UNIVERSITÀ DEGLI STUDI DI PADOVA

Development of a Fine Steering Tip/Tilt Mechanism for Space Applications

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PhD Course in Science, Technologies and Measurements for Space

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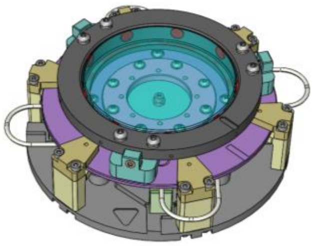
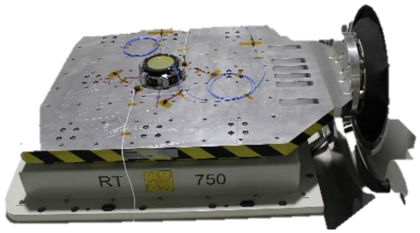
Summary

- Research project objectives
- Why a Steering Mechanism?
- Three years research activity
- Lead requirements
- Layout definition
- Actuator analysis and design
- MAiA breadboard
- Final mechanism analysis & design
- Integration and verification
- Functional tests
- Environmental tests
- Conclusions

Research project objectives





Design → **Fine Steering Mechanism**

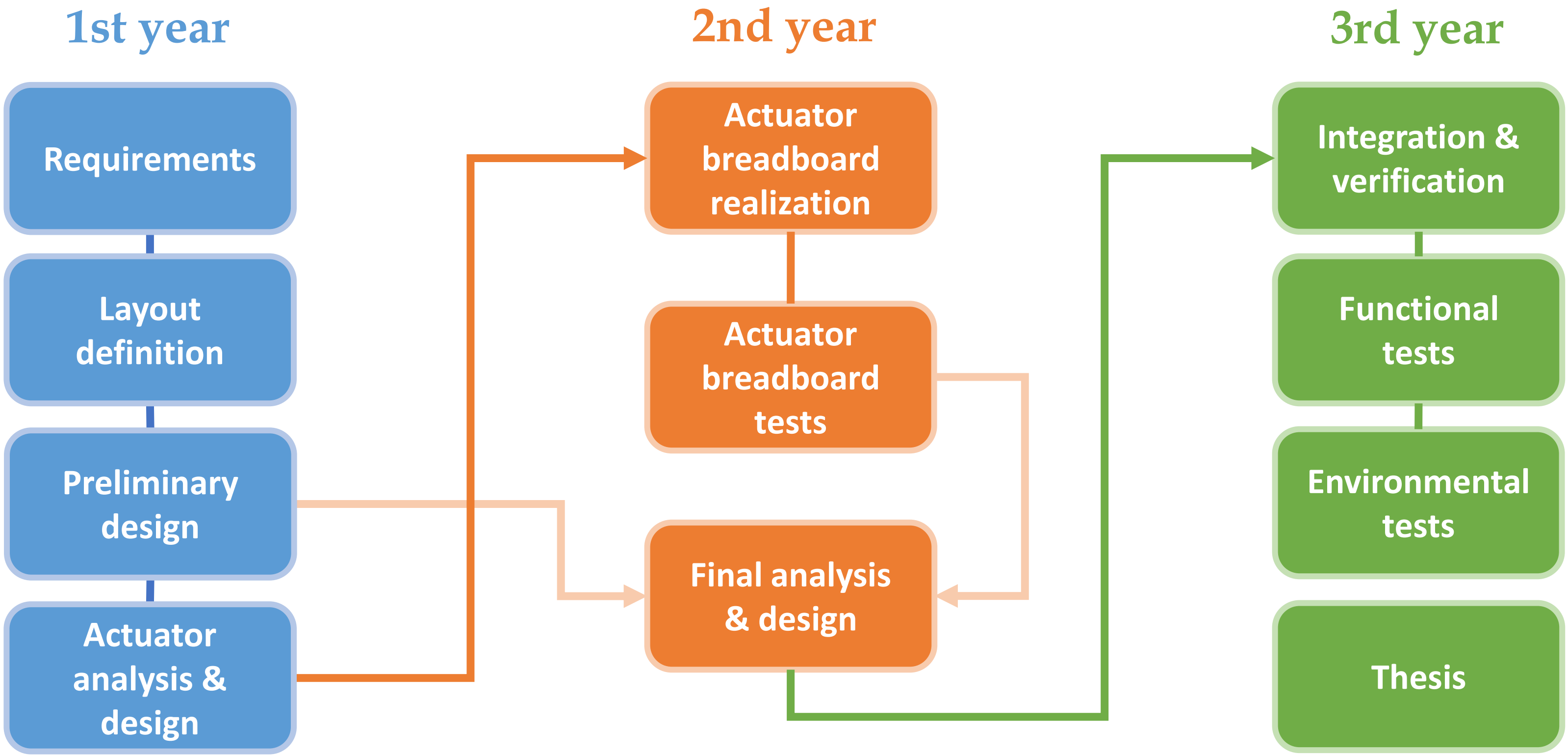
Realization → **Fine Steering Mechanism**

Space qualification → **Fine Steering Mechanism**

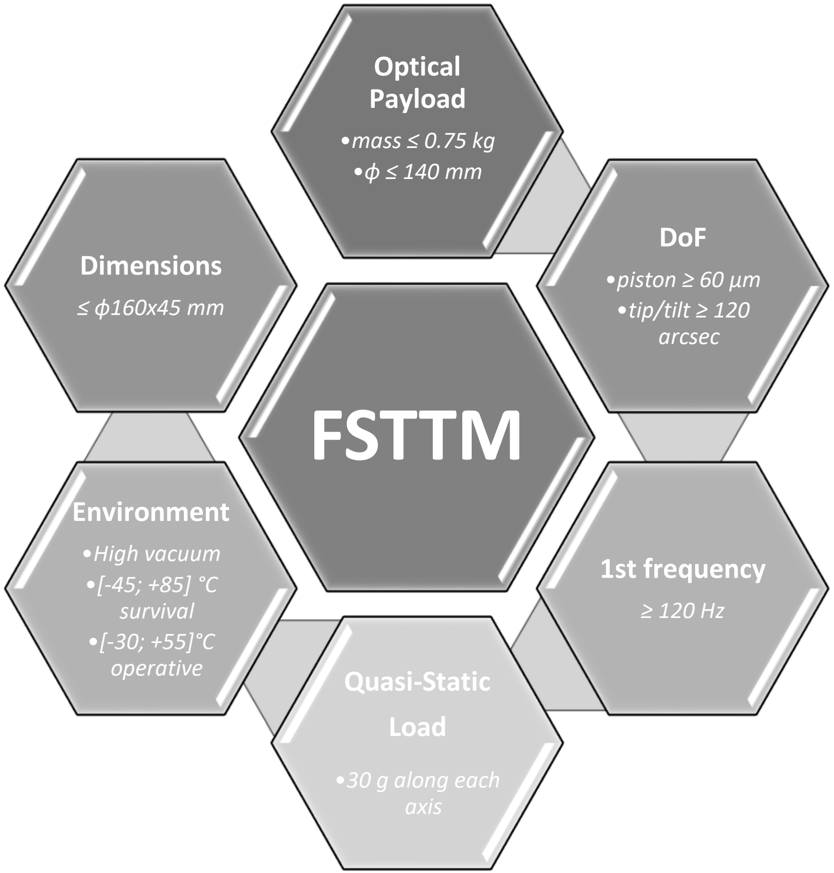
Why a steering mechanism?

- To modify/correct the position/orientation of optical elements inside a telelescope for space applications.
- Because of disalignments due to:
  - launcher vibrations;
  - thermal variations in orbit;
  - dimensional variations of structural elements (es. shrinkage of CFRP components);
  - platform micro-vibrations/jitter;
  - ground errors (manufacturing, integration, …).

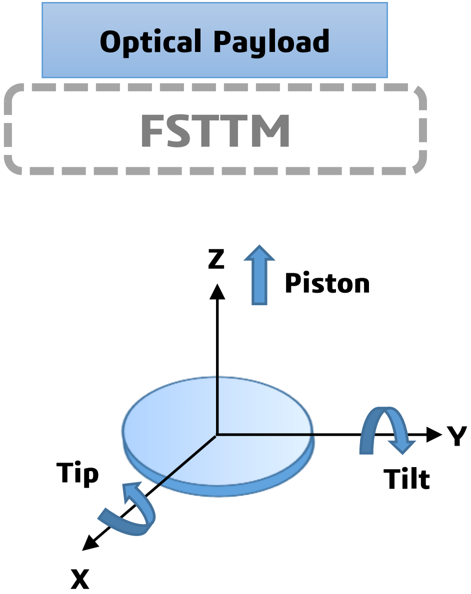
3 years research activity - *main steps*



Lead requirements



- Fine Steering Tip/Tilt Mechanism (FSTTM) requirements have been defined at the beginnning of the research activity.

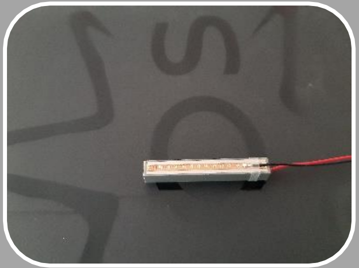


Layout definition

- A bibliographic review has been conducted on actuators, sensors and mechanisms providing 3 DoF.
- After that, the layout of the FSTTM has been defined:
  - *multilayer piezoelectric actuators to generate motion;*
  - *capacitive sensors to measure generated motion.*
- A trade-off analysis has been conducted between 3-actuators and 4-actuators layouts.
- 4-actuators layout selected because of:
  - *stiffer system;*
  - *easier control strategy;*
  - *lower required stroke for tip/tilt rotations.*

Why piezo actuators?

- *High resolution*
- *No stick-slip*
- *No lubrication*
- *High vacuum operations*
- *Low heat dissipation*

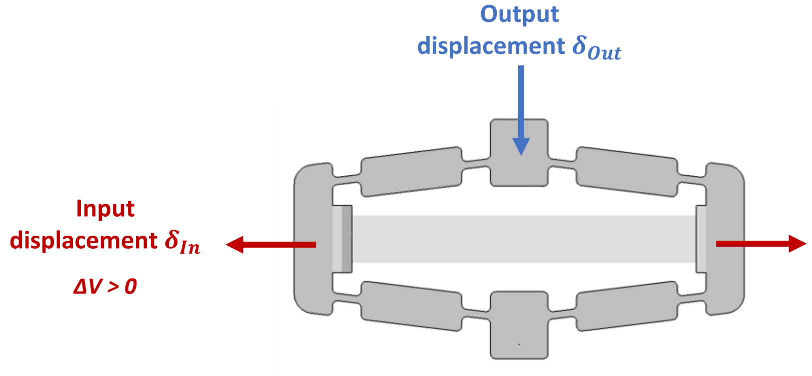


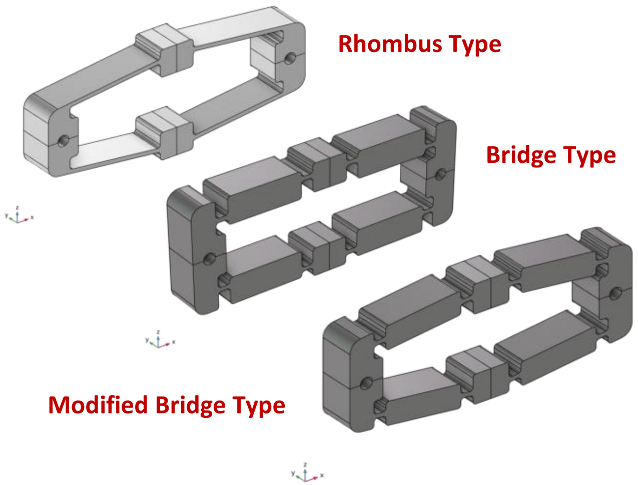
Why capacitive sensors?

- *Non-contact measurements*
- *High accuracy*
- *High resolution*
- *No magnetic field production*
- *High vacuum operations*
- *Insensitive to temperature variations*

Actuator analysis & design

- The actuator has been properly designed and analysed:
  - piezoelectric actuator preloaded and amplified by a compliant mechanism;
  - working principle based on the inverse piezoelectric effect.

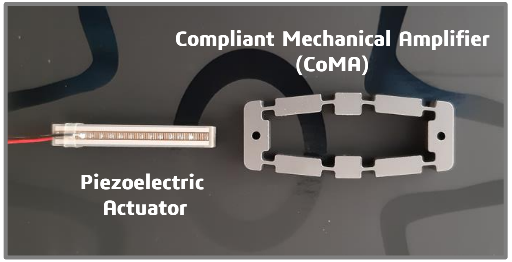


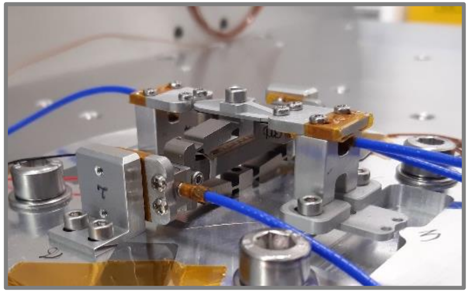


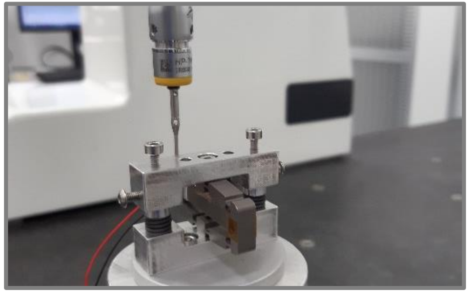
- Several geometries have been studied for the compliant mechanism, comparing their geometric advantages δ_{Out}/δ_{In}.
- A modified bridge type has been selected --> 6.9 of *geometric advantage* in free conditions.

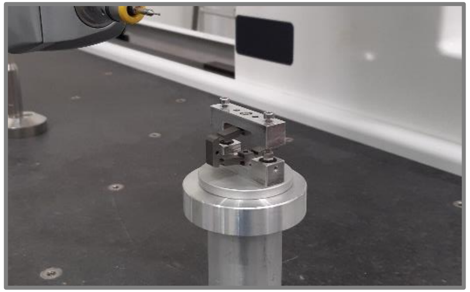
MAiA breadboard

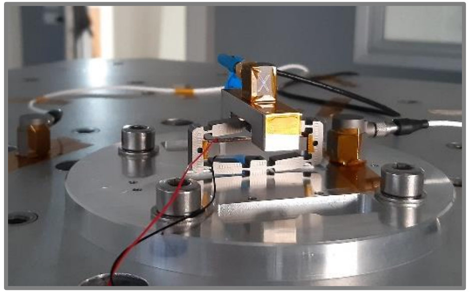
- A breadboard of the Mechanical Amplified Piezoelectric Actuator (MAiA) has been realized in the second year.











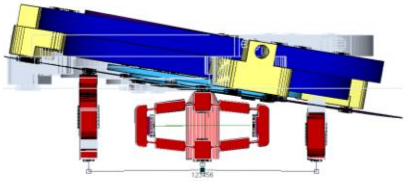
- Several tests have been carried out on:
  - *single piezo actuator;*
  - *single Compliant Mechanical Amplifier (CoMA);*
  - *complete actuator in air and in vacuum;*
  - *preload in vacuum at survival temperatures (-45 and +85°C);*
- *A resonance search has been performed to correlate Finite Element model with measured eigenfrequencies.*

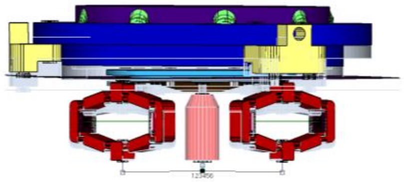
Final mechanism analysis & design

- Using breadboard test results, FSTTM design has been finalised.

- Several Finite Element analyses have been performed:

  - Modal Analysis → *to identify eigenfrequencies;*
  - Static Analyses → *Quasi-Static load verification;*
  - Frequency Responses → *sinusoidal load verification;*
  - Random Responses → *random load verification;*
  - Shock Responses → *shock load verification;*
  - Thermo-Elastic analyses → *thermal loads verification;*
  - Operative analyses → *to estimate piston and tip/tilt performances under gravity and thermal loads.*





Integration & verification - *MAiA*

- In the third year, the mechanism has been realized.

Integration & verification - *FSTTM*

- The Fine Steering Tip/Tilt Mechanism has been fully integrated.

Functional tests *- in air at 20°C*

- **TEST**
  - *FSTTM performances (tip/tilt and piston) verified in air at 20°C*
  - *Capacitive sensors measurements compared with CMM measurements*

FUNCTIONAL TEST

Pressure: *ambient*

Temperature: *20°C*

Measurement Method: *CMM + Capacitive Sensors*

Functional tests - *in vacuum*

- **PRE-TEST**
  - *Performances measured in vacuum at 20°C*
  - *Comparison with CMM measurements (in air, at 20°C)*
- **TEST**
  - *Performances measured at minimum operative temperature (-30°C)*
  - *Performances measured at maximum operative temperature (+55°C)*
- **POST-TEST**
  - *Performances re-measured at 20°C*

FUNCTIONAL TEST

Pressure: *< 1e-5 mbar*

Temperature: *-30°C , 20°C , 55°C*

Measurement Method: *Optical + Capacitive Sensors*

Environmental tests - *Vibrations*

- **PRE-TEST**
  - *Preliminary Resonance Search*
  - *FE model correlation using measured eigenfrequencies and estimated damping ratios*
  - *FEA predictions → to estimate max stress in sine and random vibrations*
- **TEST**
  - *Sinusoidal vibrations*
  - *Random vibrations*
- **POST-TEST**
  - *FSTTM performance verification with CMM*

Environmental tests – *Thermal-vacuum cycles*

- **PRE-TEST**
  - *Piston performances verified in vacuum at 20°C.*

- **TEST**
  - *1 non-operative cycle [+85;-45]°C;*
  - *7 operative cycles [+55; -30]°C;*
  - *piston measured at each +55°C and -30°C plateaus.*

- **POST-TEST**
  - *Piston re-measured in vacuum at 20°C.*

Conclusions - *done*

- ✓ A Fine Steering Mechanism has been designed, starting from requirements and layout definitions.
- ✓ The mechanism design has been verified through a breadboard of the designed actuator, and through several Finite Element Analyses.
- ✓ The mechanism has been procured and integrated.
- ✓ The mechanism has been qualified under sine and random vibrations (no frequency shifts and performances degradations have been observed).
- ✓ The mechanism has been qualified under 8 thermal-vacuum cycles, operating the system in operative environment (no degradation of performances have been observed).

Conclusions - *open-points & future developments*

- To complete the qualification with a shock test (verified only by FE analyses).
- To implement a closed-loop control (FSTTM tested only in open-loop).
- To analyze in depth MAiA actuators behaviour.
- To analyze in depth FSTTM lower performances at higher temperatures.

Thanks for the attention

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