Active Attitude and Orbit Control with Liquid-µPPT 4 thrusters system

CubeSat Propulsion

L-µPPT: European commission FP7 project: **Liquid micro Pulsed Plasma Thruster**

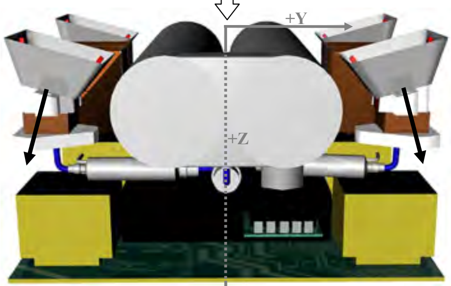
Fact: due to Centre of mass (COM) dispersions, it is almost impossible to perform accurate long thrust pulses with only 1 thruster:

- ⇨ too much torques to cancel,
- ⇨ reactions wheels (RW) can accumulate only a few part and then is useless:
- ⇨ RW cannot be off-loaded because no or only very weak other torques available.
- ⇨ **A full AOCS is needed** to perform accurate long thrust pulses (with 4 dof)
- ⇨ with the minimum number of thrusters
- ⇨ 4 thrusters system → **System 4T**

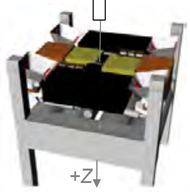
Design Logic:

priority to perform the thrust: all the thrusters first aligned on the same axis Z

- When the thrusters are in the corners of a cubesat this allows 2 full torques control around X and around Y
- For the full control around the Z axis, a tilt angle with respect to the Z axis shall be given to all the thrusters

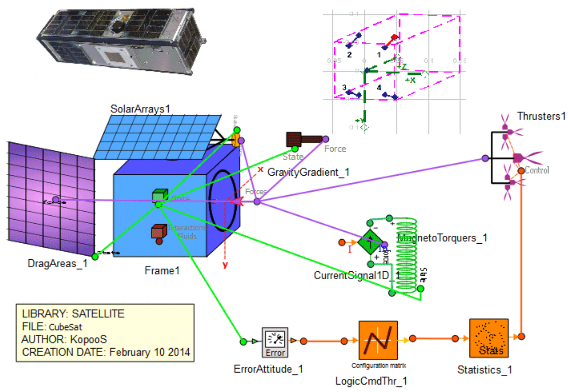


System 4T (preliminary)



Simulation AOCS:

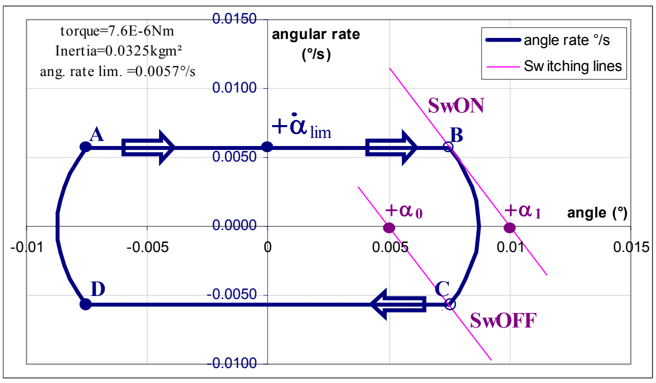
Use of ESA ESPSS library and EcosimPro® for implementing the control logic based on a dead zone with hysteresis attitude control



Dead zone with hysteresis:

principle: activate a reverse torque when the attitude angle is too high, deactivate that torque when the angular rate reverse, etc.

Sketch in the phase space (angular rate vs angle) of the limit cycle of the Dead-band



(limit cycle without any perturbations)

Dead zone cost constant

Cost of Dead-band control accuracy in "torque impulse/year T_{iy} (*Nms/year*) " is given through a kind of constant:

$$K_{DB} = \frac{T_{iy}}{I} \cdot \left(\frac{\alpha_1}{\dot{\alpha}^2_{lim}} \right)$$

$K_{DB} \approx$ **700 000** Ns²/(kg.m.year)

Very accurate determination of the angular rate limit $\dot{\alpha}_{lim}$ lead to strongly minimize the Dead-band cost T_{iy}

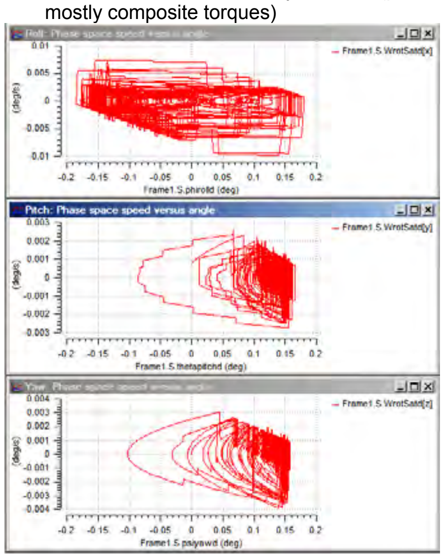
This Dead-band cost T_{iy} must be added to the cost of the simple compensation of the external torques.

Simulation Results:

Control all attitude angles at better than 0.2° with System 4T, in low earth orbit, with all perturbations.

Sketches in the phase space (angular rate vs angle):

- ⇨ Normal evolutions with respect to the theoretical limit cycle due to the perturbations
- ⇨ It is possible to master the cross couplings between the axis of the System 4T (producing mostly composite torques)



The L-µPPT:

Pulsed plasma thrusters are used in space since long time ago.

- ⇨ But those use only solid Teflon
- ⇨ Those are not suited for a system

The European commission FP7 project L-µPPT propose a Liquid PPT

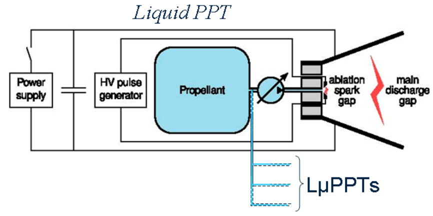
Advantage of repetitive small exposed propellant surface

- ⇨ Pulses repetitivity

Advantage of single propellant tank, lead to better utilization of total propellant mass

- ⇨ Suited for systems of several thrusters
- ⇨ With one common electronic

Liquid PPT



Conclusions

- The main advantages of the Liquid µPPT with respect to solid PPT is on both sides
  - Operational: very high mass utilisation efficiency, common tank for all the thrusters
  - Performance: better reproducibility of each pulse because the ablation is mastered
- The L-µPPT is fully compliant with the CubeSat specifications
  - No pressure vessels over 1.2 standard atmospheres
  - No toxic propellant
  - No waivers needed for using the propulsion system
- The L-µPPT **system 4T**: designed for orbit control and for fine attitude control
  - No starting delays
  - Always available (power: few W)
  - System advantages, low volume (1/2U)
  - High DV (100 m/s @ 3U)

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