Power System for Continuously Pulsed RMF-FRC Thruster

Kenneth E. Miller, James Prager*, Alex Henson, Kyle McEleney, Joshua Woods, Christopher Sercel, Tate Gill, Eric Viges, Benjamin Jorns

*prager@eagleharbortech.com

EAGLE HARBOR TECHNOLOGIES

Introduction
Eagle Harbor Technologies, Inc. (EHT) developed a power system that allowed for the first thrust-stand measurement of a continuously operating Rotating Magnetic Field (RMF) – Field-Reversed Configuration (FRC) Thruster at the University of Michigan (UM). This work extended EHT’s resonant full bridge from a single burst system to a continuously-operating, repetitively-pulsed system at 4 kW of average power. This power system can drive peak currents of ±2 kA at 500 kHz in the inductive RMF coils.

This power system was delivered to UM and integrated into the thruster so that it could be operated continuously for a thrust measurement. UM used a standard inverted-pendulum type thrust stand in their Large Vacuum Test Facility to demonstrate parametrical control of the thruster performance (thrust, specific impulse, and efficiency) by varying the energy input to the plasma, flow rate, and applied magnetic field. The new EHT power system enabled coupling efficiencies greater than 50%, active specific impulses approaching 1000 s, and a direct thrust measurement in space-like conditions.

RMF-FRC Thruster Concept
The RMF-FRC operation is shown in the image. Left: plasma fluxes into volume with biased magnetic field. Middle: RMF antenna generates azimuthal current in plasma giving rise to field reversal. Right: Lorentz force interaction with background magnetic field and induced field in flux conservers drives acceleration.

UM RMF-FRC Thruster (V2)
UM constructed a second generation thruster out of G10/FRP to minimize system complexity and use a scaffold structure to simplify fabrication. The plasma was bounded by mica sheets formed into cones, and an optional dielectric cone to better diffuse gas (not used in test). From the exit, neutral gas could be injected back into the conical thruster body.

UM Large Vacuum Test Facility
The vacuum chamber (6 m x 9 m) is cryogenically pumped (13 TM120i Cryopumps and 6 PHPK Cryomech pumps) with measured speeds up to 520 L/sec Xe. The facility can process up to 100 kW continuous power and contains an inverted-pendulum thrust stand that was operated in null mode.

RMF-FRC Thruster Power System
The Gen 1 thruster power system was a charged capacitor and switched that was closed into the inductive antenna. The current and voltage waveforms in the antenna were an underdamped LCR circuit. This circuit was capable of delivering 2 J/pulse and could operate continuously at up to 1.2 kW.

EHT developed solid-state full bridge to drive a resonant LC network at the resonant frequency. The primary inductance is the RMF antenna and a tuning capacitor was added for an operational frequency of 400 kHz. EHT had previously built similar systems and the new work focused on building a continuously-operating repetitively-pulsed system that could operate at 4 kW. Ultimately, this system output 4 kA pk-pk in 200 µs bursts of 400 kHz RF. When operated at half current, it delivered 20 J/pulse at 2 kW.

UM conducted first thrust stand measurement of CW RMF-FRC thruster in space-like conditions using an EHT RMF power system. The EHT power system was operated up to 4 kW continuous with repetitive 200 µs bursts of 4 kA pk-pk with up to 500 kHz RF. UM characterized thruster performance with the damped LC circuit and EHT power system and showed improved coupling from 3% to 50% and improved thrust from unmeasurable to 8 mN (543 mN ‘active’).

In future work, EHT plans to implement water cooling to increase the average power which should increases gas efficiency, specific impulse and average thrust. UM plans to optimize the magnetic field and gas injection schemes. For more info: http://www.eagleharbortech.com/

Conclusion
Acknowledgment
This work was supported by a USAF SBIR (FA8649-20-P-0483).

Thrust Measurements
The thruster was operated at 75 Hz for 1-5 minutes. Max energy delivered to plasma is 20 J, which is likely to increase at higher currents. Coupling efficiency near 50%. Major driver is the flow rate (gas density).

EHT developed solid-state full bridge to drive a resonant LC network at the resonant frequency. The primary inductance is the RMF antenna and a tuning capacitor was added for an operational frequency of 400 kHz. EHT had previously built similar systems and the new work focused on building a continuously-operating repetitively-pulsed system that could operate at 4 kW. Ultimately, this system output 4 kA pk-pk in 200 µs bursts of 400 kHz RF. When operated at half current, it delivered 20 J/pulse at 2 kW.

UM conducted first thrust stand measurement of CW RMF-FRC thruster in space-like conditions using an EHT RMF power system. The EHT power system was operated up to 4 kW continuous with repetitive 200 µs bursts of 4 kA pk-pk with up to 500 kHz RF. UM characterized thruster performance with the damped LC circuit and EHT power system and showed improved coupling from 3% to 50% and improved thrust from unmeasurable to 8 mN (543 mN ‘active’).

In future work, EHT plans to implement water cooling to increase the average power which should increases gas efficiency, specific impulse and average thrust. UM plans to optimize the magnetic field and gas injection schemes. For more info: http://www.eagleharbortech.com/