Design of a 30-kW RMF-FRC Thruster

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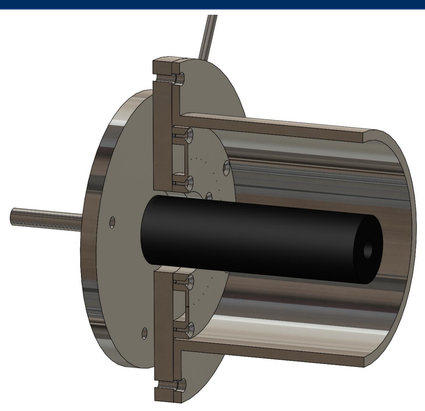
Introduction

- Field-Reversed Configuration (FRC) thrusters could fill the role of high-power (>100 kW), propellant-agnostic thruster
- These devices have been built, but direct measurements are lacking
- Physical mechanisms behind plasmoid acceleration are poorly understood
- **We seek to build a test unit to measure thrust and I_{sp}, and investigate FRC formation**

Design Requirements

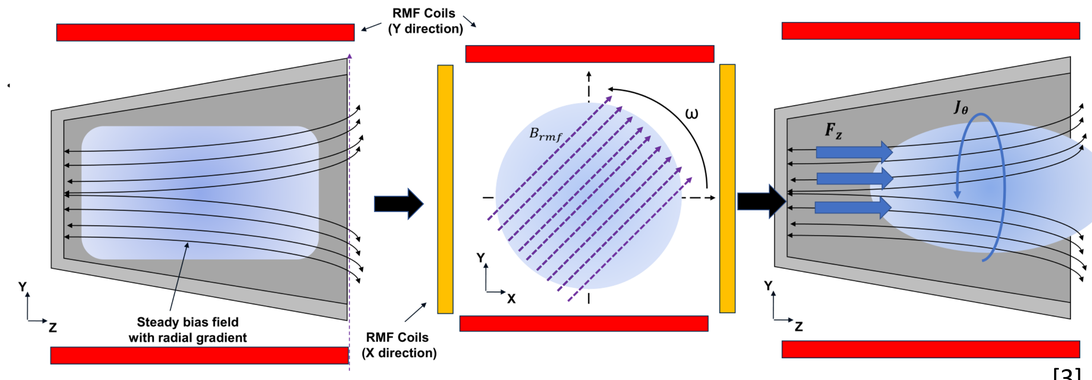
- Thruster must operate in repetitive mode (not single shot) at 1 kHz to support measurement with a traditional thrust stand
- Thruster must use a Rotating Magnetic Field (RMF) to generate the plasmoid. Necessary field strength approximately 350 G at 20 kHz → ~30 J pulse. Therefore thruster will be 30 kW class
- Supporting infrastructure must be compatible with the Large Vacuum Test Facility at the University of Michigan
- Power processing system must operate in atmosphere to reduce vacuum-related challenges with pulsed power

Plasma Source



Significant design heritage makes Lab6 hollow cathode easy to use by reducing engineering complexity relative to pulsed pre-ionization. Requires Xenon

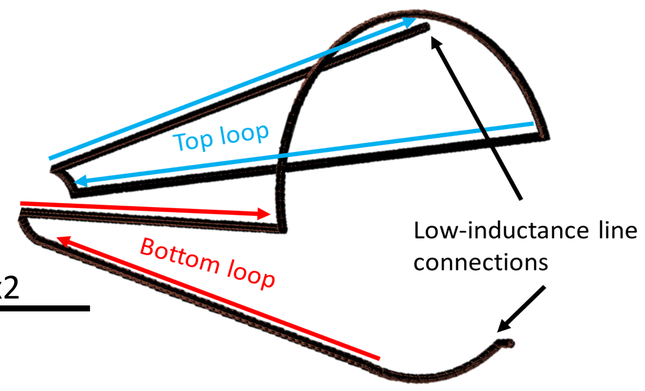
FRC Formation



[3]

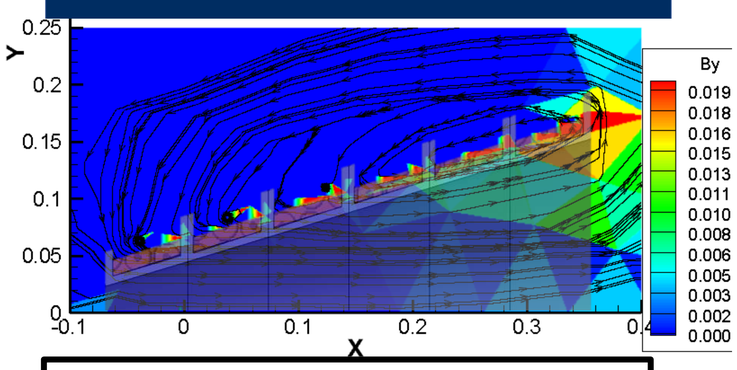
$$\vec{B}_{ext} = B_{r,ext}\,\hat{r} + B_{z,ext}z \rightarrow J_\theta = \frac{-ne\omega r}{\left(1+2\left(\frac{\eta ne}{|B_{RMF}|}\right)^2\right)} \rightarrow F_Z = J_\theta B_{r,ext}$$

RMF Antenna

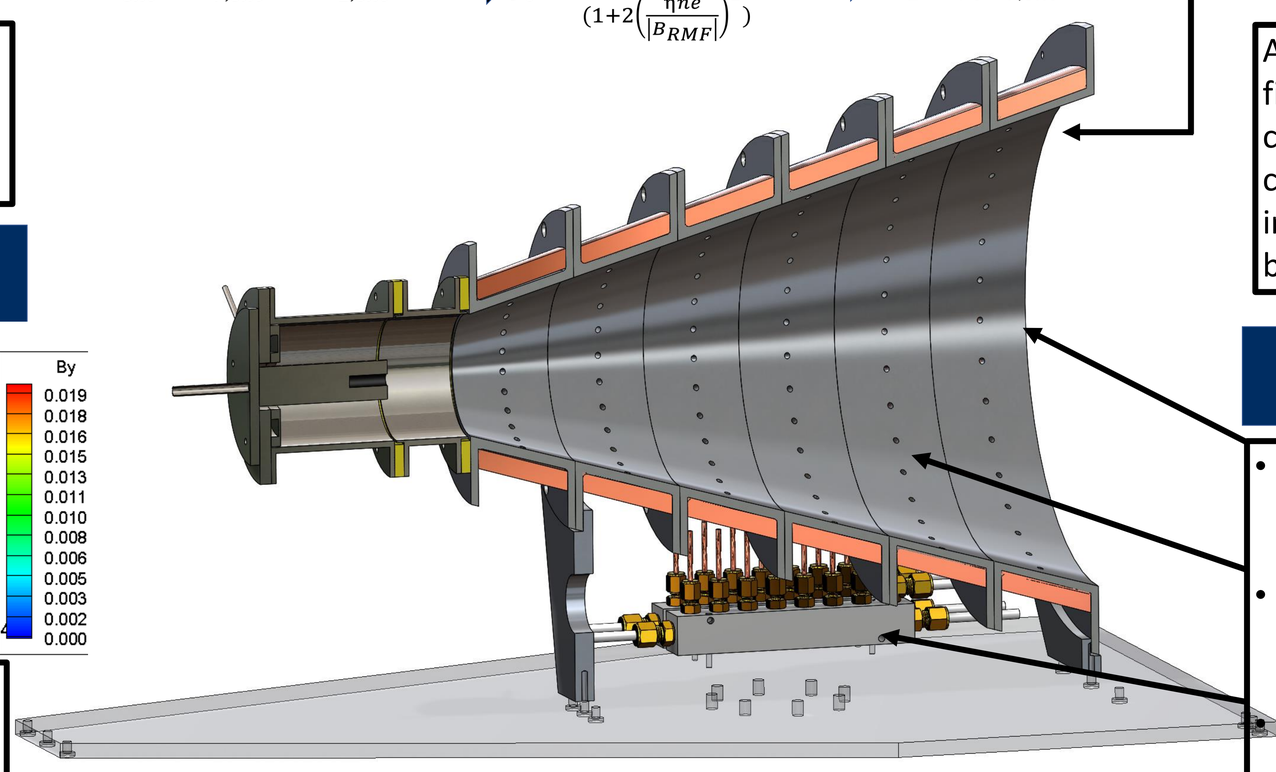


An antenna generates a rotating magnetic field (RMF) which drives the azimuthal current in the plasma. Copper tube construction allows coolant flow and increased surface area – important because of .46 mm skin depth at 20 kHz

Bias Field



A plot of the radial component of the bias field overlaid on the thruster cross-section. Units are in Tesla

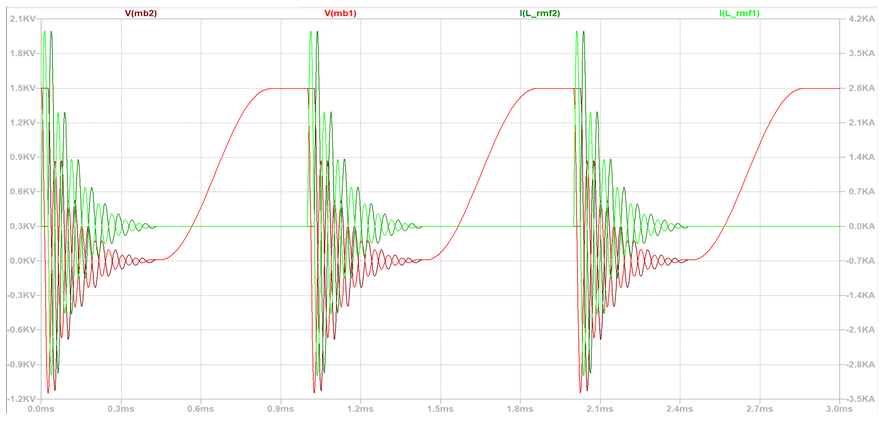


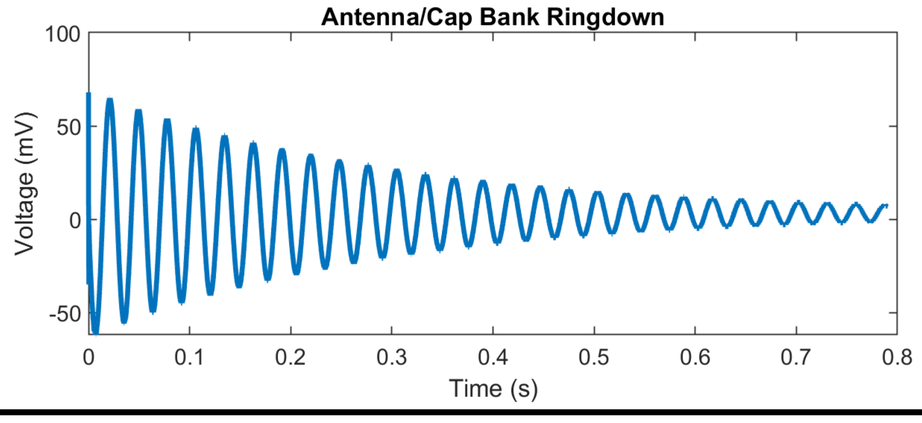
Structure

- Bias field coil bobbins double as axial flux conservers
- Interior mounting holes for antennas and instrumentation
- Water cooling manifold for bias field bobbins and RMF

Power Processing Unit

RMF Coil 1 Current
RMF Coil 1 Voltage
RMF Coil 2 Current
RMF Coil 2 Voltage





Top: Sample RMF ringdown generated in Spice. Bottom: Measured ringdown (no plasma) between RMF antenna and energy storage capacitor bank inside boost circuit. Q = 31 indicates this resonator is highly underdamped without plasma in the cone (little loss to resistance)

References

[1] Blevin, H. A., and Thonemann, P. C., "Plasma confinement using an alternating magnetic field," Nuclear Fusion Supplement, Part 1, 1962, p. 55.
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[3] Woods, J. M., Jorns, B. A., , and Gallimore, A. D., "Circuit Modeling of Rotating Magnetic Field Field-reversed Configuration Thrusters," AIAA-2018-4911, 2018

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This work was partially supported by the NASA Space Technology Research Fellowship under Grant 80NSSC18K1190