Piezoelectric components for usual space and cryogenic environment

ESA Space Passive Component Days

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CEDRAT TECHNOLOGIES
Innovation in Mechatronics

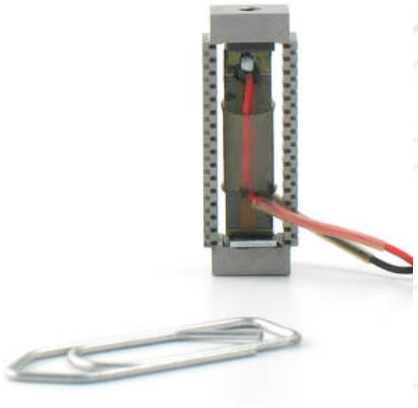
Summary

- Piezoelectric actuators in space applications
- Proposal for ESCC Generic specification
- Piezoelectric actuators in cryogenic environment
- Example of CFSM cryogenic mechanism
- Conclusion

Piezoelectric actuator

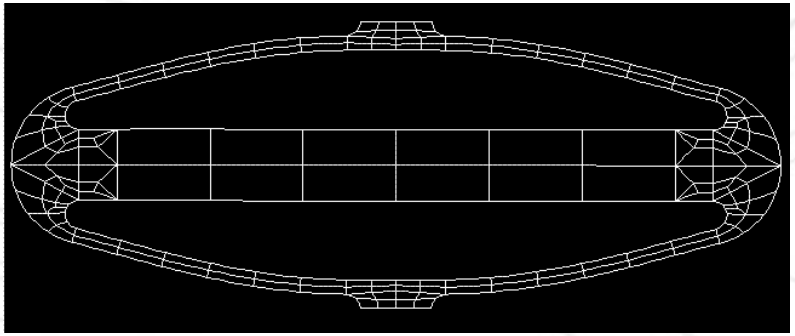
- 2 types of piezoelectric actuators
  - High voltage actuators
    - Simple stacked structure
    - Typical layer thickness : 5 mm
    - High voltage : > 1kV max voltage

  - Multilayer Actuators
    - Complex sintered structure
    - Typical layer thickness : 0.1 mm
    - Low voltage : 50 to 200V max voltage

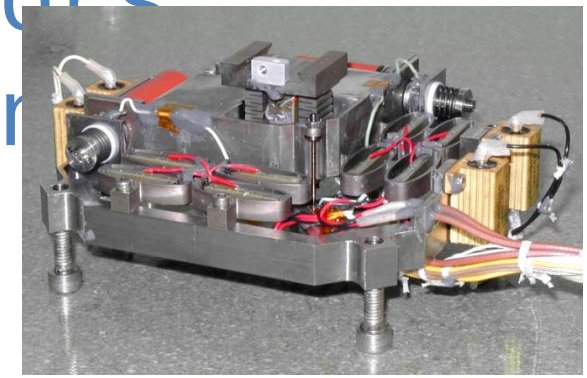


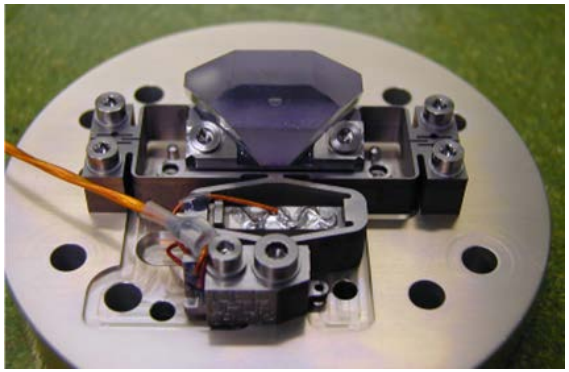
APA : Amplified Piezoelectric Actuator

- Base elements
  - 1 metal shell
    - Piezoelectric ceramic preload
    - Displacement amplification
  - 1 piezoelectric ceramic
  - 1 metal wedge

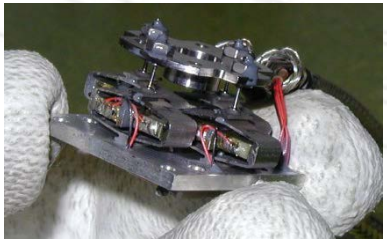


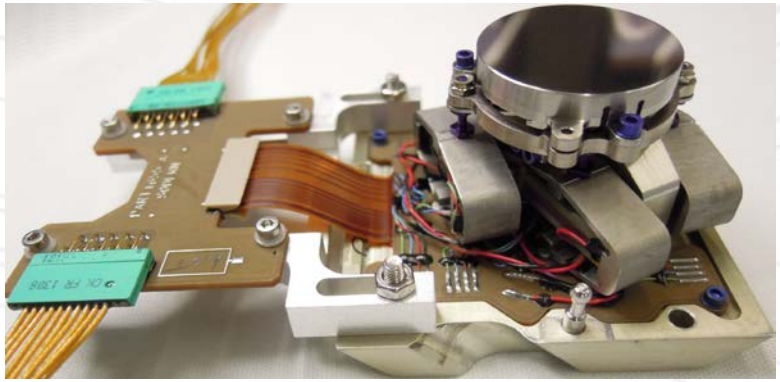
Piezoelectric actuators for space application





- Over the years, several actuators and mechanisms have been qualified and flown with piezoelectric components inside
  - Rosetta-MIDAS (flying)
  - PICARD
  - SWARM
  - LISA
  - Pharao
  - …..





Piezoelectric components specificities

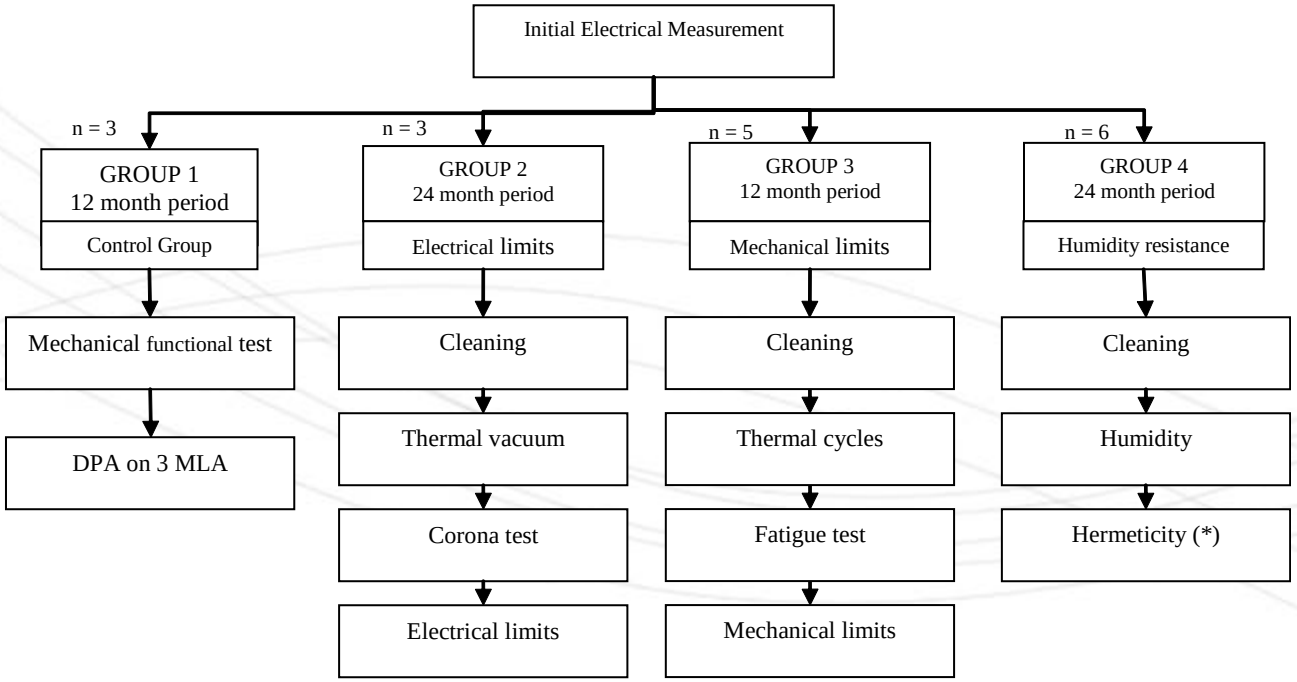
- Piezoelectric components are both
  - Electrical components
  - Mechanical components

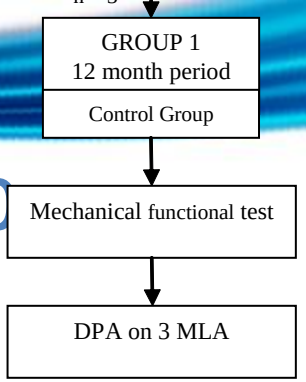
- Several suppliers available, most components vacuum compliant but no components dedicated to space applications

- A GSTP has been started by ESA to improve the accessibility of piezoelectric components in Space Applications

ESCC Generic specification

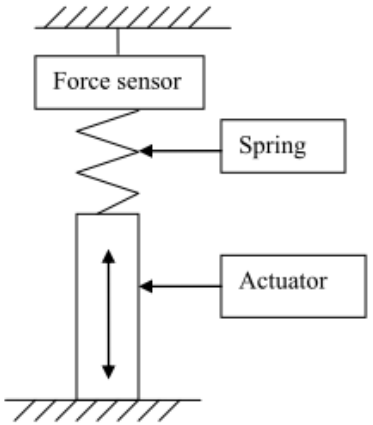
- Define activities to be performed to propose a qualified component usable off the shelf.
  - In process control verification (mainly electrical tests).
  - Qualification tests to be performed (to be repeated periodically) :

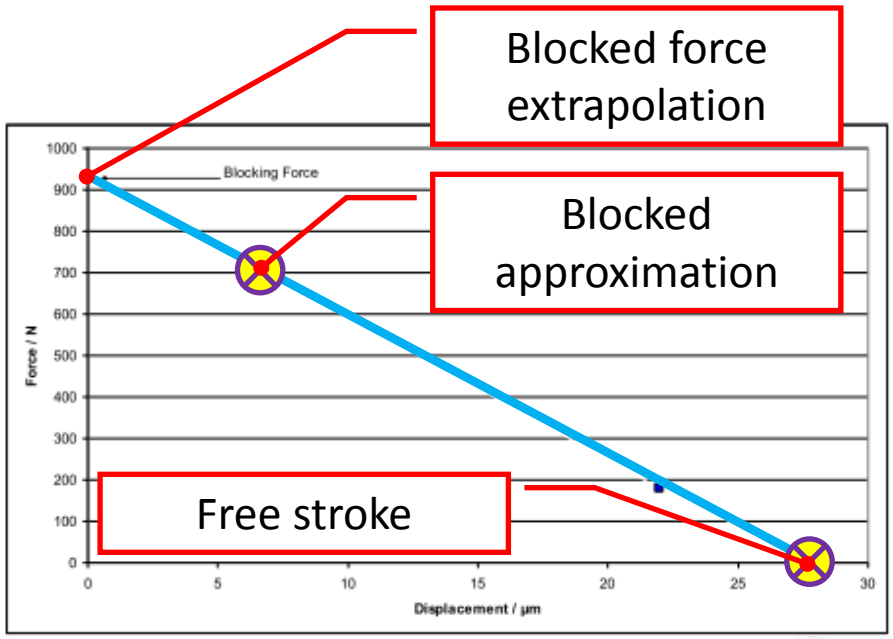


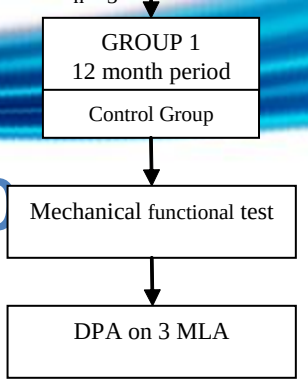


Group 1 : Control group

- Mechanical functional test
  - Measurements
    - Free stroke (f < 10Hz, sinus or triangle signal)
    - Resonant frequency in free-free conditions
    - Blocked force

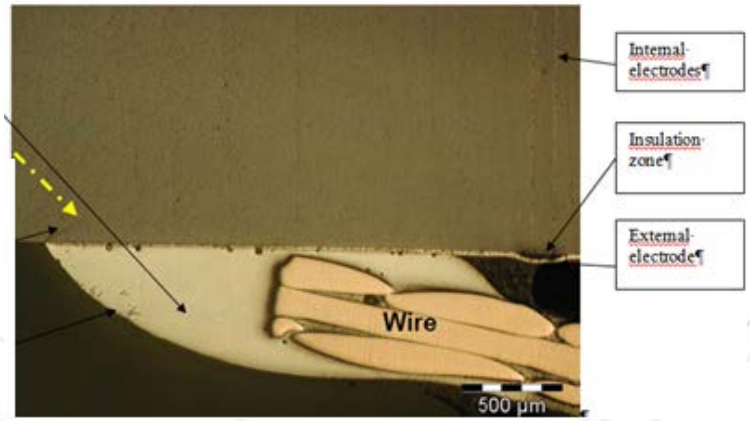


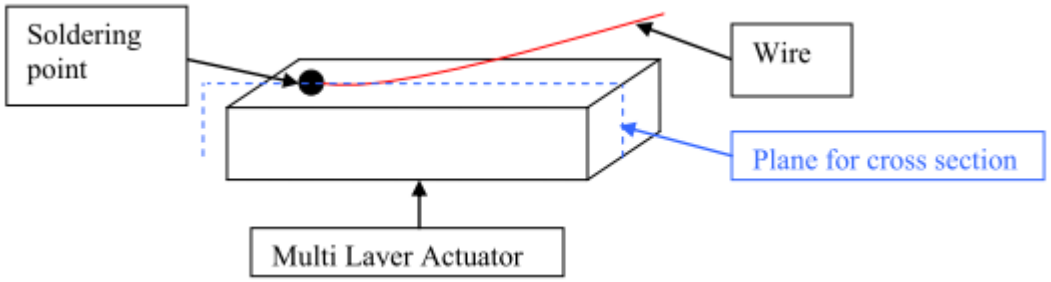




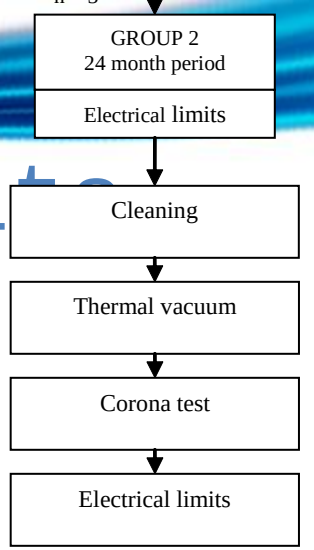
Group 1 : Control group

- Destructive Part analysis
  - Cross section done in the soldering plane
  - Criteria to check:
    - Distance between inter electrode
    - Ceramic porosity and micro defects
    - Coating thickness (if any)
    - Soldering point quality (cavities, micro-shrinkage…)



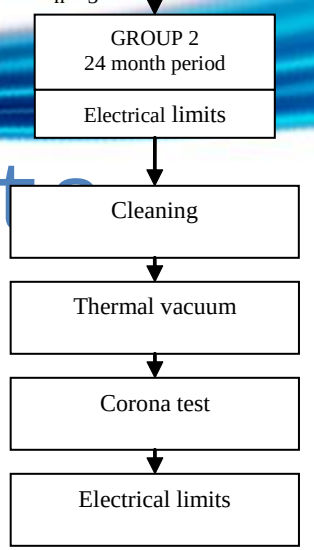


Group 2 : Electrical limits

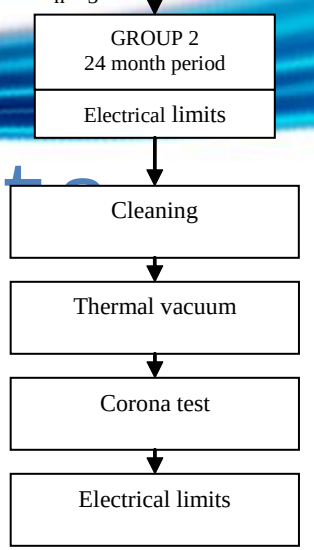


- Cleaning resistance
  - Critical for numerous space project were cleanliness is a critical aspect.
  - No ultrasonic bath requirement
  - Alcohol only (No requirement for water or strong solvent)

Group 2 : Electrical limits

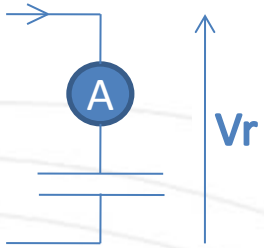


- Thermal vacuum
  - MLA operated under vacuum
    - Pressure lower than 10^{-5}mbars
    - Temperature: 80°C
    - Signal @10Hz for 1000 cycles
    - Voltage from 0V-Vr
  - Criteria is limited variation of
    - Electrical capacitance
    - Free stroke

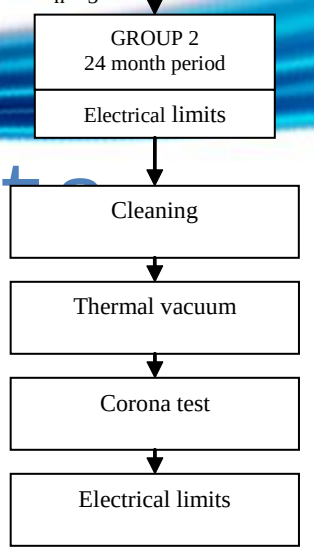


Group 2 : Electrical limits

- Corona Test (verify PASCHEN Effect)
  - Test conditions
    - Test done under low of dry nitrogen (to avoid humidity)
    - Rise of the pressure from 10^{-6} Torr to ambient (1decade/min)
    - Rated voltage (DC) applied during test

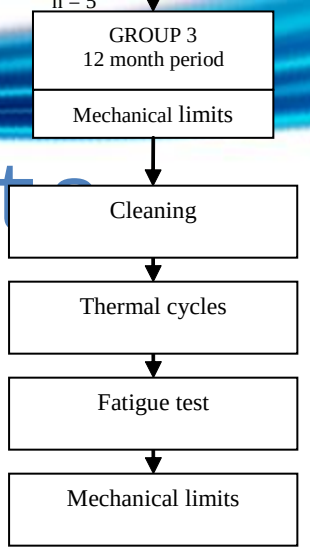


  - Criteria
    - Variation of leakage current during pressure rise.



Group 2 : Electrical limits

- Electrical limits
  - Test conditions
    - Rh below 50% during test
    - DC voltage applied : V = 1.5 x Vr (Vr = Rated voltage)
    - Duration: 1min
  - Criteria :
    - Electrical resistance remains unaffected during and after test.

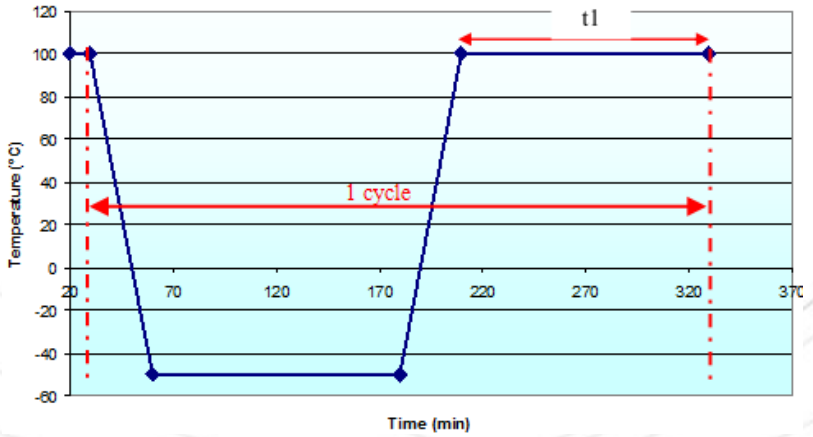


Group 3 : Mechanical limits

Thermal cycles test

Test content

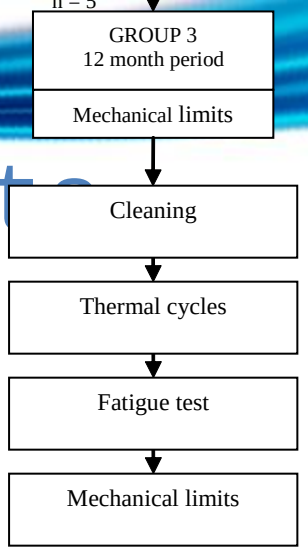
- Voltage =0V (i.e. shortcut)
- Air or vacuum
- -50°C / +100°C (target is to cover general range of temperature in space projects)
- Temperature shall not exceed component's Curie temperature
- 8 cycles



Criteria : limited change (after 24h recovery) of

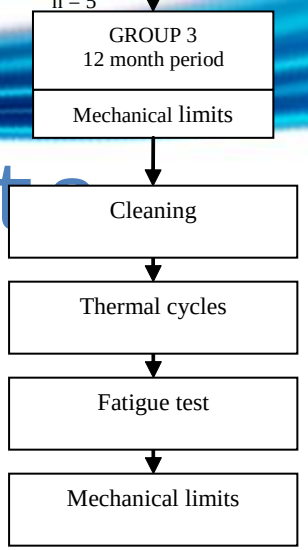
- Electrical capacitance,
- Electrical loss angle.

Group 3 : Mechanical limits

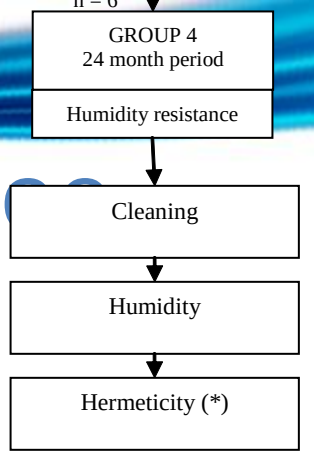


- Fatigue test
  - MLA shall be preloaded (i.e. avoid tensile stress during test)
  - Driving signal close to resonant frequency (reduce test duration and thermal dissipation)
  - Driving amplitude shall allow a strain of 1000ppm.
  - Number of cycles: 10^9
  - Success criteria : limited change of
    - Capacitance
    - Free stroke

Group 3 : Mechanical limits



- Mechanical limits
  - Apply 1.5 times the blocking force to the component (typically 60MPa)
  - Success criteria :
    - No visible damage
    - Limited variation of
      - Electrical capacity
      - Electrical loss angle
      - Free-Free resonance frequency



Group 4 : Humidity resistance

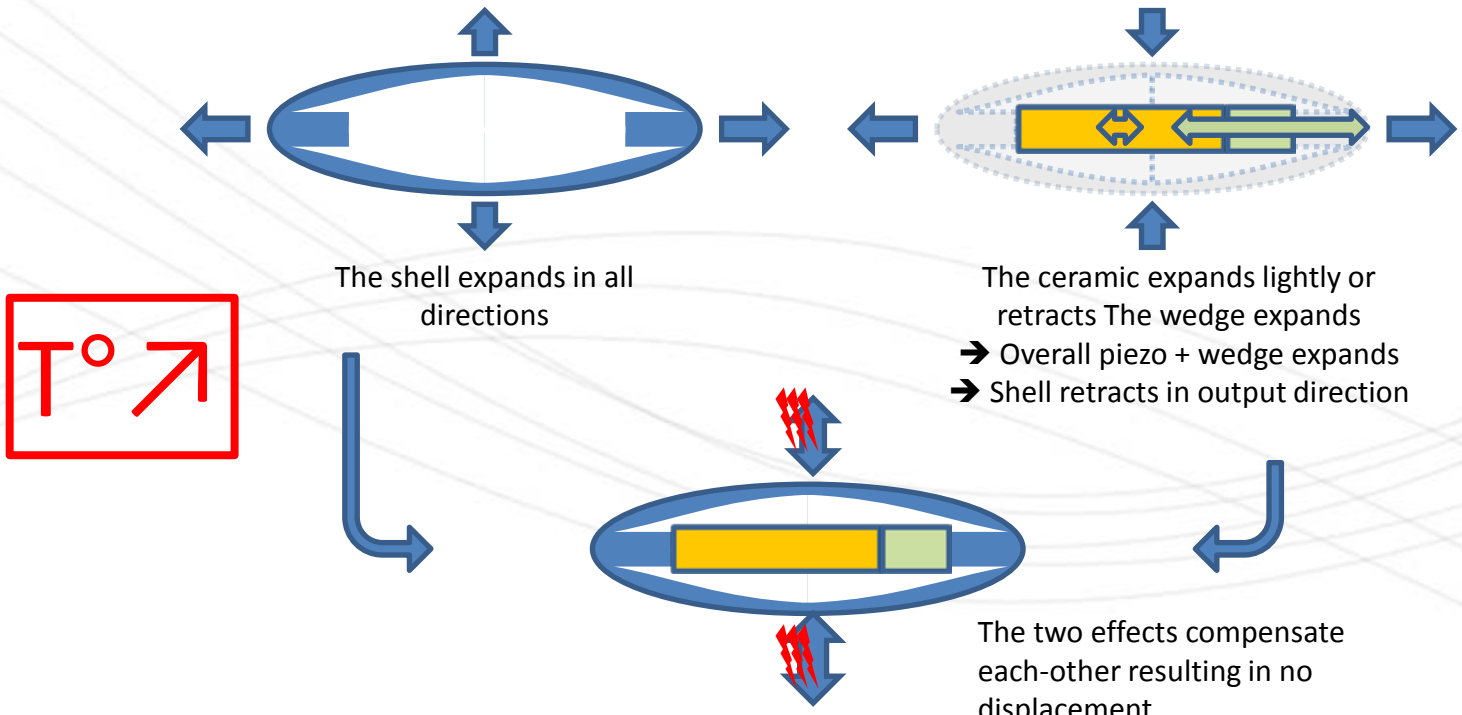
- Humidity test
  - 3 test batches with different humidity
    - 4 components tested per batch
    - DC input @ rated voltage
    - 2000h duration
    - Rh levels: 30%; 60%, 80%
  - Success criteria
    - Limited increase of leakage current during test
    - 1 failure out of 4 allowed for 80%

ESCC Generic specification

- Usual tests excluded from qualification tests:
  - Mechanical environment (Sine, Vibrations, shocks, …).
    - The MLA has to be pre-loaded for these tests;
    - Payload and upper system influence is too important to define a generic test that would be relevant
    - Component's own inertia is too low to generate significant internal forces
    - Stress level partially covered by reliability test

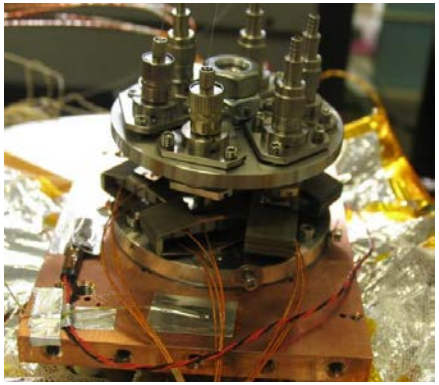
Thermal compensation

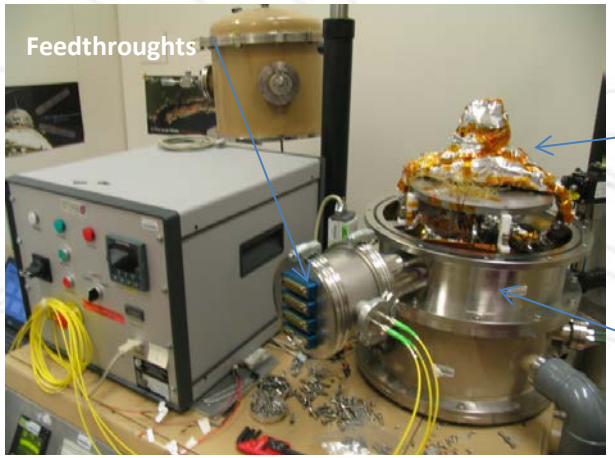
- Manage thermal expansion of materials
  - Wedge is selected in order to achieve appropriate expansion
  - The same shell can be used with various types of piezo component
  - Overall CTE can be 0 with piezo-ceramic range of [-6 ; +1.5] µm/m/K.

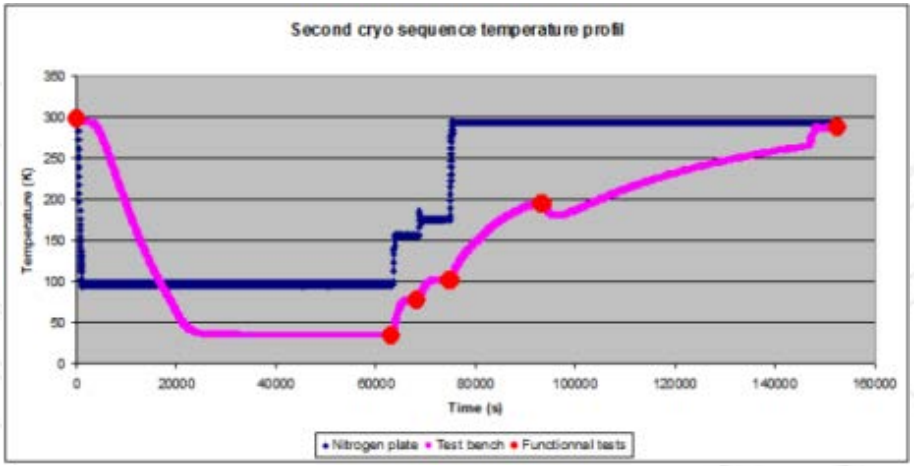


Test bench

- Thermal vacuum chamber in CNES Toulouse
- Differential measurement to compensate bench movements
- 2x3 measurement, fibered interferometer
- From room temperature down to <40K



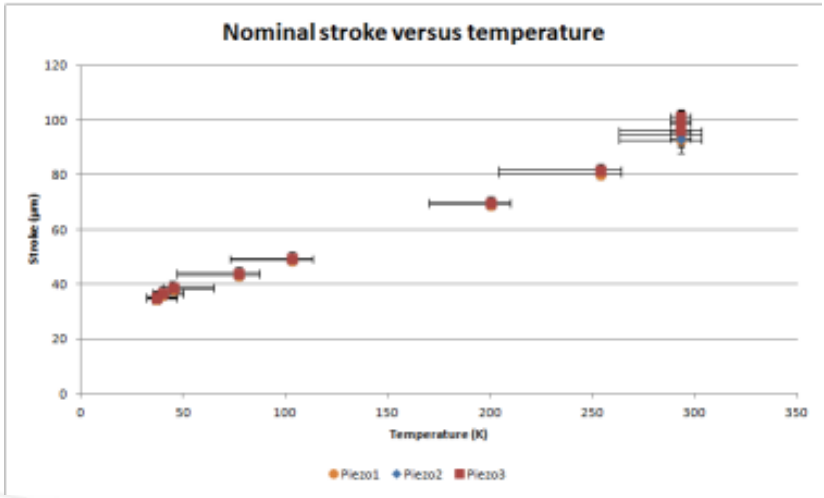




Cryogenic actuator

- Stroke reduction is roughly linear when temperature decreases

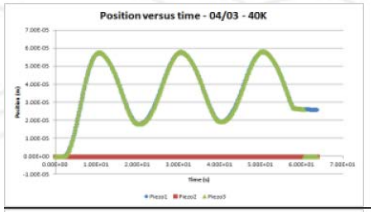
	APA X	APA Y	Unité
Stroke room temp.	95	81	µm
Stroke 40K	36	16	µm
% room/ @40K	39	20	%

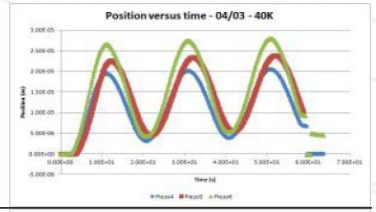


- First activation offset

Piezo Y | Piezo X

1 st





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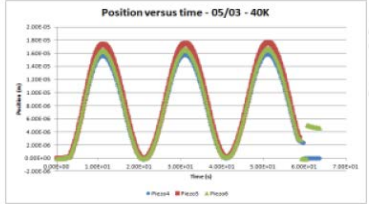
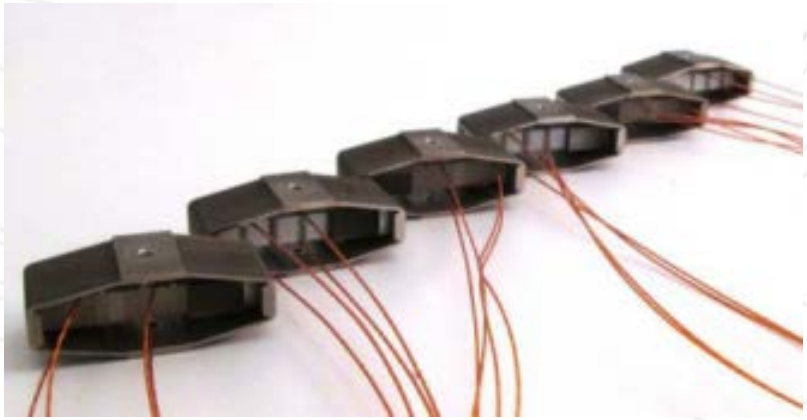
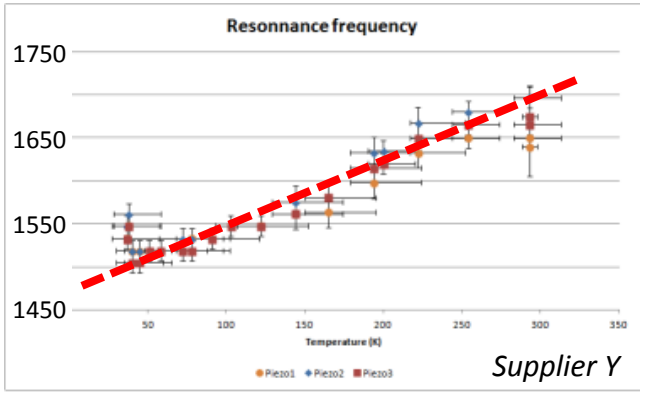


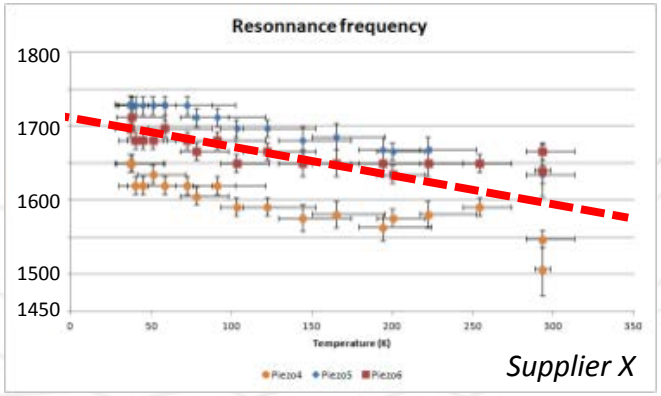


Actuator caracteristics

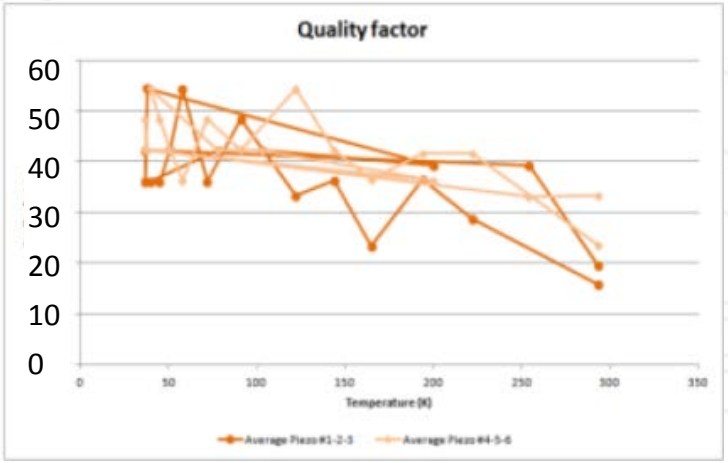
- Resonance frequency
  - Blocked – Free conditions
  - Variation is different between ceramic suppliers
- Quality factor (i.e. Damping)
  - Q factor increases when temperature decreases
  - Consistent with literature



Supplier Y

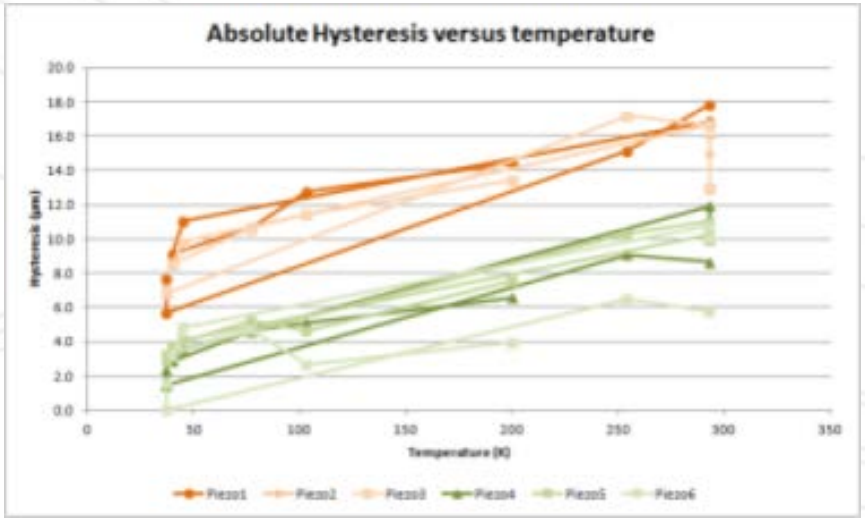


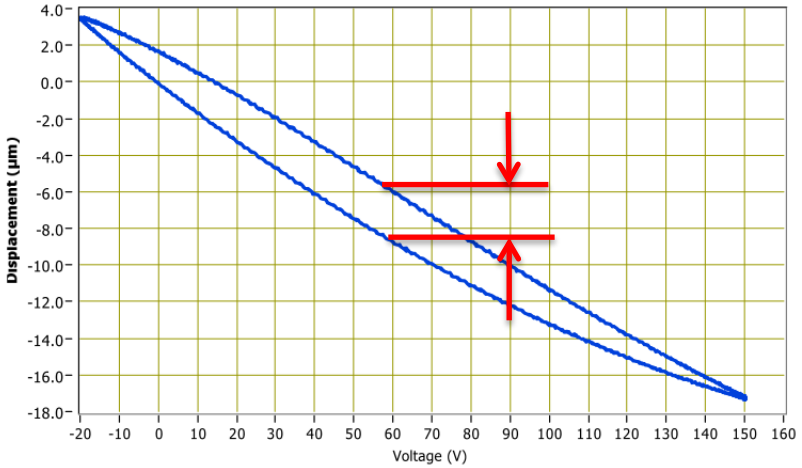
Supplier X



Actuator caracteristics

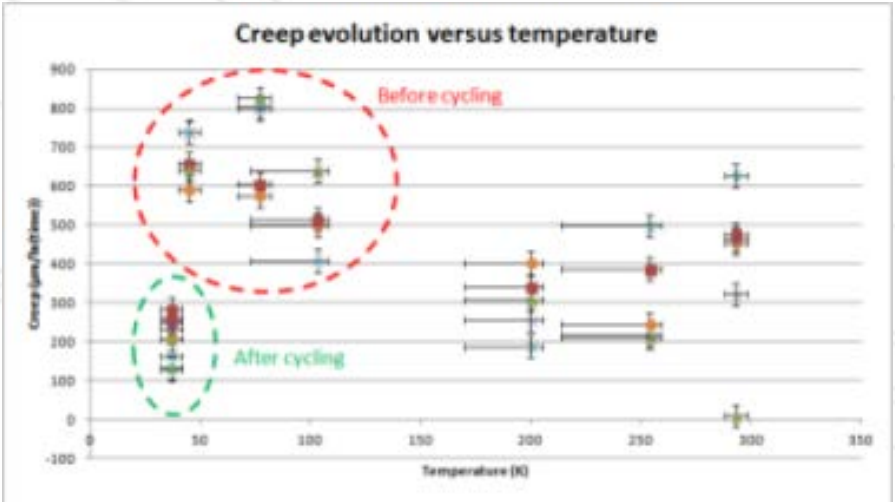
- Hysteresis
  - When temperature decreases:
  - Hysteresis amplitude is reduced
  - Relative hysteresis is increased

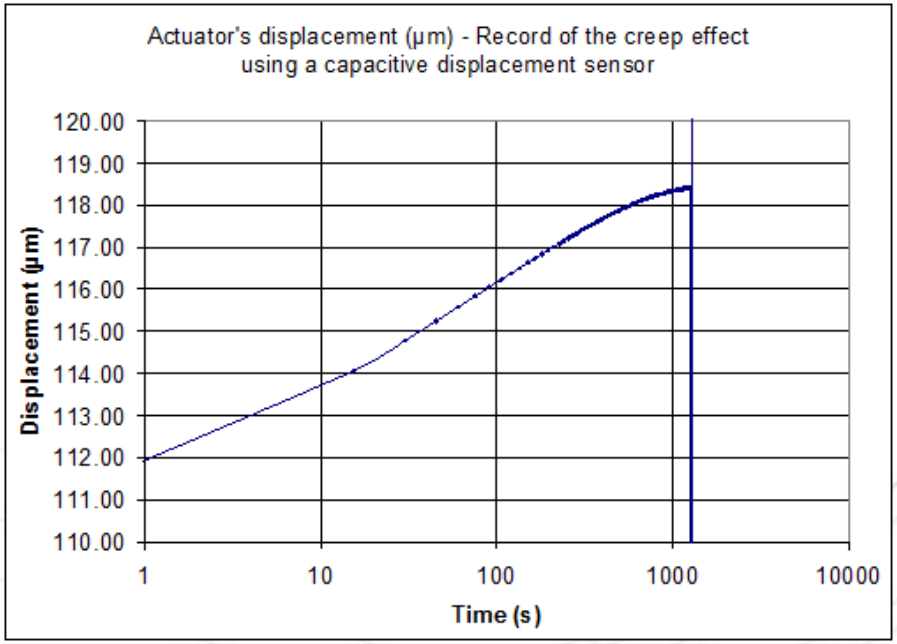




Actuator caracteristics

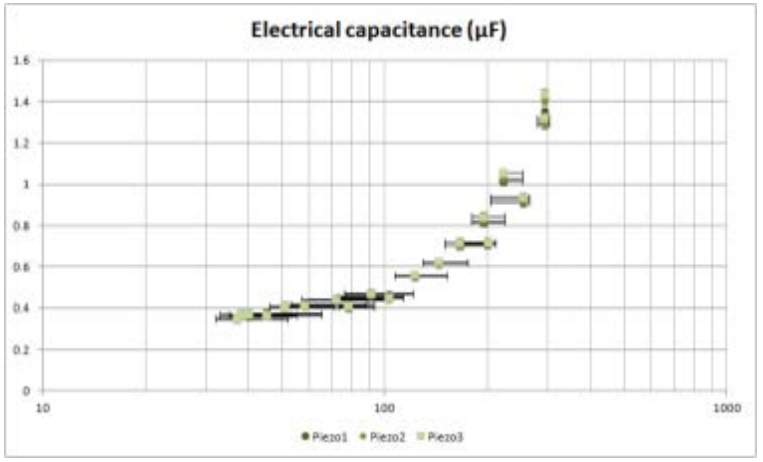
- Creep
  - Creep increases immediately after temperature decrease
  - Creep stabilises at lower value after cycling



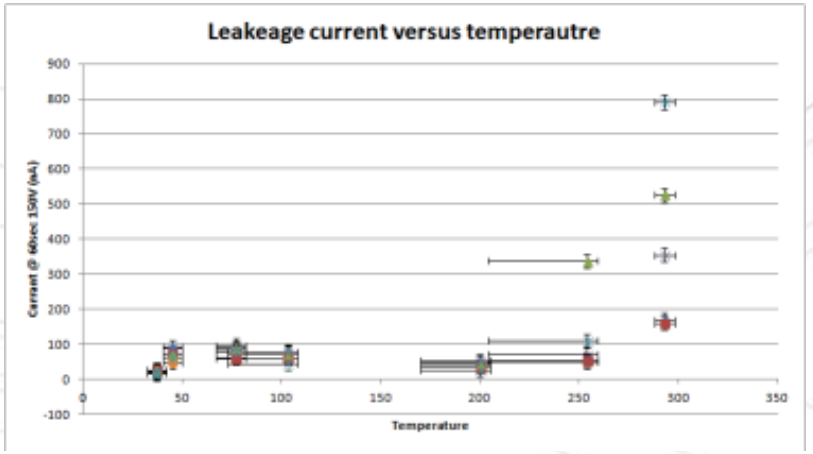


Actuator caracteristics

- Electrical capacity
  - Decreases when temperature is reduced
  - Roughly logarithmic behaviour
  - Stable behaviour with preloaded components



- Current leakage
  - Tested at 150V after 60s
  - Decreases when temperature is reduced
  - Similar behaviour for the 2 tested ceramics (<100nA @ 40K)

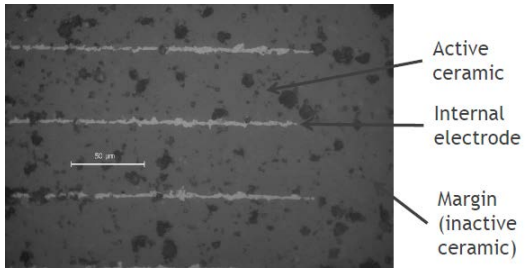


CFSM : Specifications

- 2 DoF mirror CFSM
  - Stroke of +/-0.75 Arcsec at 10Hz in cryo environment
  - High resolution: <1mArcsec
  - Low power <10mW peak dissipation
  - Ø60mm diameter
- Evaluation of thermo-mechanical behaviour [300K -> 30K]
  - Angular drift < 100 mArcsec in tip tilt (with active compensation)
  - Axial drift < 100µm along piston
    - **Life duration: 2 years on ground and 5.5 years in orbit operating continuously**
- Environmental
  - No use of HDRM: All directions
    - Sine Vibration: 20Gn
    - Random: 17Grms
    - Shock: 700Gn

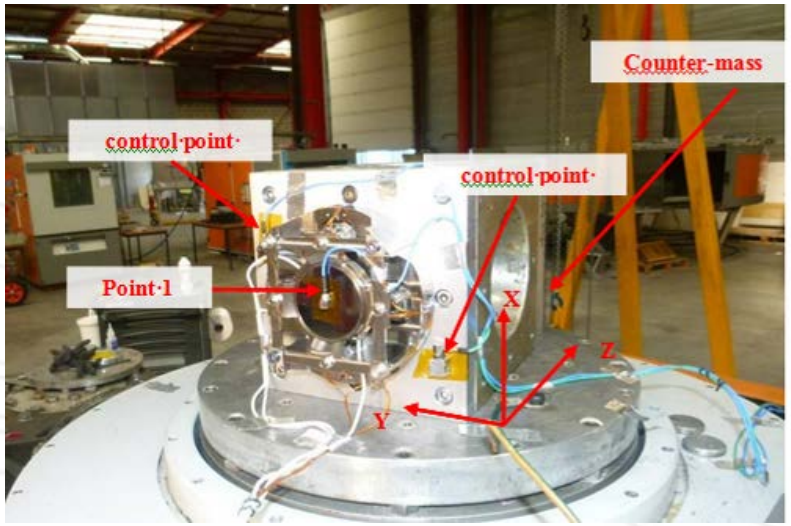
CFSM verification tests

- Piezoelectric component procurement
  - LAT Group 1
  - Burn-in / Ageing 10^7 cycles
  - Force measurement



- Environment tests
  - Random vibrations
  - Shocks

- Lifetime tests at 30K
  - 800 Hz functional stroke during 30 days



Conclusions

- A specification has been proposed to validate piezoelectric components for space use
- Actuators have been designed and tested to expand piezoelectric actuator's use to cryogenic temperatures
- An example of a space mechanism designed for cryogenic conditions is presented

Final word

- CTEC would like to thank for their support in the presented activities
  - ESA : Claudia Allegranza, Denis Lacombe, Ludovic Puig
  - CNES : Laurent Cadiergues

Questions?