Hard and Soft X-ray Mirror System Design Status

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.
Mirror system testing & final design drawings are nearly complete

- Prototype tests focused on two high technical risk areas:
  - Measuring & maintaining HOMS tangential figure
  - Measuring & maintaining HOMS pointing stability
- Requirements have been demonstrated for both these areas
HOMS and SOMS share a common design approach: HOMS requires a few additional features

- Chamber & mirror
- Pointing & centering
- Installation alignment plates
- Support Pedestal
- Vacuum Chamber
- Rotation spindle & drive cam
- Translation slide
- Tunable bending force
- Invar mount
- Si Mirror
- Chin guard
- HOMS bender for real time figure control
Figure errors predicted by analysis have been verified in prototype tests

- Figure budget limits “power” imparted upon reflection

<table>
<thead>
<tr>
<th>Mirror Flatness Requirement</th>
<th>Figure error budget, nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axis</td>
<td>&quot;Best Fit&quot; Radius, km</td>
</tr>
<tr>
<td>HOMS/ SOMS Sagittal</td>
<td>&gt;3</td>
</tr>
<tr>
<td>SOMS Tangential</td>
<td>&gt;188</td>
</tr>
<tr>
<td>HOMS Tangential</td>
<td>&gt;2600</td>
</tr>
</tbody>
</table>

- Finite element analysis guided design optimization

- Mirror figure stability after 150 nm bend: +/- 1 Cº room air
SOMS mirror #1 tangential (horizontal) figure has been measured (transmission flat correction not yet applied)
We recently calibrated our interferometer transmission flat

- Zygo does not calibrate the horizontal axis of “large” transmission flats (TF)
  - requires rotating a TF about the horizontal, which could break glass/epoxy bond
  - by design, 12” TF mounting cell design precludes this rotation

- Our horizontal calibration was done using two TF’s & the un-silvered side of an RF
  - a reflection flat (RF) mounting cell allows all three rotations (no glass/epoxy bond)

Vertical Calibration

Horizontal Calibration
Algorithm for calibrating the horizontal axis of large flats

- Convert File3(x)→File3(-x) and solve for T1(x), T2(x), R(x):
  \[ T1(x) = \frac{1}{2}[F1(x)+F2(x)-F3(-x)] \]
  \[ T2(x) = \frac{1}{2}[F1(x)-F2(x)+F3(-x)] \]
  \[ R(x) = \frac{1}{2}[-F1(x)+F2(x)+F3(-x)] \]

- The systematic error from RF weight reversal can be evaluated
  \[ \text{Check} \]
  \[ \text{Error}(x) = F4(-x)-T1(-x)-R(x) \]
  \[ \text{and double check} \]
  \[ \text{Error}(x) = F5(x)-T2(-x)-R(x) \]
Effect of ground motion amplification on pointing stability has been addressed

- Pointing jitter was noticed on our first HOMS prototype

- Motion amplification was measured with accelerometers
  - rms amplification relates to mean square acceleration $S(f)$ by:
    \[
    \frac{\langle x_{\text{top}} \rangle_{\text{rms}}}{\langle x_{\text{ground}} \rangle_{\text{rms}}} = \sqrt{\frac{S_{\text{top}}(f)}{S_{\text{ground}}(f)}}
    \]
    \[
    \approx 150 \text{ at } 20 \text{ Hz}
    \]

- The final design corrects this problem
The final design fundamental frequency is over 80 Hz

• Modes calculated by a finite element model

<table>
<thead>
<tr>
<th>Mode</th>
<th>Hz</th>
<th>% Mass participation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>1</td>
<td>27</td>
<td>66</td>
</tr>
<tr>
<td>2</td>
<td>32</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>80</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>97</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>100</td>
<td>12</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mode</th>
<th>Hz</th>
<th>% Mass Participation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>1</td>
<td>83</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>83</td>
<td>64</td>
</tr>
<tr>
<td>3</td>
<td>190</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>249</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>313</td>
<td>5</td>
</tr>
</tbody>
</table>

Amplitude “scaling” for mode $f_n$

$$\langle x \rangle_{rms} = \left[ \frac{\pi f_n S(f_n)}{\zeta} \right]^{1/2}$$

Here, $\zeta$ is damping, and $S(f_n)$ is stiffness.
Temperature induced pointing error has been measured and controlled

(1) Beam pointing drift $< 10\%$ of diameter required during experiments:

- $d\theta = 90 \text{ nrad}$ for HOMS
- $d\theta = 900 \text{ nrad}$ for SOMS

(2) Temperature dependence of mirror pointing has been measured: (next page)

- $d\theta/dT \cong 300 \text{ nrad/0.1 °C}$

∴ Temperature stability $< 0.03 \text{ C}$ required for HOMS

(3) The challenge: to demonstrate closed loop stability $< 0.03 \text{ C/week}$

- $0.01 \text{ C}$ demonstrated in an insulated enclosure around our prototype
Pointing error $\Delta \theta / \Delta T$ was measured with our prototype

Chiller control +/- 0.1 C

Uncorrelated drift was the basis for replacing struts with adjustable plates

Strut assembly

Rotation assembly: 70 nr/0.1°C

Translation stage: 300 nr/0.1°C
Pointing stability has been demonstrated in a thermal enclosure

• Heat balance: \[ q_{\text{fan}}(t) = q_{\text{wall}} + q_{\text{floor}} \approx c_{\text{wall}}[T_{\text{in}}(t) - T_{\text{out}}(t)] + c_{\text{floor}}[T_{\text{in}}(t-1\ \text{hr}) - T_{\text{floor}}(t)] \]
  \[ dq_{\text{fan}}(t) \approx -c_{\text{wall}}dT_{\text{out}}(t) \]

• Control parameters: \[ T_{\text{set}} = 21.5^\circ C \]
  \[ q_{\text{max}} \approx 15 \text{ Watts} \]

\[ \Delta T_{\text{in}} < \pm 0.03^\circ C \]

\[ \Delta \theta \]

\[ T_{\text{set}} \]

\[ T_{\text{out}}(t) \]

\[ q(t)_{\text{fan}} = \frac{V(t)^2}{R} \]

\[ T_{\text{in}}(t) \]

\[ q_{\text{wall}} \]

\[ q_{\text{floor}} \]

\[ T_{\text{out}}(t) \]

\[ T_{\text{set}} \]

\[ q_{\text{fan}} \]

\[ T_{\text{in}}(t-1\ \text{hr}) \]

\[ c_{\text{wall}} \approx 1 \text{ W/}^\circ \text{C} \]

\[ c_{\text{floor}} \approx 7 \text{ W/}^\circ \text{C} \]

\[ 40 \text{ kg} \]

\[ 400 \text{ kg insulated pedestal} \]

\[ 1 \text{\hspace{1cm} 2 \hspace{1cm} 3 \hspace{1cm} 4 \hspace{1cm} 5} \]

\[ \Delta T_{\text{in}} < \pm 0.03^\circ C \]

\[ \Delta \theta \]

\[ T_{\text{out}} \]
Summary of a mirror system “traveler”

LLNL clean rooms → LLNL B141 assembly area → Ship → FEE

Optics shop
- Measure figure
- Coat mirrors
- Mount mirrors
- Figure adjustment
- Install mirrors into chamber

Coating facility
- Assemble components on pedestal
- Connect cables
- Set limit switches
- Operate motors
- Mount chamber on pedestal
- Operational acceptance test
- Mirror survey inspection

Operational acceptance test
- Ship assembled pedestal

Install, align, & grout pedestal
- Ship mirror Inside chamber

Install & precision align chamber
- Install bellows & connecting beam tubes
- Remote operation acceptance test
- Mirror to mirror alignment
- Install thermal enclosures
- Align to exp. stations

FAC meeting
June 17, 2008
Tom McCarville
mccarville1@llnl.gov
Tasks remaining this FY:

- Complete ESD, fabrication drawings, & final review – August
  - calculate survey installation coordinates

- Measure & coat SOMS mirrors – in August

- Bid and award fabrication drawings – Sept.
  (1) chamber
  (2) pedestal & slide plate assembly
  (3) mirror mount & chin guard assembly
  (4) cam assembly