Thrust Stand Measurements of the Microwave Assisted Discharge Inductive Plasma Accelerator

Ashley K. Hallock
Mechanical and Aerospace Engineering, Princeton University

Kurt A. Polzin
NASA Marshall Space Flight Center

Gregory D. Emsellem
The Elwing Company

I. INTRODUCTION

Pulsed inductive plasma thrusters [1–3] are spacecraft propulsion devices in which electrical energy is capacitively stored and then discharged through an inductive coil. This type of pulsed thruster is electrodeless, with a time-varying current in the coil interacting with a plasma covering the face of the coil to induce a plasma current. Propellant is accelerated and expelled at a high exhaust velocity ($\mathcal{O}\,(10 - 100$ km/s$)$) by the Lorentz body force arising from the interaction of the magnetic field and the induced plasma current.

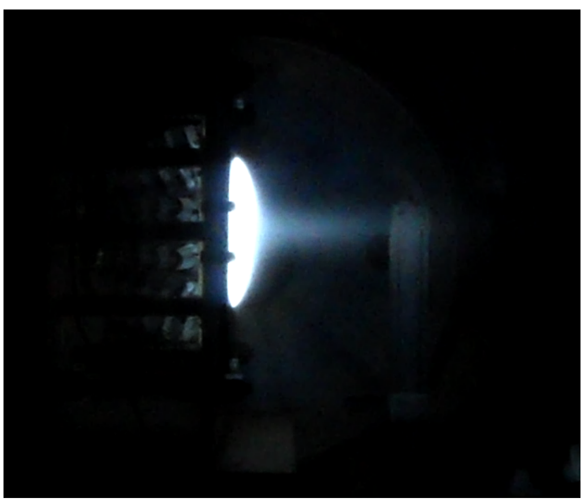

FIG. 1: MAD-IPA thruster with the preionization stage ignited. The thrust axis is to the right.

While this class of thruster mitigates the life-limiting issues associated with electrode erosion, pulsed inductive plasma thrusters require high pulse energies to inductively ionize propellant. The Microwave Assisted Discharge Inductive Plasma Accelerator (MAD-IPA), shown in Fig. 1, is a pulsed inductive plasma thruster that addressees this issue by partially ionizing propellant inside a conical inductive coil before the main current pulse via an electron cyclotron resonance (ECR) discharge. The ECR plasma is produced using microwaves and a static magnetic field from a set of permanent magnets arranged to create a thin resonance region along the inner surface of the coil, restricting plasma formation, and in turn current sheet formation, to a region where the magnetic coupling between the plasma and the theta-pinch coil is high. The use of a conical theta-pinch coil also serves to provide neutral propellant containment and plasma plume focusing that is improved relative to the more common planar geometry of the Pulsed Inductive Thruster (PIT) [1, 2].

In this paper, we describe thrust stand measurements performed to characterize the performance (specific impulse, thrust efficiency) of the MAD-IPA thruster. Impulse data are obtained at various pulse energies, mass flow rates and inductive coil geometries. Dependencies on these experimental parameters are discussed in the context of the current sheet formation and electromagnetic plasma acceleration processes.

II. EXPERIMENT AND RESULTS

All tests are performed in a stainless steel cylindrical vacuum facility 25-ft. long with a 9-ft. diameter. A base pressure of 5.7 x 10^{-7} torr is maintained by two 2400 l/s turbopumps and two 9500 l/s cryopumps. The MAD-IPA is mounted onto the VAHPER thrust stand, which is capable of supporting thrusters with masses up to 125 kg that produce between 100 μN and 1 N of steady-state thrust. The stand has been modified to support pulsed thrust measurements. More general information about the thrust stand can be found in Ref. [4].

Instead of injecting propellant into the MAD-IPA in discrete increments, neutral gas flows continuously into the thruster to replace propellant accelerated by the previous pulse. This allows sustainment of the ECR discharge, and in turn, repetition-rate discharging of the capacitor bank.

Impulse data are obtained at a variety of pulse energies ranging from 50 to 300 J, a range of propellant mass flow rates and propellant species, and for three different half cone angles (10, 20, and 30 degrees).

III. ACKNOWLEDGEMENTS

This work was supported, in part, by U.S. Department of Energy Contract No. DE-AC02-76-CHO-3073.

[1] Dailey, C. L. and Lovberg, R. H. The PIT MkV Pulsed Inductive Thruster. Technical Report 191155, Lewis Research Center, Redondo Beach, CA, July 1993.

[2] Lovberg, R. H. and Dailey, C. L. A PIT primer. Technical Report 005, RLD Associates, Encino, CA, 1994.

[3] Polzin, K. A. *Faraday Accelerator with Radio-frequency Assisted Discharge (FARAD)*. Ph.D. dissertation, Princeton University, Department of Mechanical and Aerospace Engineering, 2006.

[4] Polzin, K. A. Markusic, T. E. Stanojev, B. J. DeHoyos, A. and Spaun, B. Thrust stand for electric propulsion performance evaluation. *Review of Scientific Instruments*, 77:105108, October 2006.