Single and Multi-Pulse Low-Energy Conical Theta Pinch Inductive Pulsed Plasma Thruster Performance

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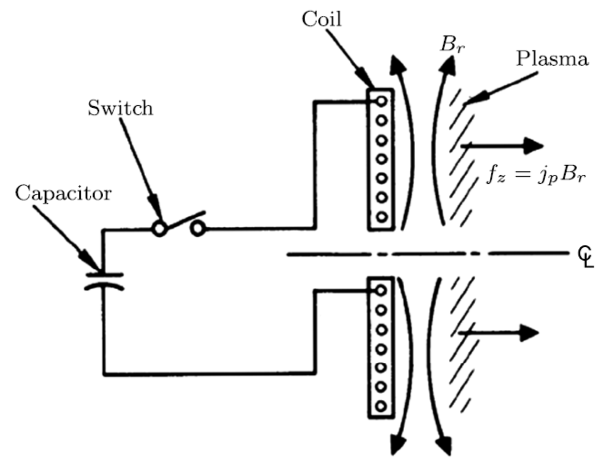
Inductive Pulsed Plasma Thrusters

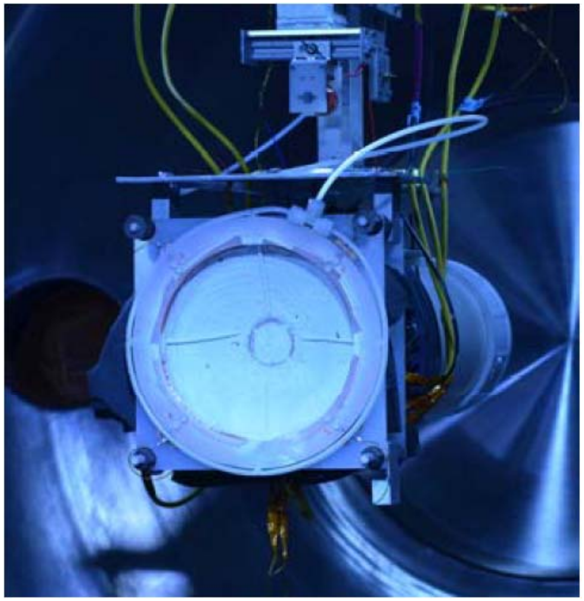


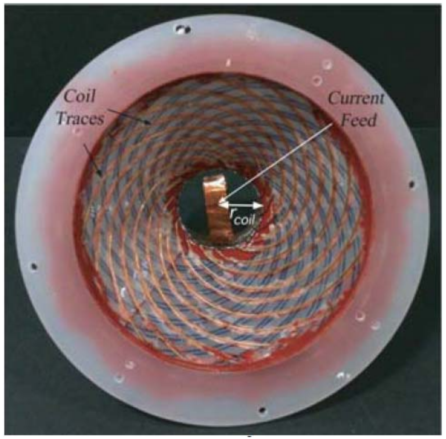
- Energy stored in capacitor banks
- High current switch permit discharge through an inductive coil
- Fast-rising current ionizes/electromagnetically accelerates gas

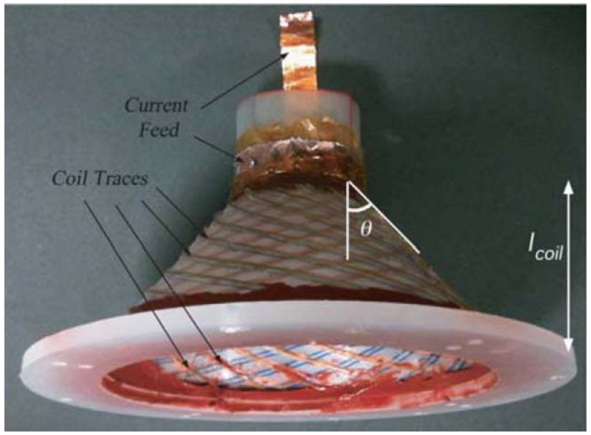
- Demonstrated and potential benefits
  - Electrodeless
  - Potential to use a wide variety of propellants (Ammonia, CO_2, H_2O, etc.)
  - Constant I_{sp} and thrust efficiency over a wide range of power
  - Regime of relative constant efficiency over a range of I_{sp}
  - Potential to process high power in single thruster (high rep rate)

Conical Theta-Pinch (CTP) IPPT

- Propellant potentially more contained and uniform on coil surface
- Three coils fabricated (θ=20^o, 38^o, 60^o) (~240 nH)
- Capacitors located directly behind coil (in pressurized enclosure)
- Spark gap-switched capacitor bank
- Direct thrust stand impulse bit measurement

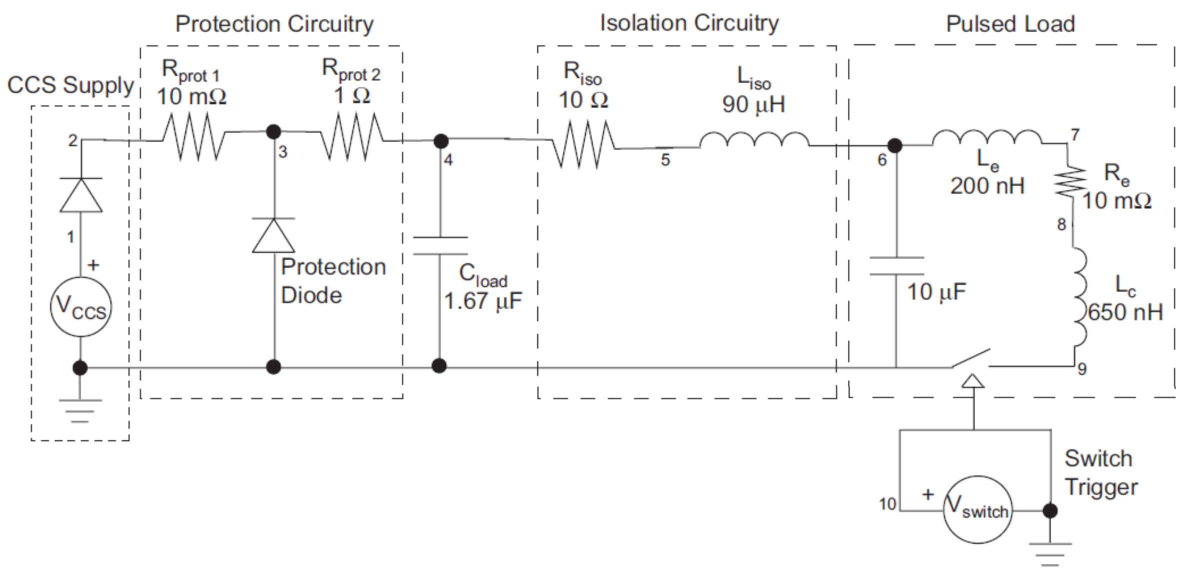






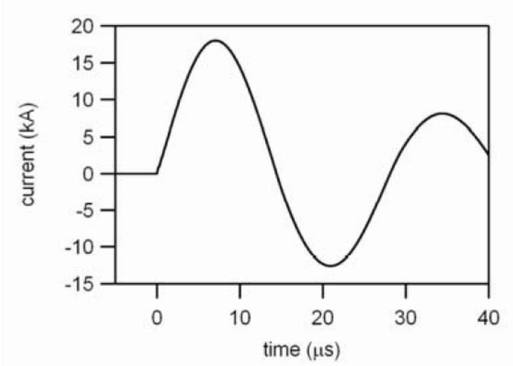
θ	r_{coil}	l_{coil}
20^o	4 cm	10 cm
38^o	4 cm	10 cm
60^o	4 cm	5 cm

Capacitor Charging System

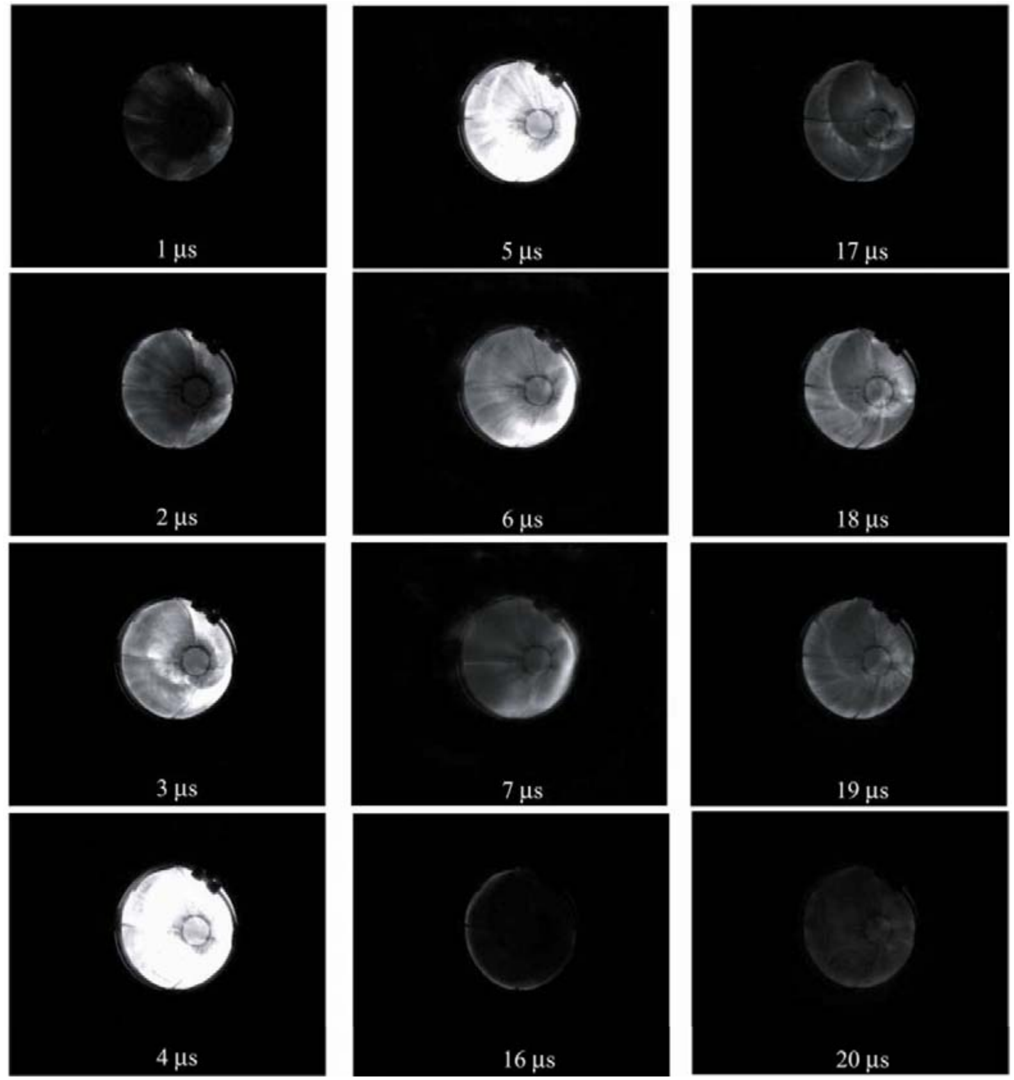


- 40 μF capacitor bank
- 16 kJ/s / 40 kV capacitor charging supply (approximate linear power derating with charge voltage)
- Capacitor bank connected to power supply during pulse – necessitates isolation and protection circuitry
- Pushes repetition-rate limit to ability to rapidly trigger spark-gap switch

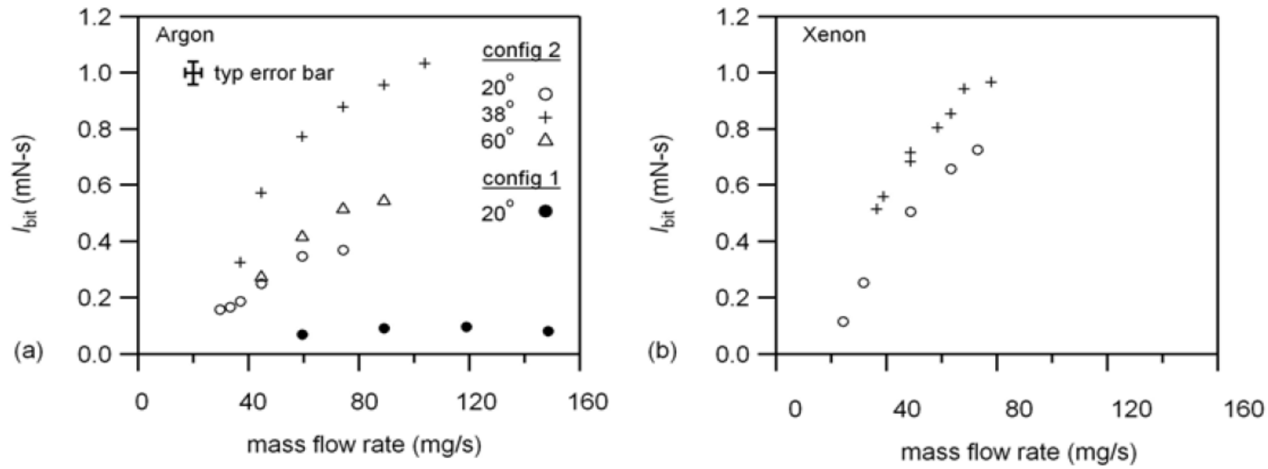
High-Speed Imaging



- All light (B&W), 125 ns exposures
- Glow begins at front of thruster and grows backwards at start of 1st/2nd half-cycles
- High intensity over coil in first half-cycle ; lower in second half-cycle
- Visible non-uniformities
- Lower coil current / lower level of gas(?) in 2nd half-cycle

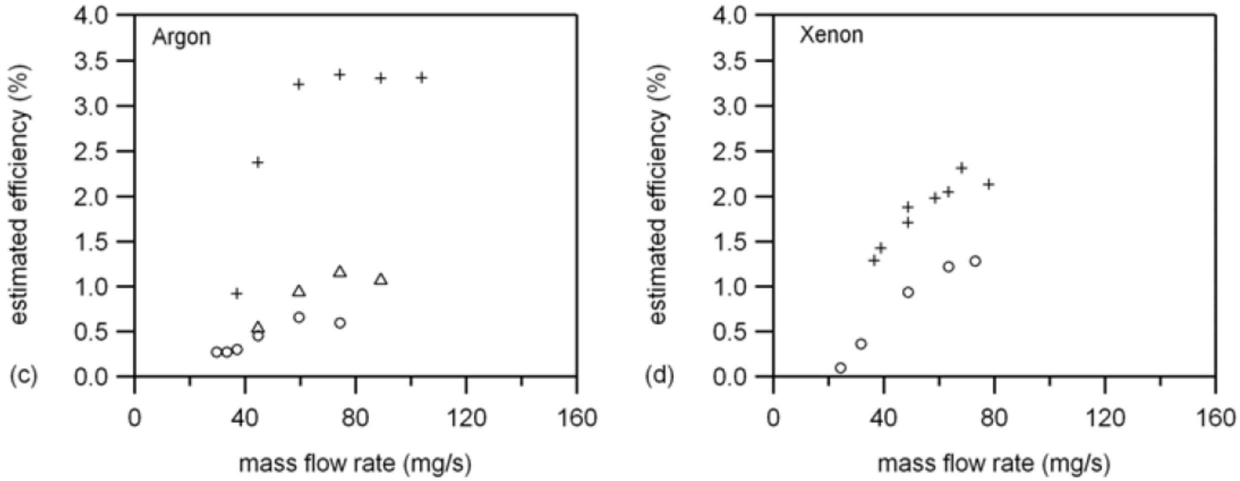


Single-Pulse Performance



- Max I_{bit} of ~1 mN-s
- Max I_{bit} with θ=38°
- Impulse bit peak faster for xenon
  - propellant utilization/more mass near coil?
- High-voltage stand-off issues prevent measurements above flow rates shown

Single-Pulse Performance

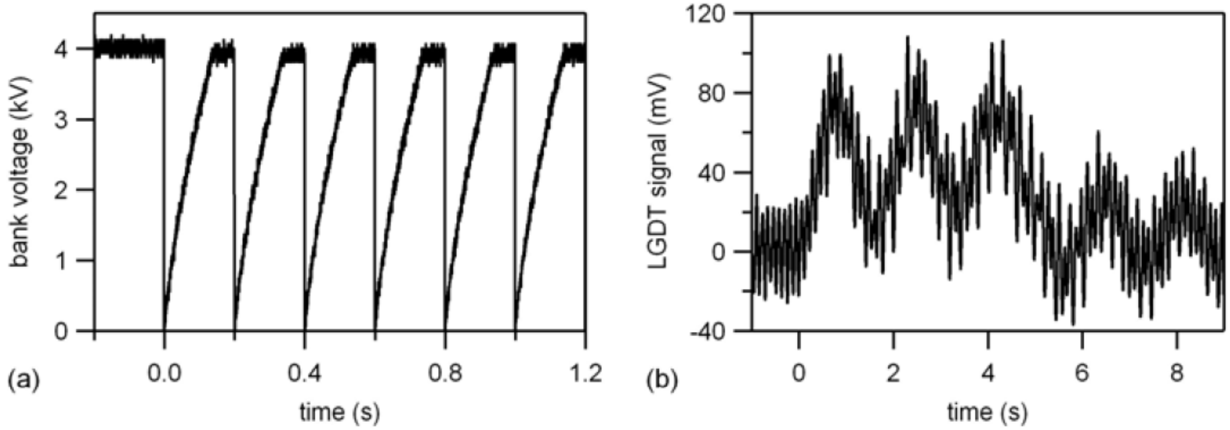


- Steady-state mass flow necessitates estimating efficiency

$$t_{char} = \frac{l}{a} \qquad m_{bit} = t_{char}\dot{m} \qquad \eta = \frac{I_{bit}^{\;2}}{m_{bit} C V_0^{\;2}}$$

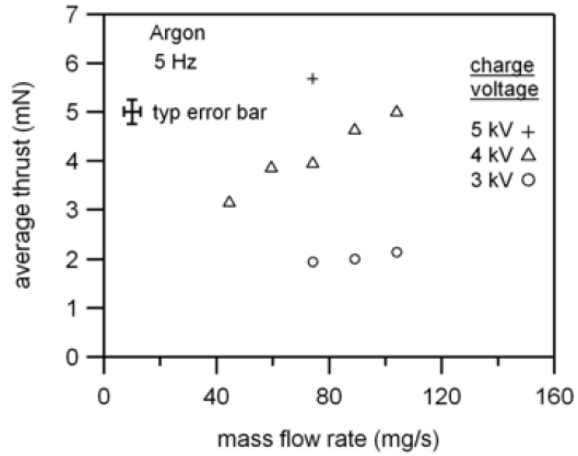
- Efficiency on argon higher, but both are low
  - Force vector in CTP partially in wrong direction for thrust
  - Similar to peak values in 20-cm PIT (static-fill in late 1960s)
    - Profile/entrainment losses high w/out pulsed injection
  - PIT MkI / MkV (on argon) efficiencies only 15-30% at high energy per pulse

Repetitive Charging and Pulsing



- Repetition rate operation at 5 Hz (up to 2.5 kW average power)
- Repetition rate limit was trigger module for spark gap switch
- Pulsing over 5 seconds
- Thrust stand average displacement yields average thrust during operation

Repetition-Rate Performance



- Average power of 0.9, 1.6, and 2.5 kW (all at 5 Hz)
- 5 kV data in repetition-rate mode greater than 5x the impulse bit in single pulse mode
- To our knowledge, the highest power repetitively-pulsed (i.e. non-CW) discharge
  - Comparison w/ EO-1 PPT (56-70 W @ 1 Hz in ground testing, 12.6 W @ 1 Hz for in-space pulsing)

Conclusions

- Fabricated and tested CTP IPPTs at cone angles of 20^o, 38^o, and 60^o, and performed direct single-pulse impulse bit measurements with continuous gas flow
- Single pulse performance highest for 38^o angle with impulse bit of ~1 mN-s for both argon and xenon
- Estimated efficiencies low, but not unexpectedly so based on historical data trends and the direction of the force vector in the CTP
- Capacitor charging system assembled to provide rapid recharging of capacitor bank, permitting repetition-rate operation
- IPPT operated at repetition-rate of 5 Hz, at maximum average power of 2.5 kW, representing to our knowledge the highest average power for a repetitively-pulsed thruster
- Average thrust in repetition-rate mode (at 5 kV, 75 sccm argon) was greater than simply multiplying the single-pulse impulse bit and the repetition rate

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