular resolution requirements;

• Post-fabrication and post-assembly figure correction provides an additional venue to meet the requirements.