Recent Progress on Correcting Components (useful for ELTs) at CILAS

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Topics

Experimental results obtained with:

- 3.5-mm spacing Concave Deformable Mirror
- 1-mm spacing Deformable Mirror (miniDM)
- Tip/Tilt Mount for heavy SAM
Different families of DMs

Stroke vs. spacing

- Actual mirror manufactured and tested
- Subscale mirror manufactured and tested
- Mirror under fabrication or design
- Preliminary design
- miniDM
- M4AU

Maximum stroke PV (µm) vs. Spacing (mm)
Different families of DMs

- Actual mirror manufactured and tested
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Graph showing the relationship between spacing (mm) and maximum stroke PV (µm) for different families of DMs.
Different families of DMs
Spherical DM
Spherical 3.5-mm spacing

Preparing:
- High order (100x100 range)
- Small spacing (< 4 mm)
- Concave/convex surface (≈1 m curvature radius)
- Lower voltage (200 V)

for E-ELT MCAO Module

28x28 Demonstrator

Small spacing SAM spherical

Started in December 07
Towards concave/convex surface

Optical plate with concave (or convex) shape
Issues to demonstrate/test

- Optical head manufacturing
- Array manufacturing (3.5 mm spacing SAM)
- Spatial behaviour (optical quality, strokes)
- Temporal behaviour (transfer function, hysteresis)
- Thermo-mechanical behaviour (ambient & -40°C)
28x28 concave demonstrator

28x28 actuator array (616 actuators) + 270 mm curvature radius optical head = 100 mm diameter 3.5 mm spacing demonstrator
Spherical demonstrator stroke

Maximum stroke

± 4.5 µm for ± 400 V

(Theory = ± 4.2 µm)

100 V on 3X3 actuators
Spherical demonstrator stroke

Single stroke

± 1.1 µm for ± 400 V

(Theory = ± 1.1 µm)

≈ 40 % mechanical coupling

Reachable (next step*):

> ± 1.9 µm for ± 400 V

≈ 25 % mechanical coupling

* Reduction of optical plate thickness

100 V on each actuator
Spherical demonstrator stroke

Interactuator stroke

1.5 µm for ± 400 V

(Theory = 1.1 µm)

Reachable (next step):

> 2.9 µm for ± 400 V

+/-100 V on each couple of neighbour actuators
Spherical demonstrator optical quality

Shape at rest (compared to best sphere)

Defect < 0.5 µm PV on 100 mm diameter
Spherical demonstrator optical quality

Best flat
(compared to best sphere)

Residual < 5 nm rms

Filtered shape at rest (defects with spatial periods > 7 mm are filtered out)
Spherical demonstrator temporal behaviour

Frequency response

Resonance frequency \(\approx 22\) kHz (theory = 21 kHz)
\(\approx 10^\circ\) phase lag at 3 kHz
Spherical demonstrator linearity/hysteresis

Full stroke response

Non linearity < 5 %
Spherical demonstrator at -40°C

- Stroke specifications: tested -> equivalent at ambient and at -40°C
- Temporal behaviour: not tested but equivalent to ambient (already tested on other demo)
- Best flat error: tested -> residual error < 10 nm rms at -40°C
- Shape at rest: tested -> increase of PV defect:
  - Ageing contribution (not stabilised before test)
  - Electrical contacting problem (minor)
  - Possible in homogeneity (?)
Spherical demonstrator next steps

- Solving of electrical contacting problem (not critical)
- Reduction of optical plate thickness
- New test
MiniDM
1-mm spacing DM

Spacing (mm)

Maximum stroke PV (µm)

Preparing:

- Very high order (200x200 range)
- Smaller spacing (≈1 mm)
  for E-ELT Extreme AO

miniDM

50x50 Demonstrator

Started in May 07
MiniDM concept

Use of piezo transverse effect

\[ \delta = d_{31} V L / h \]

* Good for small spacing
Issues to demonstrate

- Optical head manufacturing and polishing
- Lines of actuators + array manufacturing (1-mm spacing)
- 1-mm spacing electrical contacting
- Spatial behaviour (optical quality, strokes)
- Temporal behaviour (transfer function, hysteresis)
MiniDM prototype

Actuator array (front view)

Optical head (back view)

49 mm dia. - 50x50 array - \( \approx 1900 \) actuators - Spacing: 1 mm x 1 mm
MiniDM prototype

Assembled MiniDM

Mechanical mount with 1/3 HV connector
MiniDM prototype stroke

Maximum stroke

2.9 µm PV for ± 400 V
(Theory = 2.8 µm PV)

100 V on 3X3 actuators
MiniDM prototype stroke

Single stroke

0.8 µm PV for ± 400 V

(Theory = 0.7 µm PV)

≈ 60 % mechanical coupling

Reachable (next step*):

1.4 µm PV for ± 400 V

< 30 % mechanical coupling

* Reduction of optical plate thickness

- 100 V on one actuator
MiniDM prototype stroke

Interactuator stroke

0.5 µm for ± 400 V

(Theory = 0.3 µm)

Reachable (next step):

1.2 µm for ± 400 V

+/-100 V on two neighbour actuators
MiniDM prototype optical quality

Shape at rest

Defect: 1.8 µm PV (!) on 45 mm diameter

Ageing contribution
(not stabilised before polishing)
MiniDM prototype optical quality

Best flat

Residual < 3 nm rms

Filtered shape at rest (defects with spatial periods > 2 mm are filtered out)
MiniDM prototype temporal behaviour

Frequency response

Resonance frequency $\approx 31$ kHz (theory = 41 kHz)
$\approx 10^\circ$ phase lag at 3 kHz
MiniDM prototype linearity/hysteresis

Full stroke response

Hysteresis ≈ 6 %
MiniDM prototype main results of the study

- **Demonstrated elements:**
  - Use of the transverse effect of piezo material to design an array DM
  - Manufacturing of a 50x50 1-mm spacing array
  - Manufacturing and assembling of a 50x50 1-mm spacing optical head
  - Stroke specifications: tested and OK
  - Temporal behaviour: tested and OK
  - Best flat error: tested and OK
  - Shape at rest: not OK but not critical to solve

- **Encountered problems:**
  - Electrical contacting and insulation: not industrial and not reliable
  - Surface cosmetics: not OK
MiniDM prototype next steps

- Solving of electrical contacting/insulation problem
  -> need for complementary studies and manufacturing of simple breadboards
  (some tracks are available)

- Improvement of surface cosmetics
  -> continue some works on available optical head
Tip/Tilt Mount for NFIRAOS the MCAO system of the TMT
Tip/Tilt mount design

Masses:
- DM: 32 kg
- Y axis: 60 kg
- X axis: 112 kg
- Overall system: 390 kg

Specified angular stroke:
- 500 µrad PV

Specified -3dB bandwidth:
- 20 Hz (goal 40 Hz)

Specified angular noise:
- 50 nrad rms

Operating temperature:
- 20 and -35°C

First study started in September 05
KOM in April 07
FAT in January 09

Based upon l'Observatoire concept
Tip/Tilt mount ready for test

Back view (with DM wires)
Mechanical modes

Simulation:

Tilt Y: 8 Hz

Tilt X: 15 Hz

Piston (spurious mode): 125 Hz

Measurement:

\[ f_{X/Y} = \frac{1}{2\pi} \sqrt{\frac{Tr}{I_{X/Y}}} \]

Open Loop responses to white noise

\[ P_{Y+} - P_{Y-} \]

\[ P_{X+} - P_{X-} \]

\[ P_{X+} + P_{X-} \]
Correction bandwidth

Measurement:

Tilt Y: 92 Hz @ -3 dB (21° phase rotation @ 20 Hz)  
55° phase margin & 13 dB gain margin in open loop

Tilt X: 98 Hz @ -3 dB (27° phase rotation @ 20 Hz)  
56° phase margin & 9.8 dB gain margin in open loop

Closed Loop* responses to swept sine

* Used numerical corrector: Dumping loop on speed + Predictive Functional Command (PFC) on position
Angular noise

Measurement with optical sensor:

Noise = Gain.Voltage = 48 µrad/V x 676 µV rms = 33 nrad rms
## Compliance matrix

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specified value</th>
<th>Obtained Result at ambient and -35°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angular stroke</td>
<td>500 μrad PV</td>
<td>500 μrad PV</td>
</tr>
<tr>
<td>Angular resolution and noise</td>
<td>50 nrad rms</td>
<td>&lt; 40 nrad rms</td>
</tr>
<tr>
<td>Linearity and hysteresis</td>
<td>0.1 %</td>
<td>Not measurable (phase lag limitation)</td>
</tr>
<tr>
<td>Angular stroke at 20 Hz</td>
<td>25 μrad PV</td>
<td>&gt; 25 μrad PV</td>
</tr>
<tr>
<td>Achievable closed-loop, small amplitude -3dB bandwidth</td>
<td>20 Hz (goal 40 Hz)</td>
<td>&gt; 90 Hz</td>
</tr>
<tr>
<td>Piston</td>
<td>X</td>
<td>&lt; 10 nm rms</td>
</tr>
</tbody>
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Merci à :

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