Novel Piezoelectric Actuators and Motors for Space Optics

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Outline

- Electromechanical actuations
- Single crystal piezoelectrics
- Flextensional actuators for deformable membrane mirrors
- Actuator arrays with fine pitch for piezo DM
- Cryogenic actuators and motors for passive optics
- Summary
# Electromechanical Actuators Requirements for Space Applications

<table>
<thead>
<tr>
<th>Actuator Type</th>
<th>Shape Control</th>
<th>Position Control</th>
<th>Force Control</th>
<th>Deformable Mirror</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resolution (nm)</td>
<td>≤20</td>
<td>≤ 10</td>
<td>≤ 20</td>
<td>≤ 10</td>
</tr>
<tr>
<td>Life Cycles</td>
<td>≥10,000</td>
<td>≥ 100,000</td>
<td>≥ 10,000</td>
<td>≥ 100,000</td>
</tr>
<tr>
<td>Stroke (mm)</td>
<td>≥ 0.3</td>
<td>≥ 0.5</td>
<td>≥ 6</td>
<td>≥ 10</td>
</tr>
<tr>
<td>Operating temperature range (K)</td>
<td>20-60</td>
<td>20-300</td>
<td>20-60</td>
<td>20-300</td>
</tr>
<tr>
<td>Mass (g)</td>
<td>≤ 40</td>
<td>≤ 20</td>
<td>≤ 40</td>
<td>≤ 20</td>
</tr>
<tr>
<td>Outside Diameter (cm)</td>
<td>≤ 2</td>
<td>≤ 1</td>
<td>≤ 5</td>
<td>≤ 1</td>
</tr>
<tr>
<td>Creep, OM (nm/Day)</td>
<td>≤ 0.1</td>
<td>≤ 0.01</td>
<td>≤ 0.1</td>
<td>≤ 0.01</td>
</tr>
<tr>
<td>Power, CM (W)</td>
<td>≤ 1.0</td>
<td>≤ 0.1</td>
<td>≤ 1.0</td>
<td>≤ 0.1</td>
</tr>
</tbody>
</table>

-- [http://www.jwst.nasa.gov/Hardware/text/actuator_reqs.html](http://www.jwst.nasa.gov/Hardware/text/actuator_reqs.html)

Requirements for the various types of actuators that may be used on JWST as of 1997.
Cryogenic Actuators for Space Applications

**Available Electromechanical Actuations:**

- Electromagnetic with superconducting coils: temp < 77K
- Magnetostrictive with superconducting coils: temp < 77K
- Specially modified ferroelectric ceramics: temperature 20-65K
- *Single crystal piezoelectrics: <20K - >300K*

**NASA Applications:**

Passive optics, adaptive optics, deployable truss structures, antenna tuning, and positioning for the primary mirror on JWST and in other space exploring missions such as SIM, SAFIR, TPF and others.
Single Crystal Piezoelectrics

- High electromechanical coupling
- Low hysteresis
- Large piezoelectric coefficient
- Excellent cryogenic property

**Piezoelectric property**

**Cryogenic piezoelectric coefficient**
TRS Single Crystal Actuators

- Stack Actuator
- In-plane actuator ("31", IDE, Shear)
- Unimorph/Bimorph
- Flextensional (moonie, cymbal, Thunder, etc.)
- Piezomotors (ultrasonic and inertial)
**Objective:** Develop large stroke, large aperture, lightweight, low cost, scalable deformable membrane mirror technology using advanced hybrid electrostatic/flextensional actuation.
Flextensional Actuators for Membrane DM

ATILA modeling of single crystal double stack flextensional actuator showing 456.77 micron displacement at 300 V (10 kV/cm)
Flextensional Actuators for Membrane DM

Actuator Displacement vs Voltage

- FlexAct 5
- FlexAct 6
- FlexAct 13/14
- FlexAct 16/17
- FlexAct 18/19
- FlexAct 13/14&16/17

0 50 100 150 200 250 300 350 400 450
0 100 200 300 400 500 600

Applied Voltage (V)
Displacement (microns)

Actuator 25/37
Actuator 1/17/13/15

50 100 150 200 250 300 350 400 500
50 100 150 200 250 300 350 400 450

Voltage Applied (V)
Displacement (µm)
Flextensional actuators with stroke > 400 um were demonstrated and ~ 10 actuators were prototyped and tested for tip-tilt-piston demonstration, 18 actuators are being delivered to MSRS for membrane control.

Next step: improve actuator prototyping yield, supply ~ 54 actuators for a 0.25 m membrane DM.
Actuator Array for DM

NASA Phase I Contract No. :NNX08CD13P

Program Manager: Stuart B Shaklan (JPL)

Team: TRS, MSRS, and Stevens University

Objective:
Micro-actuator arrays consisting of actuators with footprint of 1.0 mm × 1.0 mm and spacing between actuators < 0.5 mm to be designed, fabricated and tested. The actuators were expected to be individually addressable with large stroke (> 10 μm) or strain (~ 0.2%).
Actuator Array for DM

- Single crystal piezoelectric actuator array (3x3) with fine pitch of < 1.5mm and large strain of > 0.18% (1.35 μm stroke from an array with height of 0.75 mm) at 200 V was successfully fabricated without floating wires.

- Conductive through-wafer-vias fabrications were developed for single crystal piezoelectric composite plates, which is scalable for large array fabrication in Phase II.
Cryogenic Actuators and Motors for Passive Optics

--- NASA Phase II Contract No.: NNL06AA09C
Program Manager: William B Cook, LaRC
Team: TRS and NIA

--- NASA Phase II Contract No.: NNL08AA14C
Program Manager: William B Cook, LaRC
Team: TRS, VT and MTECH

Objective: Develop high resolution and large stroke cryogenic actuators for FPI fine tuning and coarse tuning in passive optics.
Cryogenic Stack Actuators for Passive Optics

10 x 10 x 50 mm PMN-PT single crystal stack actuators

Resonant modes of a 10 x 10 x 50 mm PMN-PT single crystal stack actuator

Stroke performance of a 10 x 10 x 50mm PMN-PT single crystal stack at room temperature and at liquid nitrogen environment
Cryogenic Flextensional Actuators for Passive Optics

10 x 5 x 7.6 mm PMN-PT single crystal flextensional stack actuator
Ultrasonic Piezomotor for Passive Optics

Flexural Traveling Wave Motor

<table>
<thead>
<tr>
<th></th>
<th>Resonance frequency (kHz)</th>
<th>Freq-band width (Hz)</th>
<th>Starting voltage (V_{p-p})</th>
<th>Working voltage (V_{p-p})</th>
<th>Torque (kg-cm)</th>
<th>Power (^\circ)(W)</th>
<th>Working temperature range (^\circ)(C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PZT</td>
<td>41.5</td>
<td>177</td>
<td>200</td>
<td>400</td>
<td>~5 (@400V_{p-p})</td>
<td>7.5 (@400V_{p-p})</td>
<td>(-30—70)</td>
</tr>
<tr>
<td>PMN-PT</td>
<td>43</td>
<td>929</td>
<td>50</td>
<td>100-200</td>
<td>~3 (@200V_{p-p})</td>
<td>2.1 (@110V_{p-p})</td>
<td>(-200—50)</td>
</tr>
</tbody>
</table>
Summary

- Single crystal piezoelectric actuators showed unprecedented cryogenic actuation performances;
- Light weight, low profile single crystal piezoelectric actuators showed large strain and low power consumption;
- Single crystal piezo motors can be driven at much lower voltage and operate at a broad temperature range (<77K-300K);
- Single crystal actuator array will advance piezo DM technology.
Acknowledgement

**TRS:** Dr. Wesley S. Hackenberger, Dr. Jun Luo, Ms. Heidi Hohnson, Mr. Raffi Sahul, Ms. Hua Lei, Mr. Thomas Walker, Mr. Matt Corbin and Mr. Brad Dunkin.

**MSRS:** Brian Patrick, Jim Moore, Jenny Otto

**UAH:** Jackie Roche

**NIA:** Dr. Tianbing Xu

**VT:** Dr. Shuxiang Dong