μCAT Micro-Propulsion solution for Autonomous Mobile On-Orbit Diagnostic System (AMODS)

J. Kolbeck, J. Lukas, G. Teel, M. Keidar
The George Washington University

E. Hanlon, J. Pittman, M. Lange, J. Kang
United States Naval Academy
Outline

- AMODS
  - The Mission
  - Mission Goals
- Vacuum Arc Thrusters
  - Introduction
  - Discharge Characteristics
  - μCAT at GWU
  - Flight legacy and Future Missions
- Conclusion
AMODS

- Mission designed by the US Naval Academy as part of the University Nanosat Program (UNP)
- GWU provides the µCAT (Micro-Cathode Arc Thruster) propulsion system for attitude and orbit control
- Technology demonstration mission
The Mission

AMODS

- To be launched as a 6 U CubeSat
The Mission
The Mission

- Phase 1: Maneuvers as 6 U satellite (3 axis)
- Phase 2: Separation (~5 m) – Rendezvous & docking
- Phase 3: Separation (~1km) – Rendezvous & docking
Mission Goals

• Qualification of the robotic arms & cameras
• Qualification of the µCAT propulsion system
  • Total of 14 µCATs for attitude and orbit control
• Verification of rendezvous and docking algorithms
• and…. 
Mission Goals

• Selfies!
Vacuum Arc Thrusters

- Small form factor
  → 3-axis stabilization of 1 U CubeSats possible
- Solid metallic propellant
  → No need for valves, pressurized tanks, pipes, etc.
- Safe for the satellite and launch vehicle
- Highly ionized plasma
  → virtually zero backflux on spacecraft
Discharge Characteristics

- High plasma densities
  - Approx. $10^{26}$ m$^{-3}$ near the cathode, $10^{20}$ m$^{-3}$ a few millimeters away from the cathode
- Relatively high ion velocity
  - Order of magnitude: $10^4$ m/s
- Discharge inherently produces highly ionized species
  - E.g. tungsten: 25% ions ≤ 2+, 75% ions > 2+ (mean charge state). Record: Bi$^{13+}$
Cathode Arc Spots

- Plasma originates from small spots on the cathode
  - Non-stationary spots of up to 10 µm in diameter
  - Current densities of up to $10^{12}$ A/m$^2$
  - Fractal in nature
  - Governed by electron emission
  - Source of macroparticles
Cathode Arc Spots

• “Motion”: ignition and extinction of cathode arc spots (red arrow)
Apparent Arc Spot Motion

Cathode: 15 mm diameter Zinc
Anode: 35 mm diameter

Arc spot motion on a cathode zinc (here: clockwise)
GWU’s Micro-CAT

- Ion velocities: 20 km/s (0 T), 40 km/s (300 mT)
- Total mass: < 200 g (incl. PPU)
- Isp: 2000 – 3000 s
- Impulse bit: 1 μNs at 1 Hz
- Trigger Signal: 5 V square wave
- Av. Power Consumption: 1 W @ 10 Hz
- Firing Rate: 1 - 50 Hz
- Size: 27.6mm x 20.1mm x 14mm (LWH)
- Charging voltage: 15 - 25 V
- TRL-7
Operation

- Pulsed vacuum arc thrusters (VAT) generally use a booster circuit to trigger the discharge.
- Sequence:
  - Loop 1: Charging of inductor
  - IGBT is closed
  - Loop 2: Voltage spike produced \((LdI/dt)\)
GWU’s Micro-CAT

Thrusters delivered to the US Naval Academy for the BRICSat-2 mission.
Flight Legacy

- Four GWU µCATs flew on BRICSat-P (USNA) on May 20th, 2015
  - Successfully detumbled to < 1 °/s within 48 hours
- GWU/NASA GSFC/Yonsei Univ. joint project Canyval-X (launch TBD, exp. September 2016)
- USNA BRICSat-2 (launch TBD, exp. March 2017, Falcon 9 Heavy)
- USNA AMODS, launch exp. 2018
- More partnerships & missions after SmallSat 2016?
Conclusion

- Vacuum Arc Thrusters are ideal for CubeSat applications
  - Low mass / small size
  - Low power consumption
  - Variable firing rate (1 – 50 Hz)
  - High Isp
  - TRL 7
- System with flight legacy
Thank you! Any questions?

BRICSat-P launch, May 20th, 2015
Backup
Backup – Ion Backflux