F. Barillot
Cedrat Technologies

MEFISTO
Design & tests of a demonstrator for filet compensation mechanism

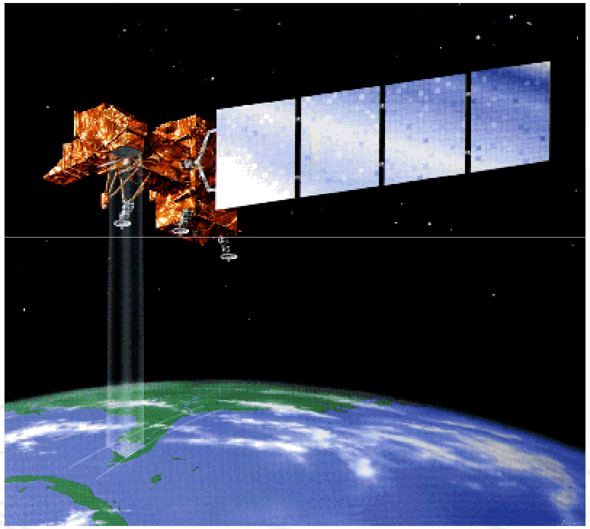
CEDRAT TECHNOLOGIES

SODERN

CEDRAT TECHNOLOGIES
Innovation in Mechatronics

Project goal

- Future matrix sensors will acquire an area on ground and are then susceptible to image shift due to satellite movement during acquisition.



- Design, Build and Test a breadboard mechanism that could shift telescope line of sight and freeze observed area during image acquisition.

Project organization

- RAPID project funded by French DGA
- Technical overview provided by CNES

- CTEC :
  - Project management
  - Mechanism design and manufacturing
  - GSE design and manufacturing
  - Functional testing
  - Vibration testing with CNES support
- SODERN :
  - Optical specification analysis
  - Mirror design and manufacturing

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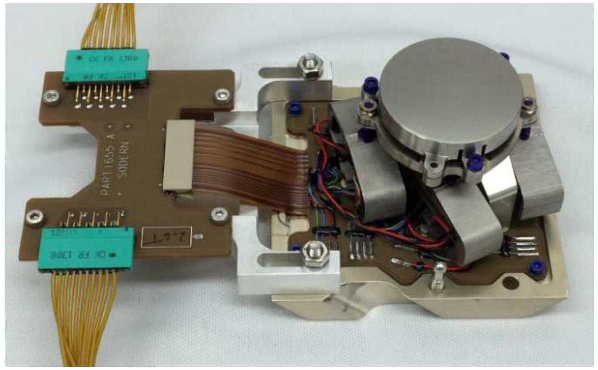
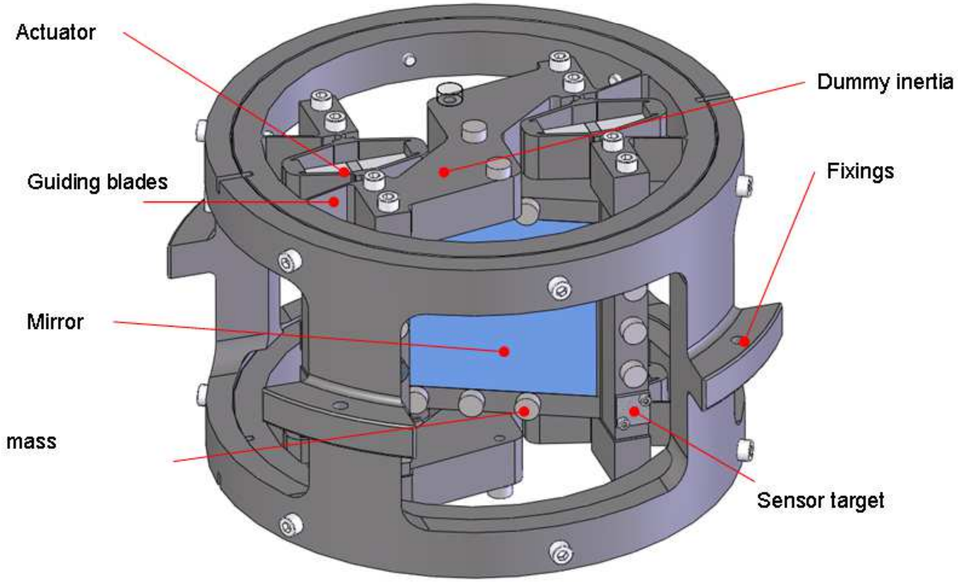
CTEC space heritage with tilting mechanisms

	MEF Pharao (2006)  	BSM ATLID (2015) 
Mirror size	Ø 4 mm	Ø 27 mm
Stroke	3 mrad x 3 mrad	3 mrad x 4.24 mrad
Pointing stability	2 µRad over 20 days	0.5 µRad [1mHz – 10 Hz]
Temperature	Regulated ~10mK	24°C – 40°C, 1 K to 4 K drift
Long term stability	Not requested	50 µRad
Repeatability	Not requested	50 µRad

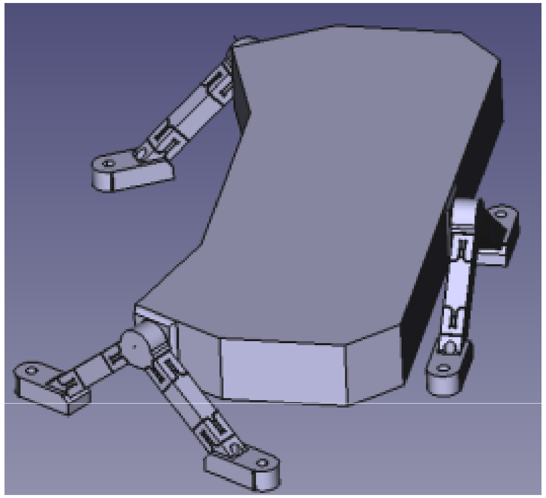
Single axis compensated mechanism

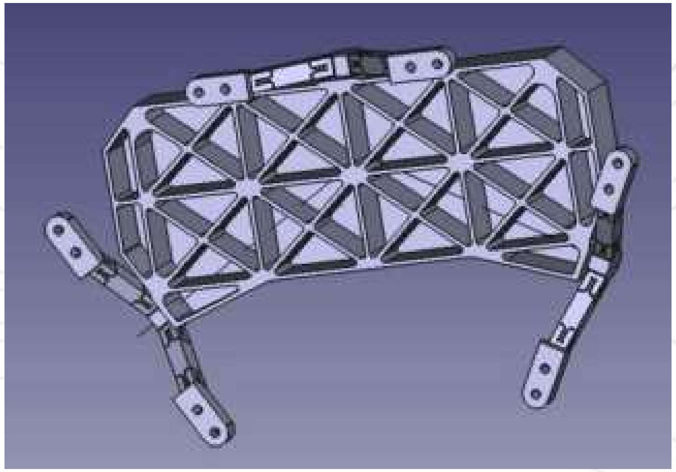
- Single axis tilt mechanism, partly funded through R&T CNES
- Compensation patented by CNES
- Stroke: 1 mRad , Response time : 3ms with1kg mirror



Requirements for the mirror (Sodern)

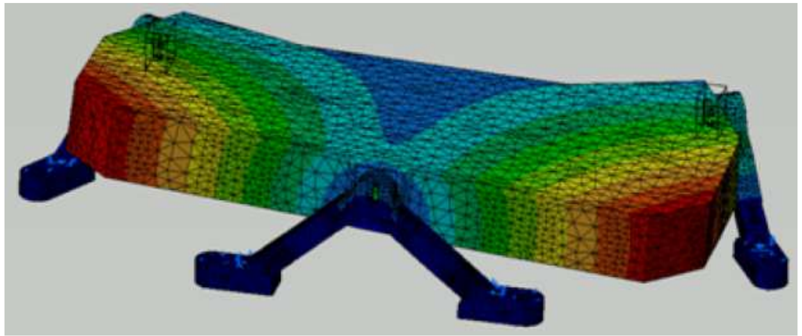
- Analysis of the optical requirements to define main performances of the mechanism and especially mirror.
- Mirror specification:
  - High opto-mechanical performances
    - Mirroring surface (roughly 200 x 100) is part of requirement
    - Very good flatness is required
  - Mechanical performances
    - Mass < 1kg
    - 1^{st} Eigen frequency > 1kHz
  - Assembly based on isostatic tripod





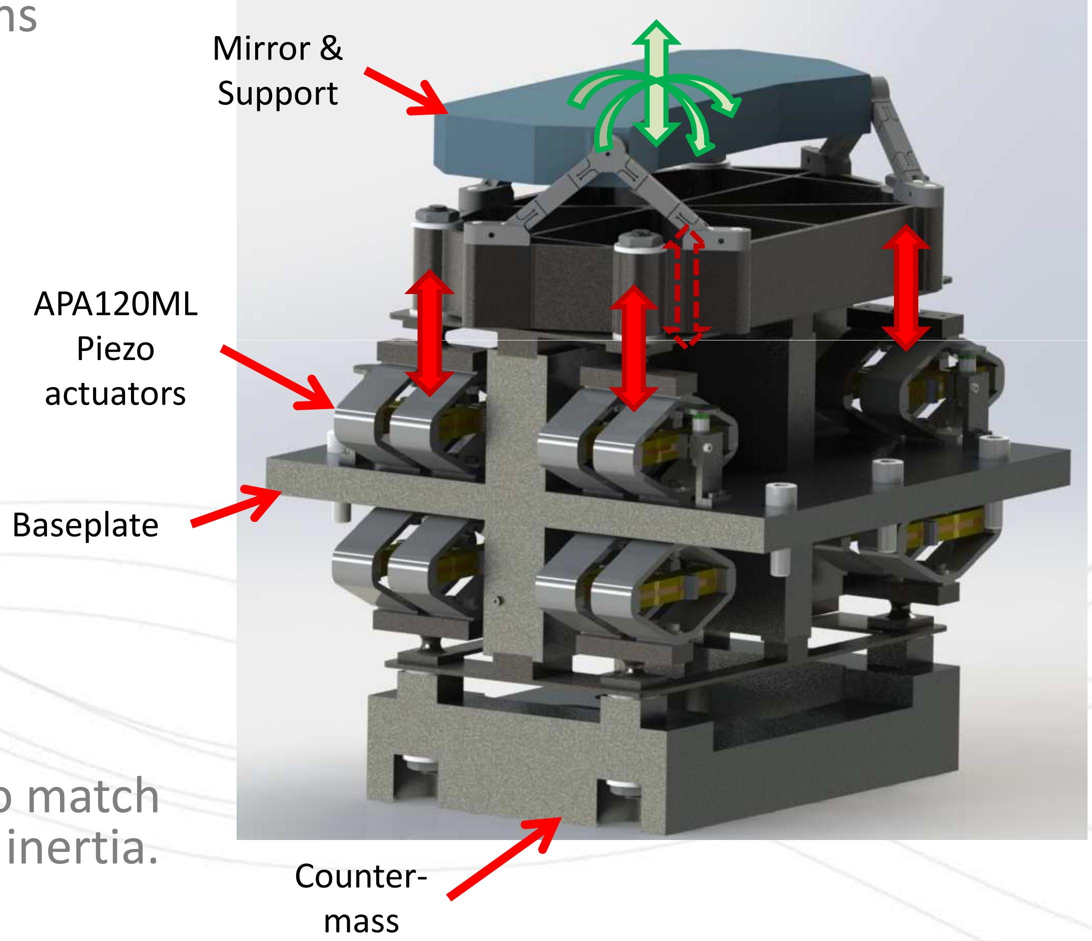
Design and Manufacturing of Mirror (Sodern)

- Mirror design successful
  - Mass = 745g
  - 1st Eigen mode = 1088 Hz
- Material is Aluminum but study includes SiC and ZeroDur
- Mirror built by Sodern for assembly in MEFISTO mechanism



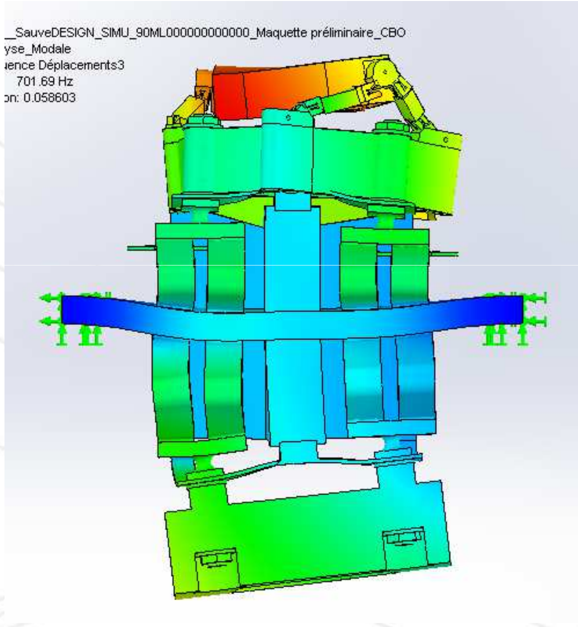
Amplified Actuator Mechanism

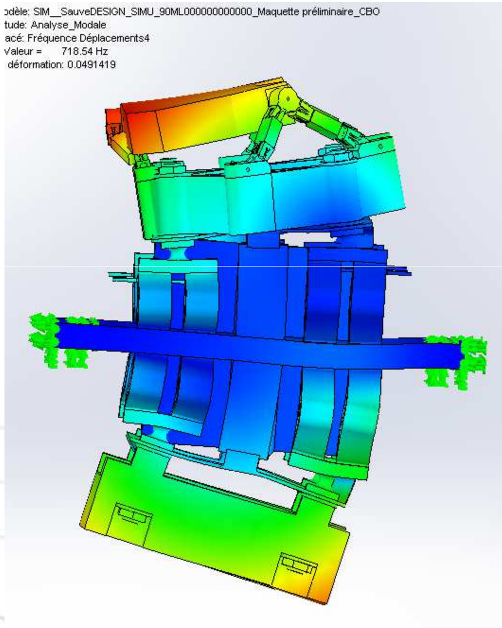
- 2 x 8 APA120ML piezoelectric amplified actuators which offer a reinforced variant for space applications
- Total moving mass 2Kg
- Available stroke
  - 80 µm
  - 1.5 mrad
- Hot redundancy
- Counter mass is balanced to match Mass, Cog and moments of inertia.



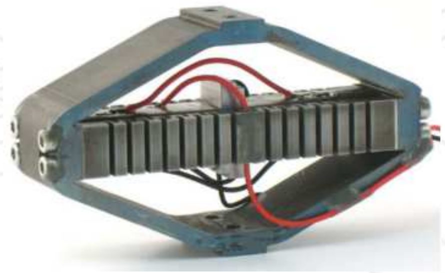
Amplified Actuator Mechanism

- Simulation results
  - 1st mode 700Hz (without support plate)

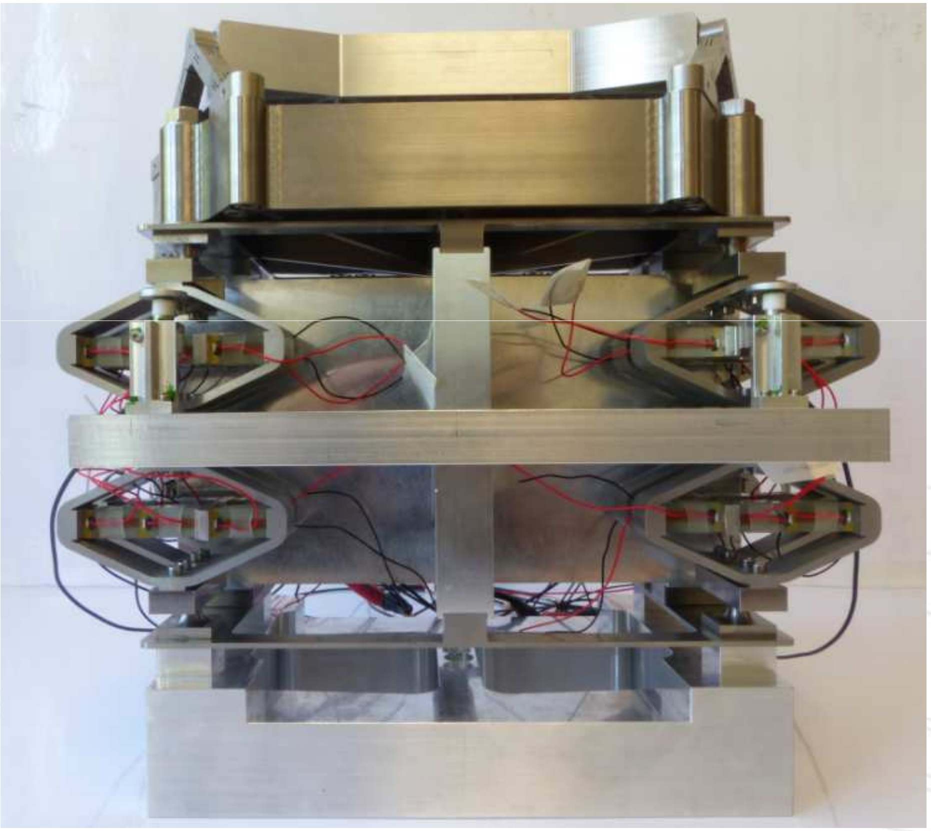


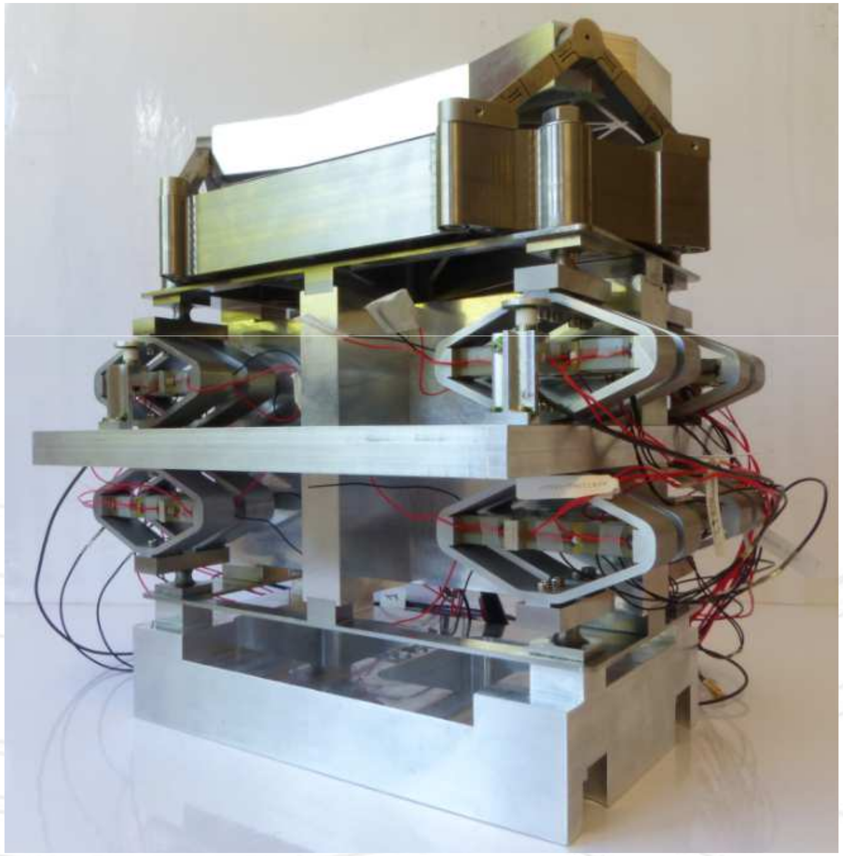


- Shocks (≈250g SRC) and Random (15g RMS) capability compliant with ECSS using reinforced APA120ML-PP



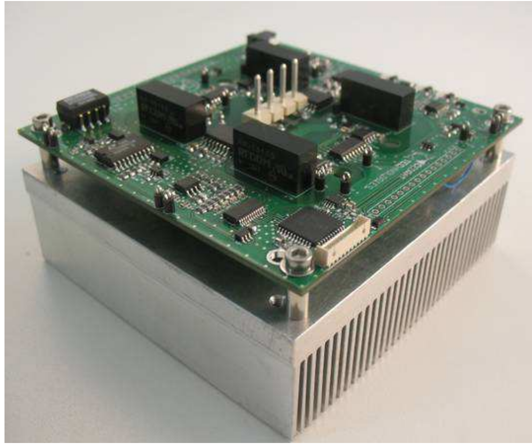
Mechanism demonstrator

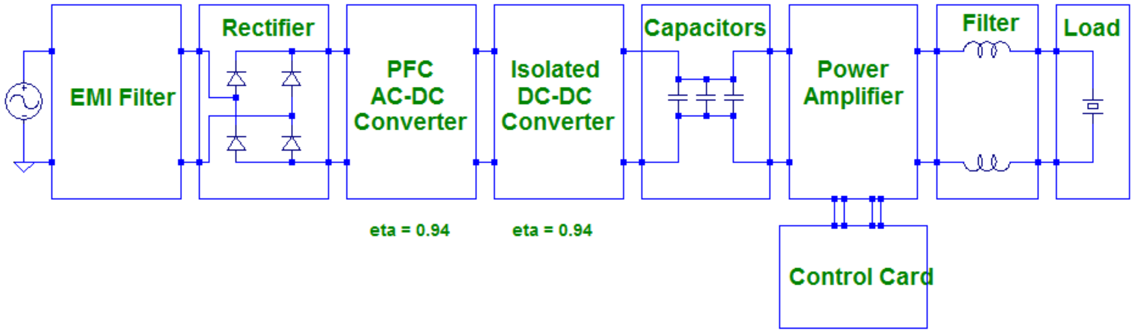




SA 75 Electronic driver

- Switching Amplifier
- Energy recovery
- Current limitation
- Protected vs. over-current & over-voltage





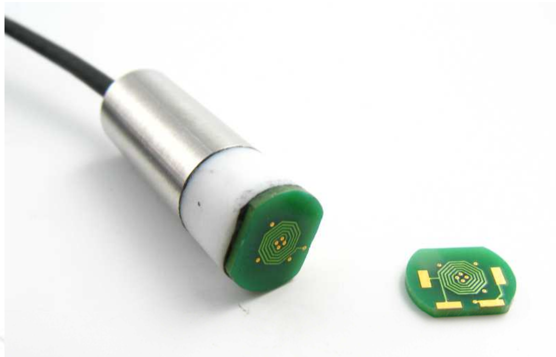
SA75 Driver properties

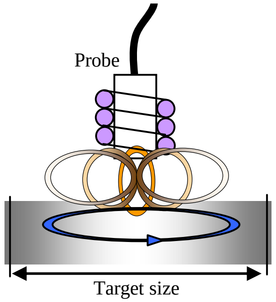
Data	*Values*
Output Voltage	*170Vppk*
Output current	*Max 20Apk continuous*
Input Voltage	*110VAC-263VAC*
Expected input power	*<75W*
Efficiency (max power)	*~93%*
Voltage Bandwidth (-3dB)	*1.3kHz*
Current Bandwidth (-3dB)	*Min 5kHz*
Output Control	*Voltage or Current*

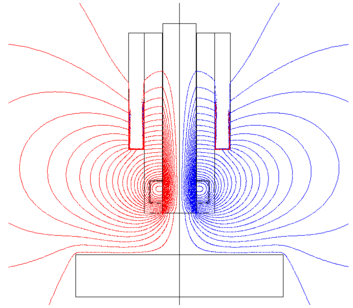
Position sensor - Probe

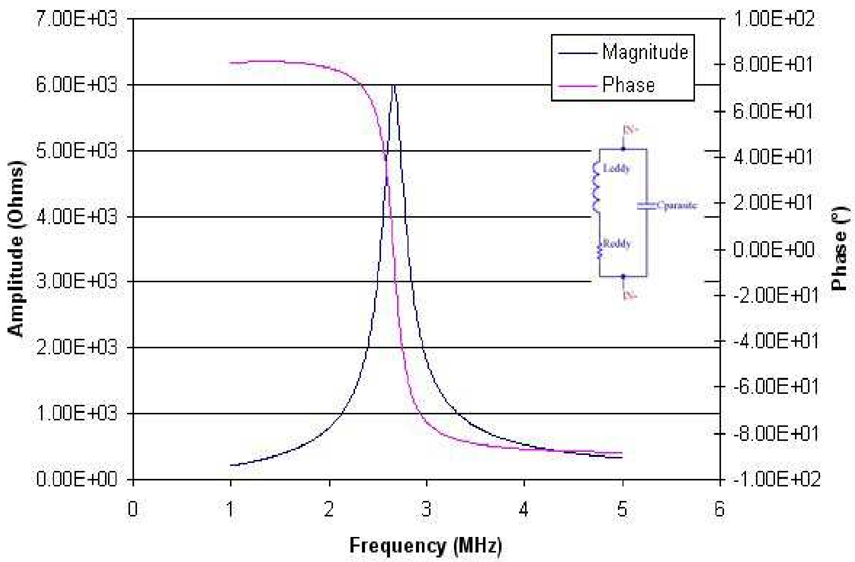
- Eddy current sensor:
  - Impedance measurement allows monitoring position

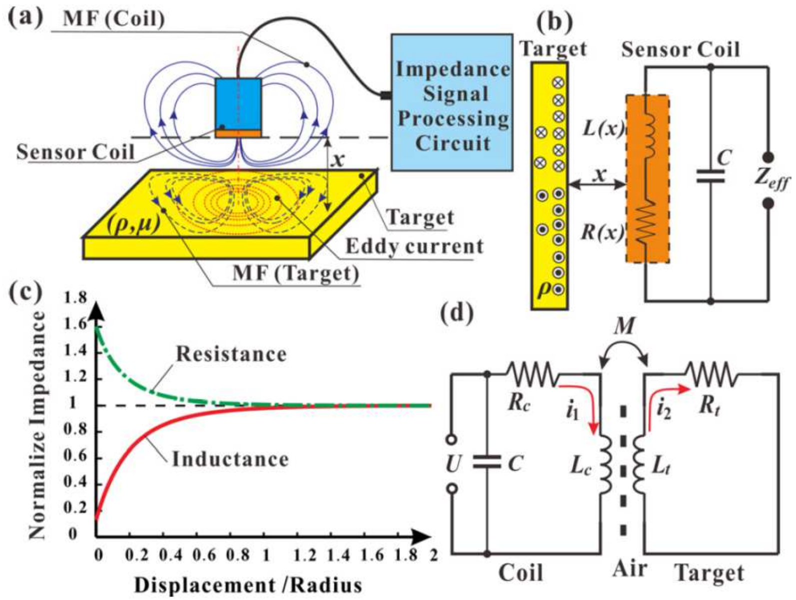
$$Zeff = R(x,T) + j\omega L(x,T)$$





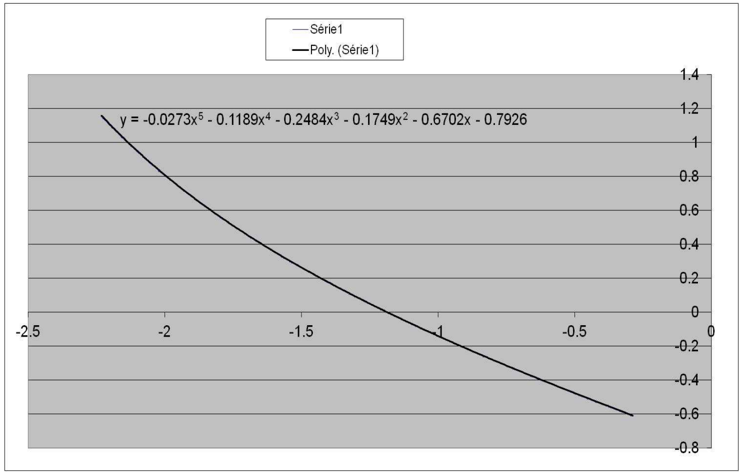






Position sensor – Conditionning electronic

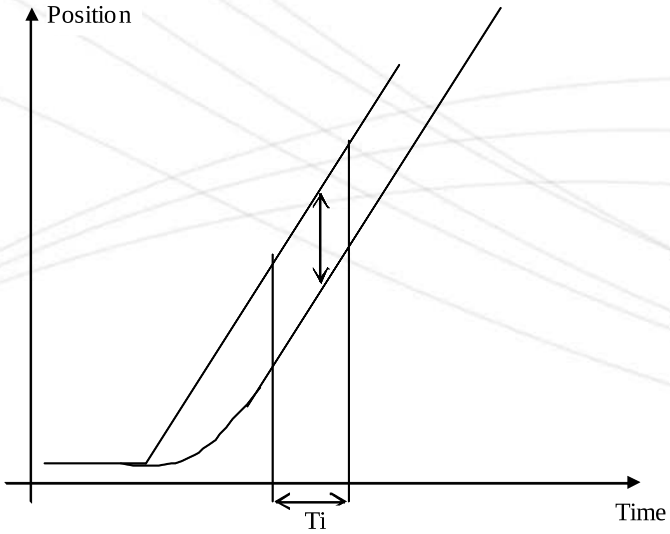
- ECS75-2 standard sensor conditioning electronic
  - Fixed frequency measurement
  - Integrated polynomial correction

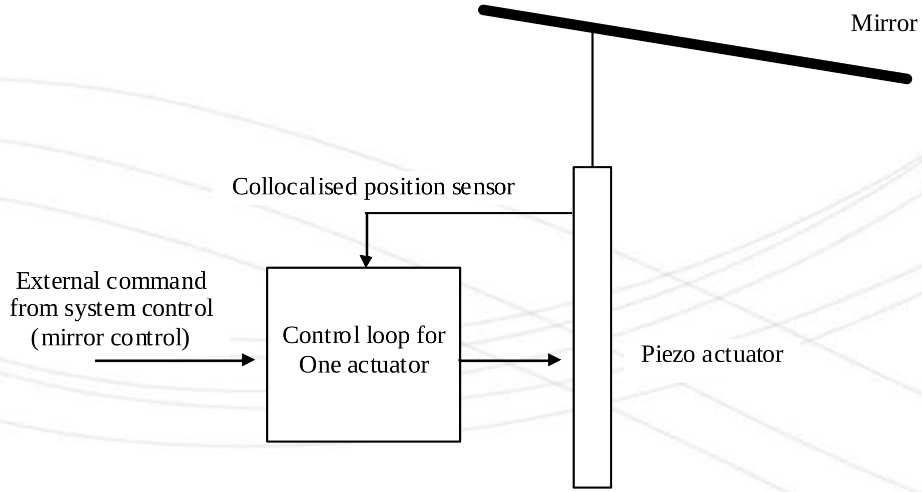


PERFORMANCES ATTENDUES	*VALEURS*
Measurement range	*50-150µm*
Linearity	*+/-1% stroke or +/-800nm*
Resolution	*< 10nm*
Short term (1cycle) repeatability	*+/-200nm*
Long term stability (3 month)	*+/-600nm*
Thermal requirement	*+/-0.5°C*
Sampling rate	*>100kSamples/s*

Base principle of the control loop

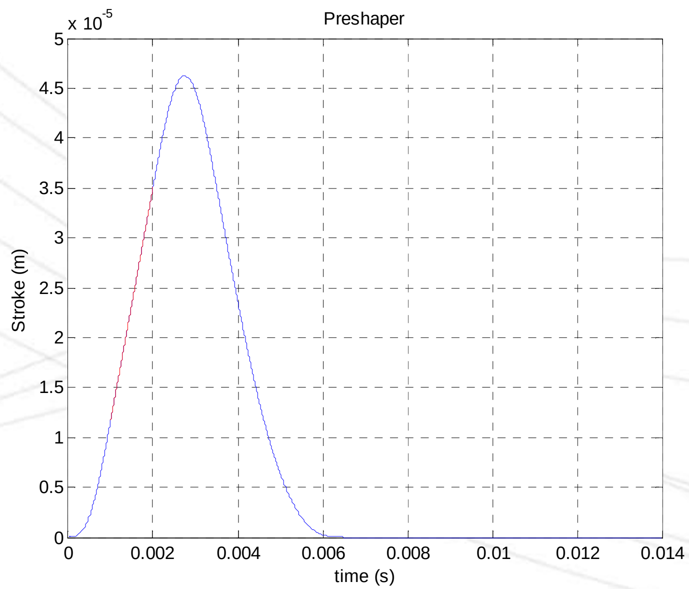
- Control strategy:
  - Ensure that following error is small and as stable as possible during the integration (Ti).
  - Linearise the piezoelectric actuators’ response using local sensor
  - Counter reacted closed loop

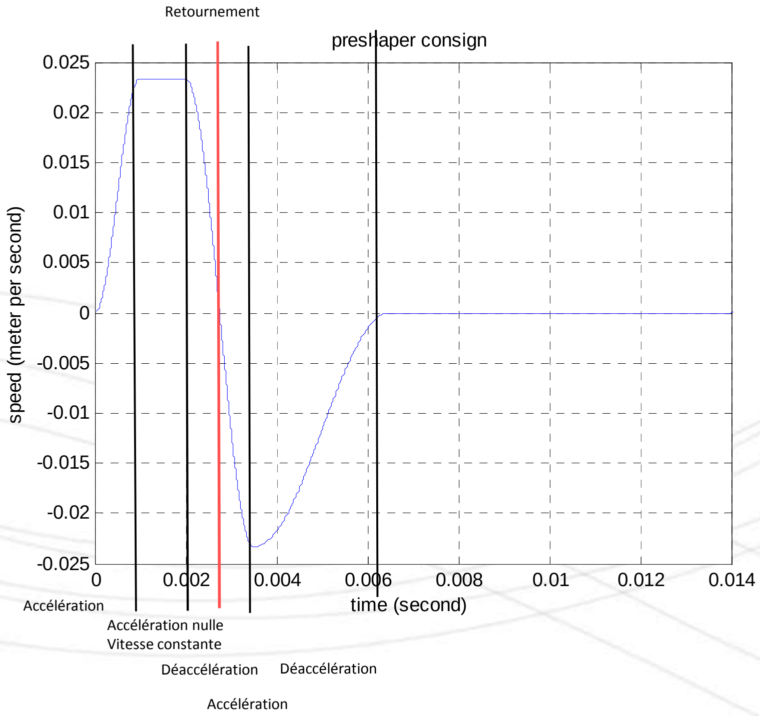




Injected profile definition

- ❑ Purpose: Shape the command signal to achieve the expected speed position/speed command while avoiding discontinuities.
- ➢ Reduce oscillations and rejected µvib in the overall structure

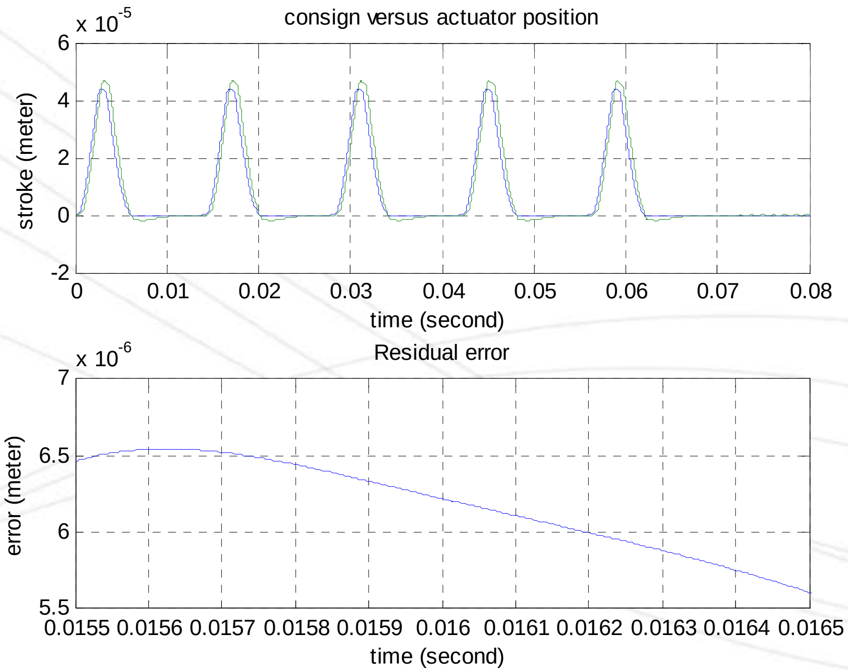




Control law design
Single mode foot model

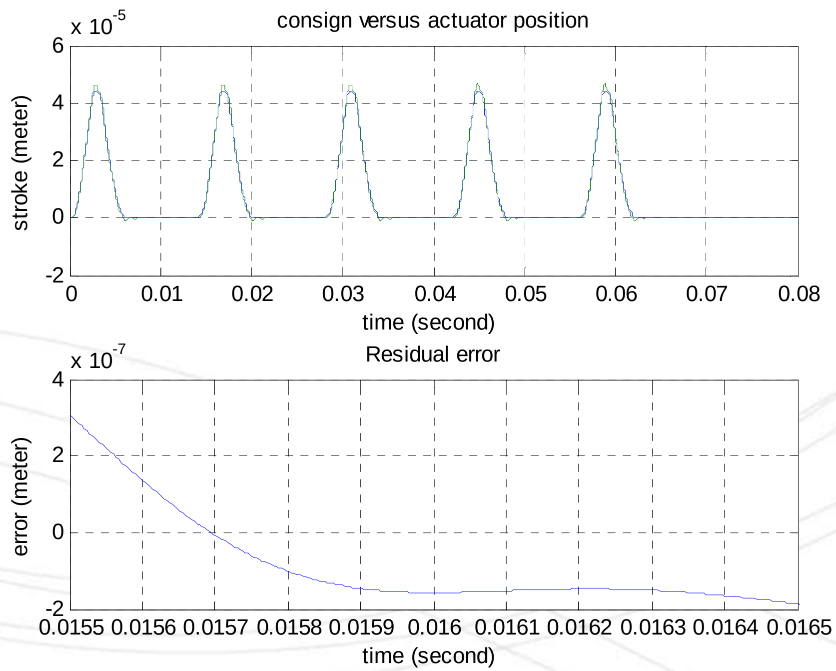
- Preliminary study based on Fr≈800Hz foot resonant mode assumption
- ≈25 / 50 µm useful displacement, Ti = 1ms

Without preshaping



Residual error: ~1.5µm

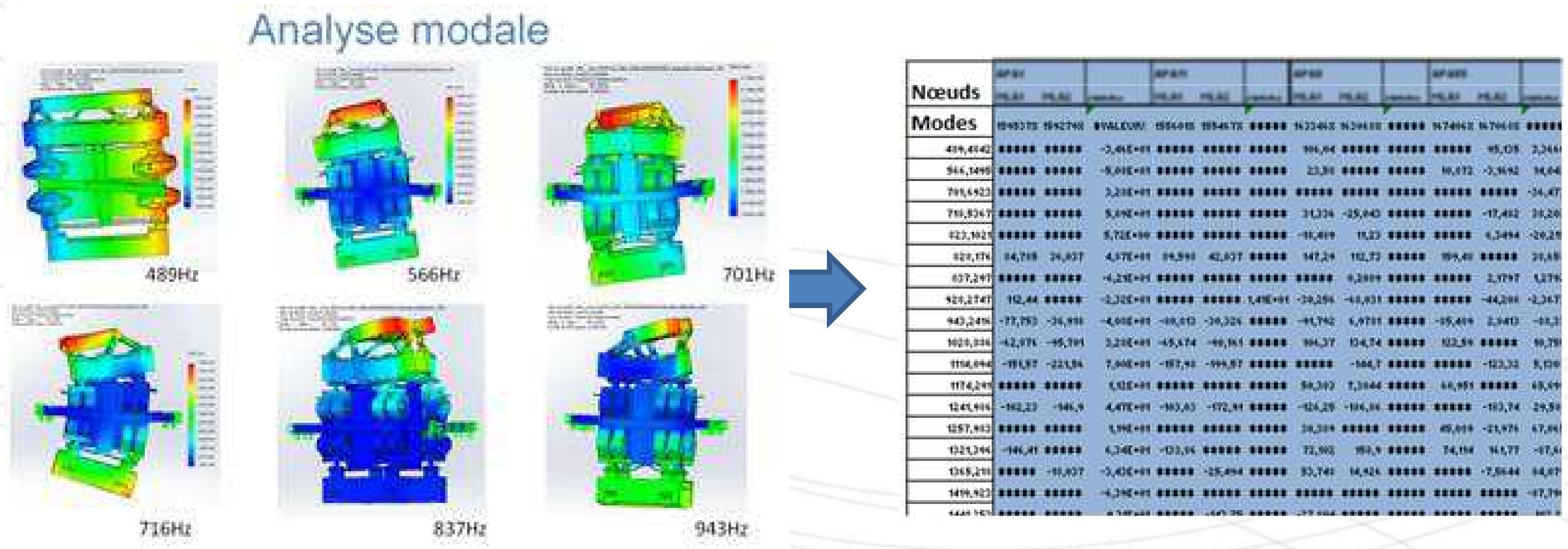
With preshaping



Residual error: ~500nm over Ti, ~100nm over Ti/2

Mechanism dynamic model
Multiple inputs / outputs / modes

- Dynamic model of the complete mechanism is built in MATLAB/Simulink
  - Based on Finite Element Model
  - Piezoelectric components electromechanical conversion is included



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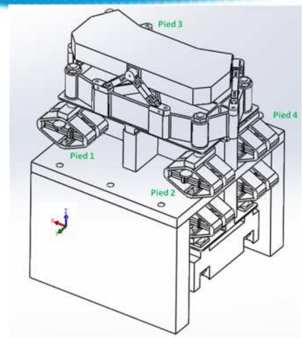
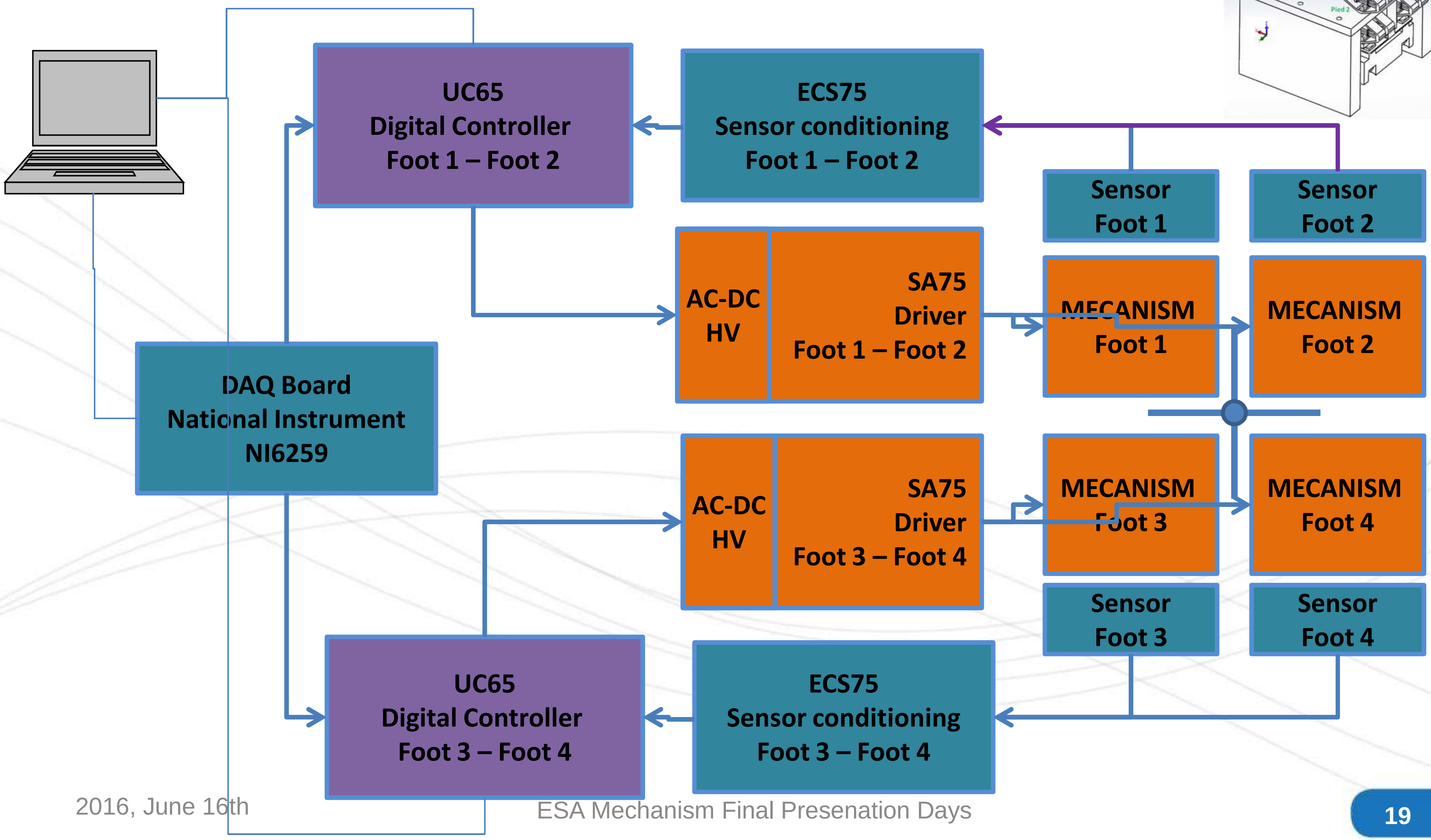
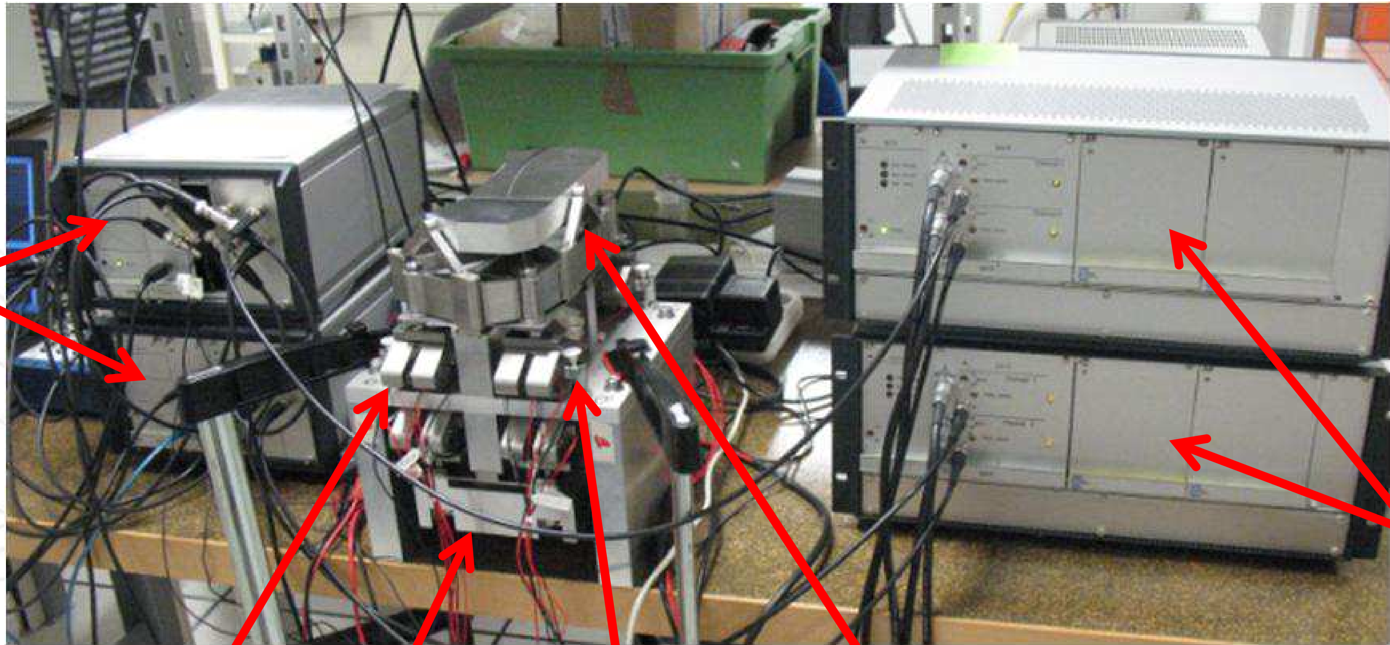
Electrical architecture

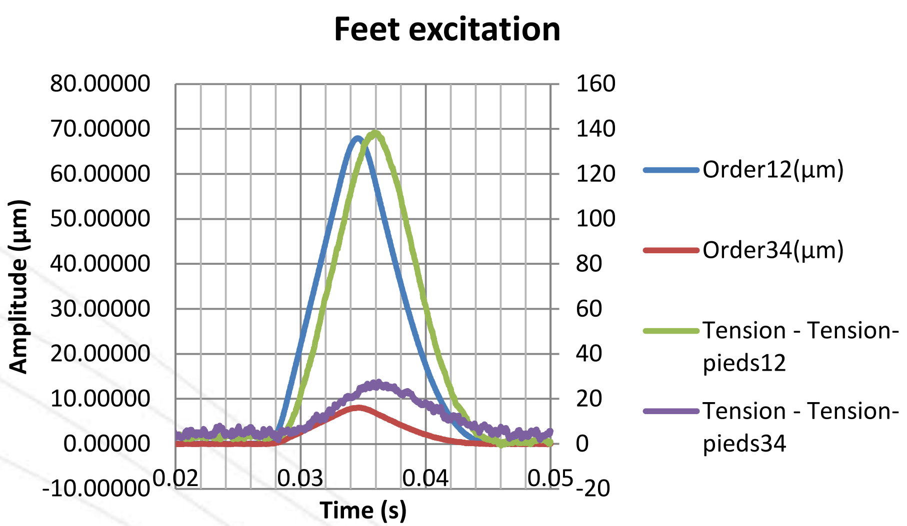


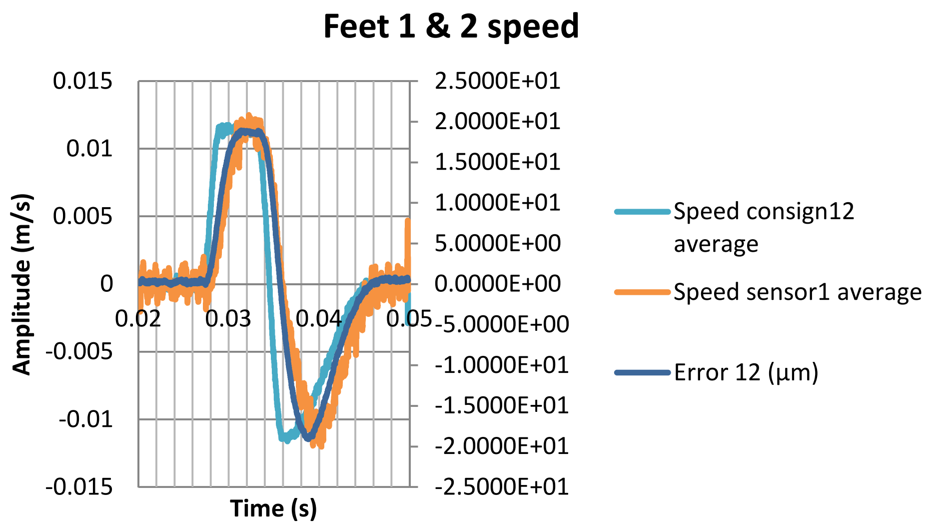


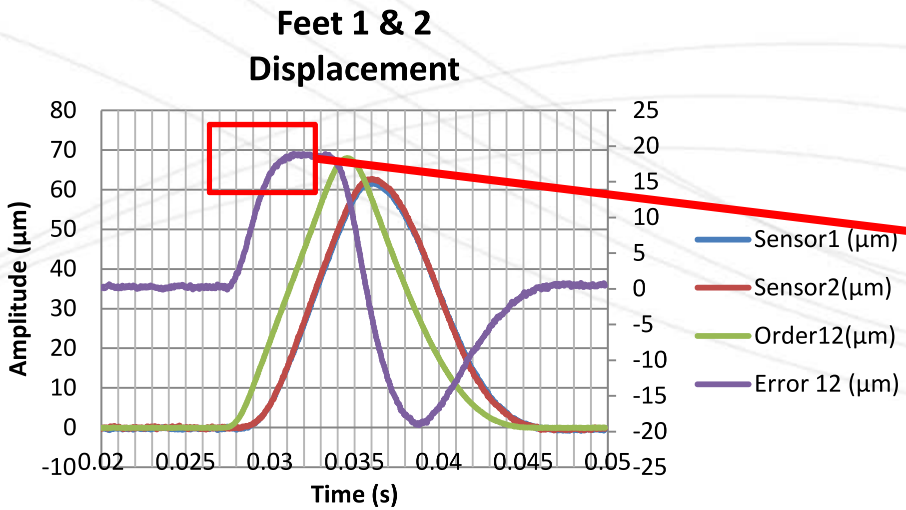
Overview of test bench

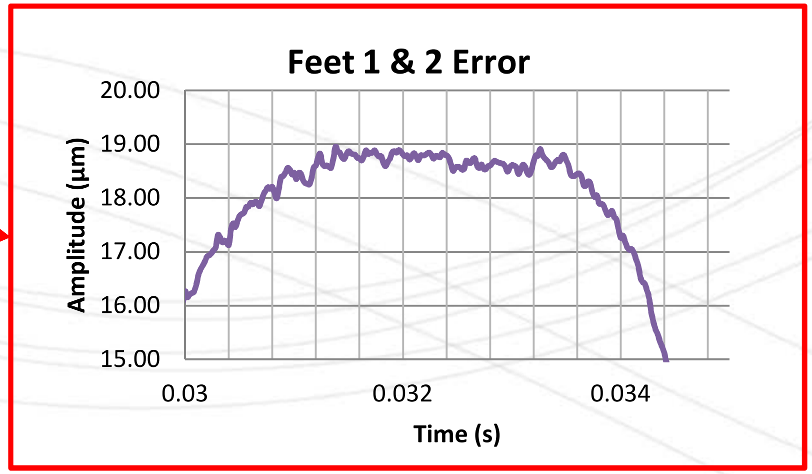


Control loop test results





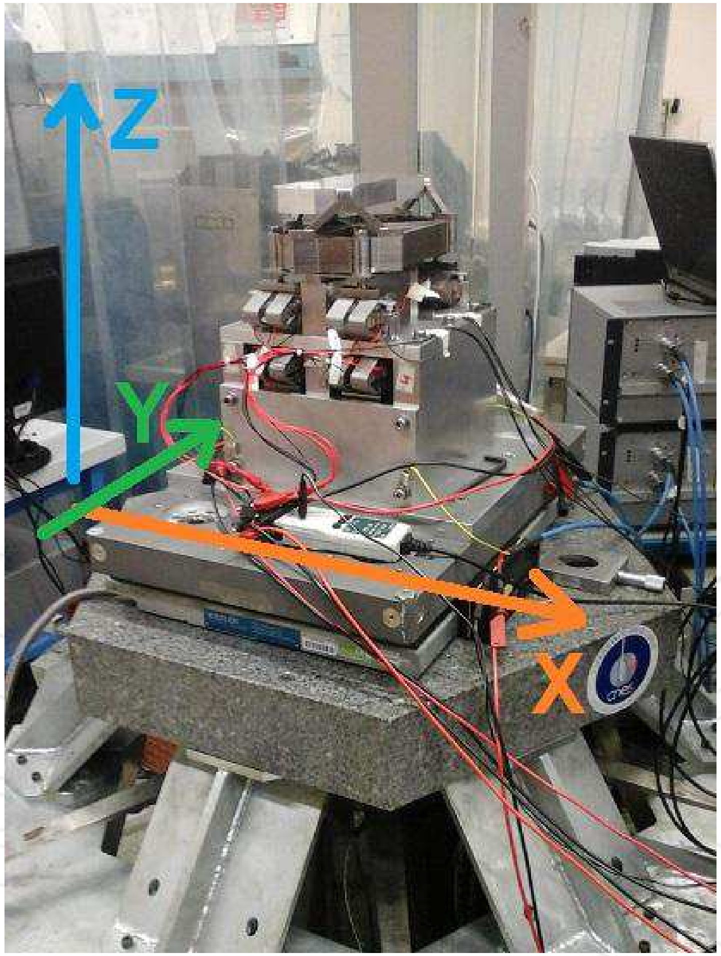




Rejected vibrations measurement

- Measurement done in Toulouse at CNES CST facilities with CNES funding.

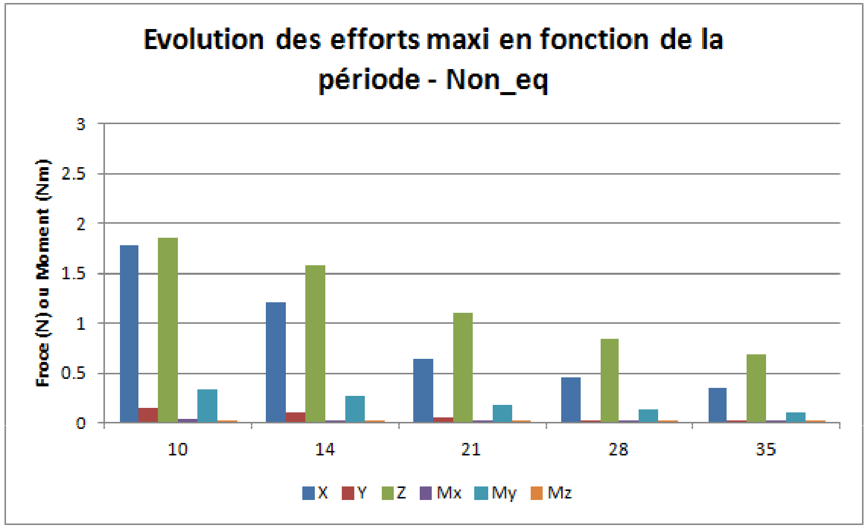
- Operating mechanism with and without countermass and measure rejected forces & moments

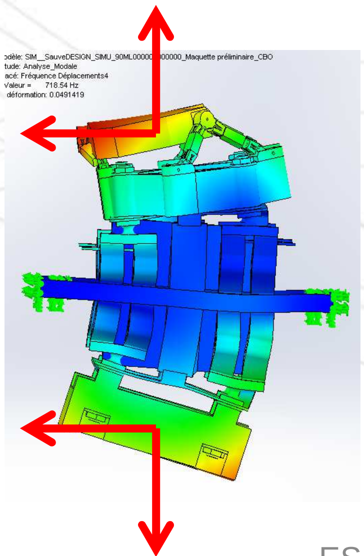


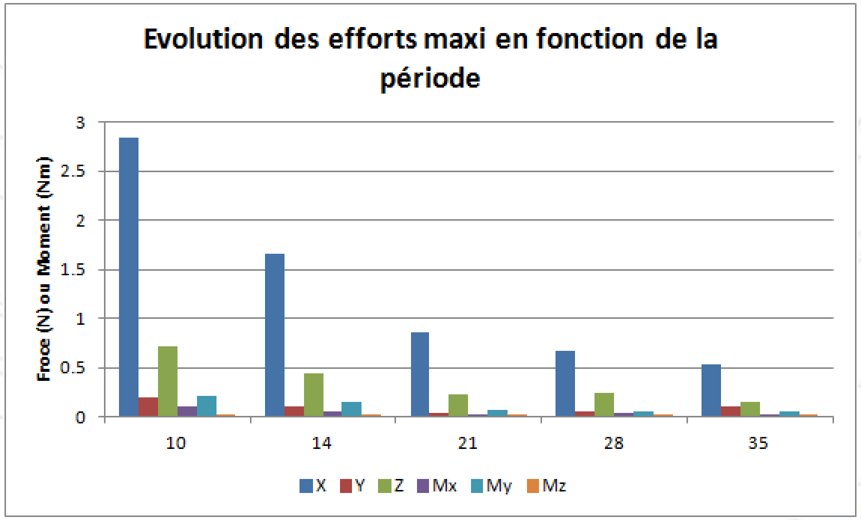
Verification of countermass influence

- Various cycle speed tested

- Result
  - Negative influence for X and MX due to CoG offset
  - Significant improvement for Z, MY







Conclusion

- MEFISTO mechanism designed, built and tested.
  - It provides 1.5 mrad / 80µm displacement capability.
  - Using reinforced actuators, it can survive launch shocks and vibrations
  - Fast moving capability for 0.75 kg mirror is demonstrated
- A complete closed loop test bench has been built
  - Simulation capability has been demonstrated
  - Control law have been tested to verify filet compensation capability
- The rejected forces & moments have been measured

- **The MEFISTO project has allowed us to go through all the key aspects for a fillet compensating mechanism. The lessons will be valuable addition for future design of similar mechanisms.**

- We would like to acknowledge CNES and French DGA for their continuing support in this project.