Preliminary design status of the M4AU based on piezo-stack technology

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ESO (a), CILAS (b), AMOS ©, ONERA (d), ASTRIUM (e), ObsPM (f), Boostec (g)
CILAS at a glance

Shareholders
ASTRIUM SAS 63% (EADS)
AREVA 37%

Turnover (FY2010)
M€19.3

45% Marchés
55% Export

140 employees

France
Export

Ingénieurs & Cadres
Techniciens & Agents de Maîtrise
Agents Administratifs
Techniciens d’Atelier & Ouvriers

12%
11%
21%
50%
Introduction

- ESO has initiated in 2007 a preliminary design study (5,2 Meuros / 30 months) to demonstrate feasibility of an adaptive unit (M4AU) φ2,7 m, for the E-ELT
  - Preliminary design study
  - Breadboards tests
  - Demonstration prototype tests

- CILAS proposed a solution based on piezo-electric ceramics (SAM=piezo-stacks) for the adaptive mirror

- CILAS and its partners have successfully passed the preliminary design review in July 2010
M4AU in the E-ELT

- Correct the atmospheric turbulences
- Correct deformation of the telescope (wind, thermal, gravity…)
- Select Nasmyth foci

M4AU in the E-ELT

F/17.7

M1: 42m
M2: 6m
M3: 4m
M4-AO: 2.6m
M5-TT: 3x2.4m
## Risk assessments

<table>
<thead>
<tr>
<th>Risks list</th>
<th>Breadboard 1</th>
<th>Breadboard 2</th>
<th>Demonstration prototype</th>
</tr>
</thead>
<tbody>
<tr>
<td>Free stroke</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mechanical coupling and effective stroke</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thermal behavior</td>
<td>x (local)</td>
<td>x (global)</td>
<td></td>
</tr>
<tr>
<td>Dynamical behavior</td>
<td>x (local)</td>
<td>x (global)</td>
<td></td>
</tr>
<tr>
<td>Hysteresis et creep</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Replacement of an actuators</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reliability of the actuators</td>
<td>x (envt stress)</td>
<td>x (meca stress)</td>
<td></td>
</tr>
<tr>
<td>Large size mirror credibility</td>
<td></td>
<td></td>
<td>x</td>
</tr>
</tbody>
</table>
DP subsystems manufacturing (step 1)

Actuators

Base plate

Optical plate
Assembling of the DP (step 2)
Lapping and polishing (step 3)

- CILAS technology enables final polishing after assembly allowing to suppress possible defects

- Dedicated tools:
  - Waterproofing
  - Optical plate blocking

- Process in 4 steps:
  - Thickness reduction (1mm)
  - Lapping
  - Polishing (<5µm PV)
  - Figuring (CCP) (<7,5nm rms)
Mechanical design of the M4AU

Adaptive mirror

6 mechanical interfaces

Mounting structure

Positionnning system

Control system
## Mass breakdown

<table>
<thead>
<tr>
<th>Sub-system n-1</th>
<th>Subsystem n-2</th>
<th>Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M4AM</td>
<td>Optical plate</td>
<td>3126</td>
</tr>
<tr>
<td></td>
<td>Actuators</td>
<td>126</td>
</tr>
<tr>
<td></td>
<td>Equipped Base plate</td>
<td>833</td>
</tr>
<tr>
<td></td>
<td>HV distribution</td>
<td>1970</td>
</tr>
<tr>
<td></td>
<td>Main covers</td>
<td>147</td>
</tr>
<tr>
<td></td>
<td>M4PS</td>
<td>2155</td>
</tr>
<tr>
<td></td>
<td>M4CS</td>
<td>2200</td>
</tr>
<tr>
<td></td>
<td>M4MS</td>
<td>1900</td>
</tr>
<tr>
<td>M4AU total</td>
<td></td>
<td>9380</td>
</tr>
</tbody>
</table>
Cutting the Mirror

- Fixing structure: Invar
- Base plate: Silicon carbide
- Actuators: Hard PZT
  Removable!
- Optical plate: Zerodur®
Print-through issue

New design with tips:
2nm/°C -> 0.2nm/°C
Design of the positioning system

Satellite roller screw technology to reach the highest possible stiffness
### Stroke capability

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Static stroke</strong></td>
<td>37 µm</td>
</tr>
<tr>
<td><strong>Dynamic stroke</strong></td>
<td>50 µm</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>87 µm</td>
</tr>
<tr>
<td><strong>Stroke capability</strong></td>
<td>96 µm</td>
</tr>
</tbody>
</table>

**Telescope optical**: 5µm

**Gravity/thermal load**: 27µm

**Polishing**: 5µm

**Telescope vib & atmo t/t**: 38µm

**Telescope vib defocus**: 7µm

**Atmo (without t/t)**: 32µm

**New design with more PZT plates**: 250 PZT plates -> 400 PZT plates per actuator

**Margin 10%**
Arrangement of the actuators

- Triangular meshing geometry
- Inter actuator spacing of 29mm for reaching the FE goal value (113nm around REQ 110nm, confirmed by ONERA)

HV=+400 V/-400 V
Inter stroke = 6 μm

HV=400 V
Single stroke = 5 μm
Mech coupling = 54%
Dynamical behavior test benches

Divided in two steps:

- EMA performed to identify eigen-modes and damping factors
  - Validation of the FEM

- Spurious modes study
  - Identif. spurious modes
  - Validation state model
Main eigen modes of the mirror

<table>
<thead>
<tr>
<th>Mode 1</th>
<th>Mode 2</th>
<th>Mode 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>$69\text{Hz}$: actuator modes with rigid body rotation of the OP around $\text{z}$ axis.</td>
<td>$76\text{Hz}$: actuator modes with rigid body translation of the OP along $\text{Y}$ axis + tilt of the $\text{BP}$</td>
<td>$76\text{Hz}$: actuator modes with rigid body translation of the OP along $\text{X}$ axis + tilt of the $\text{BP}$</td>
</tr>
<tr>
<td>Mode 4</td>
<td>Mode 5</td>
<td>Mode 6</td>
</tr>
<tr>
<td>$249\text{Hz}$: $\text{BP}$ $1^{\text{st}}$ astigmatism</td>
<td>$354\text{Hz}$: $\text{BP}$ $2^{\text{nd}}$ astigmatism</td>
<td>$424\text{Hz}$: actuator modes with rigid body rotation of the OP around $\text{Z}$ axis</td>
</tr>
<tr>
<td>Mode 7</td>
<td>Mode 8</td>
<td>Mode 9</td>
</tr>
<tr>
<td>$426\text{Hz}$: actuator modes with rigid body translation of the OP along $\text{X}$ axis</td>
<td>$426\text{Hz}$: actuator modes with rigid body translation of the OP along $\text{Y}$ axis</td>
<td>$471\text{Hz}$: $\text{BP}$ defocus</td>
</tr>
</tbody>
</table>
Dynamical behavior status

- FEM model validated ($\delta \ exp/\text{theory}<5\%$)
- State model validated (all main modes)

- Thanks to these models, we predict active damping of the base plate necessary to reach residual on-sky tip-tilt errors
Conclusions

- PDR successfully passed July 2010 (PDR=2311 pages delivered to ESO)
- The study allowed to show that CILAS technology for AO is adaptable for decametric to multi-metric dimensions (challenging but realistic)
- One meter prototype manufactured in short time (∼1,5 yr)
- Progress in various domains such as lifetime of the PZT actuators, finite element model of complex structure, control of the hysteresis and creep effect, improvement of local thermal behavior, active control of high degrees freedom structure, mass production...
THE END

Thanks for attention!
Questions?