Primary Mirror Interface Including Safety Clips

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Safety Clip System Outline

- Puck Bond Tests
- Safety Clip System
- Flexures and Mounting Bracket
- Experienced System Forces
- Applied Loads
- Fabricated Components
- Safety Factors and Margin of Safety
- Instillation Procedure
- Bonding Procedure
- Final Procedure
- Monitoring System
- Conclusion
Puck Bond Test Results

• **Purpose**
  – To determine if Dow-Corning Q3-6093 silicone RTV puck bonds will perform adequately over the 10 year design lifetime of the collimator under worst-case axial tension loading (55 lbf).

• **Safety Clip System Implication**
  – Design Features:
    • The safety clip system will completely offload the lateral (shear) force on the collimator puck bonds in ~180 days. This prevents *shear* creep-rupture of the bond.
    • The puck bonds must still resist *axial* forces because the safety clip system cannot offload these forces.
      – The puck bond axial forces are due to the “overturning moment” of the primary mirror. The worst-case axial tension is 55 lbf for pucks bonded to the “top” area of the mirror back plate. (Note that pucks bonded to the “bottom” area of the back plate see a complimentary of ~55 lbf axial compression).
      – With the safety clips, the worst-case load on the puck bonds is now 55 lbf axial tension. This force must be resisted for the 10 year collimator lifetime requirement.
Requirements

• Summary of requirements

  – The Maximum Stress in the glass must be less than 100psi.
  – The Safety Clips need to hold 5X the maximum load experienced by the load spreader.
  – The Safety Clip System is necessary to meet the 10 year perspective delivery lifetime.
  – The Safety Clip System CTE must match the Mirror CTE.
  – The Safety Clip System must be compatible with the vacuum being pulled in the Delta Chamber.
  – All Stainless Steel hardware and or tapped and clearance holes must be vented.
  – RTV used for Bonding of the clips must be Q-36093
    • Viscous
    • Relatively compliant
    • Strongest in shear
  – Invar CTE Certification to match Analysis
Safety Clip System
Flexures and Safety clip mounting bracket
Safety clip forces

F_{vert} = 144\text{lb}

F_{vert} = 280\text{lb}
Applied loads on the Clip and Flexure

P = 280 lb.

R1 = 50 lb.

R2 = 50 lb.
Safety Clip System Components

Safety clip

Safety clip flexure

Mounting block flexure

Safety clip rod
## Safety Factors and Margins of Safety

<table>
<thead>
<tr>
<th>Part</th>
<th>Safety Factor</th>
<th>Margin of Safety</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety Clip</td>
<td>4.22</td>
<td>0.3</td>
</tr>
<tr>
<td>Flexures</td>
<td>4</td>
<td>0.22</td>
</tr>
<tr>
<td>Rod</td>
<td>25.2</td>
<td>0.88</td>
</tr>
<tr>
<td>Hardware</td>
<td>4.27</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Lotis Yield Factor of Safety $= 3$
Lotis Ultimate Factor of Safety $= 5$

- See the Technical Data Package for Analysis of the Primary Mirror Safety Clip System
Safety Clip System
Special Triple Load Spreader Application
Installation Procedure

- Alignment procedure
  - Design and fabricate an alignment jig using nylon for positioning the safety clips before applying the bonding material and tensioning the turnbuckles on the safety clip rods.
Bonding Procedure

- PTFE Spacer used on the top of the clip to achieve the correct thickness of bonding material 0.040” DOW Q36093.
- Steel shim and fish line used on the bottom of the clip to achieve the correct thickness of bonding material 0.040” DOW Q36093.
- PTFE Fish line used on the hole I.D. to achieve the correct thickness of bonding material 0.040” DOW Q36093.
- Rods coupled to the clip and snugged up to a torque value of 10 oz-in. 0.040” DOW Q36093
Final Procedure

- After the bonding material has cured in place
- Un-Torque the safety clip rods
- Remove the PTFE spacer from top of the safety clip.
- Remove the Fish line from the bottom of the safety clip
- Remove the Fish line from the hole I.D. of the safety clip
- Re-torque the safety clip rods to 10 oz-in
Load cells

• Load cells added to 4 locations of the mirror to monitor forces in the safety clip system.
• Will determine when the puck forces have relaxed to 94% of the load.
Conclusion

- Puck Bond Tests establish a need for an Auxiliary Support System.
- The Safety Clip System meets all of the requirements desired.
- Analysis has been performed and is complete.
- The Design is finished, and is ready for fabrication.

Schedule
References

- Blain Olbert, “LMSSC-MSO LOTIS COLLIMATOR PROJECT, MIRROR PUCK BOND & RTV TESTING, STATUS REPORT & RESULTS SINCE 03/04/03 GROUP TELECON,” PowerPoint Summary, 04/25/03, File: LOTIS_PUCKTEST_UPDATE_03.ppt
- Blain Olbert, “LMSSC-MSO LOTIS COLLIMATOR PROJECT, MIRROR PUCK BOND & RTV TESTING, STATUS REPORT & RESULTS SINCE 05/01/03 GROUP TELECON,” PowerPoint Summary, 04/25/03, File: LOTIS_PUCKTEST_UPDATE_04.ppt
The thermal characteristics of the primary are derived from detailed model of a typical group of cells.
Thermal Conductance With Clips

- Adding load spreaders and clips to the thermal model increases the net conductance by 1%

<table>
<thead>
<tr>
<th>Gradient Direction</th>
<th>No pucks or loadspreaders</th>
<th>Add Loadspreaders and Clips</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Btu/hr/F</td>
<td>Btu/hr/F</td>
</tr>
<tr>
<td>Top to Bottom</td>
<td>4.4407</td>
<td>4.4407</td>
</tr>
<tr>
<td>in plane A</td>
<td>4.6836</td>
<td>4.7245</td>
</tr>
<tr>
<td>in plane B</td>
<td>4.6836</td>
<td>4.7368</td>
</tr>
<tr>
<td>Change</td>
<td></td>
<td></td>
</tr>
<tr>
<td>in plane A</td>
<td></td>
<td>0.87%</td>
</tr>
<tr>
<td>in plane B</td>
<td></td>
<td>1.14%</td>
</tr>
</tbody>
</table>
Stress plot, 50.4 lb reaction inside core

Max principal stress = 54.9 psi
FEM element plot (green elements are ¼”, blue are ½”)

Steward Observatory Mirror Laboratory
Supported on Pucks
WF = 30.6 nm-rms after optimization

Supported on Pucks and Straps. WF = 30.08 nm-rms after optimization.
Calculation of Load Change Over Time

• Load Relaxation in the pucks
  – The Invar rod expansion rate is 0.38 $\mu$in/day
    – Jacobs, S. F. gives 0.019 ppm/day *20” long rod = 0.38 $\mu$in/day
  – The puck creep rate is 164.17*(Puck Load/420)$^{1.157}$ $\mu$in/day
    – From Blain Olbert’s test results at 45% humidity
    – At 10% nominal load the puck creep rate is 11 u/in/day
      » This is much larger than the Invar expansion so the puck unloads.
      » At 0.5% (0.005) of nominal load puck creep matches the Invar expansion.
  – A spreadsheet was used to calculate the change in puck/clip load sharing over time.
Calculation of WF Change Over Time

- **WF Distortion Change due to puck load relaxation.**
  - Calculated the zenith to horizon mirror deflections
    - With the pucks carrying 30% of the load (elastic load sharing)
    - With the pucks supporting none of the vertical load when horizon pointing.
  - The difference between these two cases is the distortion change due to complete puck load relaxation. This was:
    - 904 nm-rms WF if only focus correction performed
    - 45 nm-rms if focus, astigmatism and coma are corrected (baseline)
    - 35 nm-rms if a 16 mode (Hartman) correction is made.
  - Since the clip load changed by 147 lbs in generating the WF errors above, the baseline relation between distortion change and clip load change is $45/147 = 0.31$ nm-rms/Lb
  - The distortion change is calculated from the clip force change and integrated over time to obtain the effect of puck load relaxation.
WF Distortion, Clip and Puck Loads Over Time

- Standard Size Pucks with 2 mm bonds (LS compliance Incl.)
- Creep rate at 80 °F, 40% RH used.
WF Distortion, Clip and Puck Loads Over Time

- Effect of adding Load Cells, Load spreader Compliance is Included.

Comparison of WF Change With and Without Load Cells. Load spreader Compliance is Included

![Graph showing comparison of WF change over time with and without load cells.]
Axial Loading on Pucks

- Creep Strain verses Stress:
  \[
  \frac{d\varepsilon}{dt} = 31.71 \times 10^{-6} \sigma^{1.157}
  \]
  - Creep strain rate is per day
  - Stress is Von Mises equivalent stress, psi
  - This relation is based on the observed puck displacement of 164 µ-in/day at a shear stress of 140 Lbs/12 in² = 11.7 psi.
    - Converting 11.7 psi shear to equiv. Stress gives \( \sigma = 20.2 \) psi
    - The shear strain rate, \( \frac{d\varepsilon}{dt} \) is related to equivalent strain rate, \( \frac{d\sigma}{dt} \) as \( \frac{d\varepsilon}{dt} = 3 \frac{d\sigma}{dt} \).
    - For the 0.080” layer, \( \frac{d\varepsilon}{dt} = 164 \frac{\text{in}}{\text{day}} \cdot \frac{1}{0.08”} = 0.00205/\text{day} \)
    - This gives \( \frac{d\sigma}{dt} = 21.02 \times 10^{-6} \sigma^{1.157} \) but this underpredicts the shear displacement when modeled so I adjusted the rate coefficient from 21.02E-6 to 31.71E-6 so that a shear creep model displaces 164 µ-in/day.
Shear Block, 0.433x0.08, at 1.25 years (456 days)

- Validation of creep law.
  - At 1.25 Years
    - Shear displacement = 0.079”
    - Maximum Creep Strain = 1.243
  - Load was 15.16 lbs
    - 1” of rubber strip as defined by 1 mm fish line 12 mm apart.

![Graph showing shear displacement over time]

![Graph showing creep strain over time]

Total displacement at 1.25 years
Standard Puck With and Without Fish line Perforations

Time to a creep strain of 1.24 at the specified axial load.

<table>
<thead>
<tr>
<th>Load</th>
<th>Time to Limit strain, years</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Without Fishline</td>
</tr>
<tr>
<td>100</td>
<td>25.6</td>
</tr>
<tr>
<td>50</td>
<td>57</td>
</tr>
<tr>
<td>25</td>
<td>127</td>
</tr>
<tr>
<td>15</td>
<td></td>
</tr>
</tbody>
</table>
Standard Puck with Fish line Holes

- At 4299 days (11.8 years) creep strain = 0.718
- Extrapolated life (1.24 strain) = 20.3 years
Standard Puck, No Fish line

- At 5834 days (16 years) creep strain = 0.77
- Extrapolated life (1.24 strain) = 25.7 years
Tensile Puck Loads > 15 Lbs

- Listing of actuators on one side of mirror with tensile axial load > 15 lbs (allows 7 Lb/puck adjustment)

<table>
<thead>
<tr>
<th>Actuator</th>
<th># pucks</th>
<th>Nom F axial</th>
<th>Nom/Puck</th>
<th>Delete Fishline</th>
</tr>
</thead>
<tbody>
<tr>
<td>52</td>
<td>1</td>
<td>84.4</td>
<td>84.4</td>
<td>84.4</td>
</tr>
<tr>
<td>50</td>
<td>1</td>
<td>16.2</td>
<td>16.2</td>
<td></td>
</tr>
<tr>
<td>49</td>
<td>2</td>
<td>134.2</td>
<td>67.1</td>
<td>67.1</td>
</tr>
<tr>
<td>48</td>
<td>2</td>
<td>120.9</td>
<td>60.4</td>
<td>60.4</td>
</tr>
<tr>
<td>47</td>
<td>3</td>
<td>70.2</td>
<td>23.4</td>
<td></td>
</tr>
<tr>
<td>46</td>
<td>2</td>
<td>50.9</td>
<td>25.5</td>
<td></td>
</tr>
<tr>
<td>44</td>
<td>3</td>
<td>69.3</td>
<td>23.1</td>
<td></td>
</tr>
<tr>
<td>43</td>
<td>2</td>
<td>60.1</td>
<td>30.1</td>
<td></td>
</tr>
<tr>
<td>42</td>
<td>3</td>
<td>112.1</td>
<td>37.4</td>
<td></td>
</tr>
<tr>
<td>38</td>
<td>3</td>
<td>94.6</td>
<td>31.5</td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>2</td>
<td>84.3</td>
<td>42.1</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>3</td>
<td>66.5</td>
<td>22.2</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>3</td>
<td>70.9</td>
<td>23.6</td>
<td></td>
</tr>
</tbody>
</table>

For Pucks loaded to more than 50 Lbs, delete fishline. Life at 84.4 Lbs is 31 years.

Life of pucks loaded to 50 Lbs is 21 years.
Perforations were added to reduce axial stiffness.

- Metal flexure in the puck provides compliance also.
- The only significant net effect of removing the fish line holes is the increase in axial stiffness.

<table>
<thead>
<tr>
<th>Stiffness Component</th>
<th>Stiffness, Lbs/in or in-lb/rad</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Metal Flexure</td>
</tr>
<tr>
<td>Fishline spaced 12 mm apart</td>
<td></td>
</tr>
<tr>
<td>Radial Shear</td>
<td>29,550</td>
</tr>
<tr>
<td>Axial</td>
<td>858,369</td>
</tr>
<tr>
<td>Radial Moment</td>
<td>17,050</td>
</tr>
<tr>
<td>Axial Moment (twist)</td>
<td>61,809</td>
</tr>
</tbody>
</table>

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<thead>
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<tr>
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<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>
Loadspreader Model (Puck/Elastomer Compliance)
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
UZ
TOP
RSYS=0
DMX = .011374
SEPC=42.244
SMX = .011374

321 Lbs Fz
SEQV (AVG)

DMX = .011374
SMN = 39.825
SMX = 8087
SMXB = 15476

39.825
933.905
1828
2722
3616
4510
5404
6298
7192
8087

321 Lbs Fz
420 Lbs Fx Applied From Actuator
420 Lbs Fx Applied From Actuator
• Load spreader stiffness as it affects the safety clip:
  – Rotation at LS end of the assembly is .0015
  – Displacement at 420 lbs is 0.0026” so K = 161,500 Lb/in
Effect of Elastomer Axial Stiffness on Glass Loads

- The maximum reactions at the pucks on a triple load spreader are listed along with the maximum glass stress.
  - Glass stress = 0.488*Fr+0.3621*Fz+0.553*M

<table>
<thead>
<tr>
<th>Nominal Elastomer Layer (Fishline holes 12 mm apart)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loading</td>
</tr>
<tr>
<td>Fr</td>
</tr>
<tr>
<td>Fz = 321 Lbs</td>
</tr>
<tr>
<td>F vertical = 420 Lbs</td>
</tr>
<tr>
<td>Fvert = 420, reacted by straps</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Nominal Elastomer Layer (No Fishline holes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loading</td>
</tr>
<tr>
<td>Fr</td>
</tr>
<tr>
<td>Fz = 321 Lbs</td>
</tr>
<tr>
<td>F vertical = 420 Lbs</td>
</tr>
<tr>
<td>Fvert = 420, reacted by straps</td>
</tr>
</tbody>
</table>

There is no significant difference in loads or stress between the two elastomer stiffness conditions.