Comparison Between MAD-IPA Thrust Stand Measurements and Performance Modeling

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I. INTRODUCTION

The high specific impulse values associated with electric propulsion (EP) that allow for higher payload fractions than conventional, chemical propulsion are achieved by the acceleration of ionized propellant (plasma) by electromagnetic body forces. The lifetime of many EP devices is limited by electrode erosion caused by direct plasma-electrode interaction, while the efficiency is often limited by, among other thruster-specific factors, the available power in space. The efficiency can be increased during higher power operation since the amount of power required to ionize the propellant is fixed and decreases as a percentage of the increased input power.

Pulsed inductive plasma accelerators [1–3] are a potentially elegant solution to the problems of high power demands and electrode erosion. The former is addressed in the pulsed nature of these devices, which allows for instantaneous operation on the order of megawatts while requiring a continuous supply on the order of only kilowatts, while the latter is addressed by inductive coupling of the thruster to ionized propellant. These devices operate by rapidly (on the order of microseconds) discharging stored energy at a given pulse repetition rate through a coil creating time-varying magnetic and electric fields that cause ionization, current formation and acceleration of propellant away from the coil. While the inductive (contact-less) nature of the energy transfer from the thruster to the propellant alleviates the problem of erosion and enables the use of in-situ and storable propellants incompatible with metallic electrodes, it places high voltage demands (on the order of tens of kilovolts) on the energy storage system to achieve propellant ionization.

The Microwave Assisted Discharge Inductive Plasma Accelerator (MAD-IPA) was designed to alleviate the need for high voltage by decoupling the preionization and acceleration mechanisms of a pulsed inductive plasma accelerator. Propellant is first partially ionized using an electron cyclotron resonance (ECR) before current provided by a capacitor bank is pulsed through a conical coil. the discharge in the coil further ionizes the plasma and forms a current sheet at much lower voltages than previous concepts due to the availability of an initial population of electrons provided by the ECR.

In this paper we describe inductance measurements of the MAD-IPA for various inductive coil geometries, and use an existing and well-documented circuit model (described in Ref. [3]) to calculate the specific impulse of the thruster. The plasma current trajectory, specifically the radial compression rate, is measured using magnetic field probes to produce a more accurate representation of the inductance variation as a function of time. Thrust stand measurements are compared to the results of modeling.

II. MODEL AND EXPERIMENT

An expression for the coil inductance as a function of plasma current displacement is determined experimentally by simulating the presence of plasma with copper sheets formed into roughly the same geometry as the coil. The copper is displaced radially and axially from the coil, and the terminal inductance of the coil is recorded. This expression closes a well-known set of equations (described in Ref. [3]) comprising an acceleration model that permits the calculation of plasma velocity as a function of time. Four different coil geometries were explored, two having a half cone angle of 20 degrees but different lengths, two having half cone angles of 12 and 38 degrees. The lengths of the 12 and 38 degree coils and one of the 20 degree coils are set so they possess the same inductance. Results from this numerical model are compared to thrust stand measurements of the MAD-IPA.

All four coils were tested in the MAD-IPA surrounding structure that supports the arrangement of permanent magnets required for an ECR discharge.

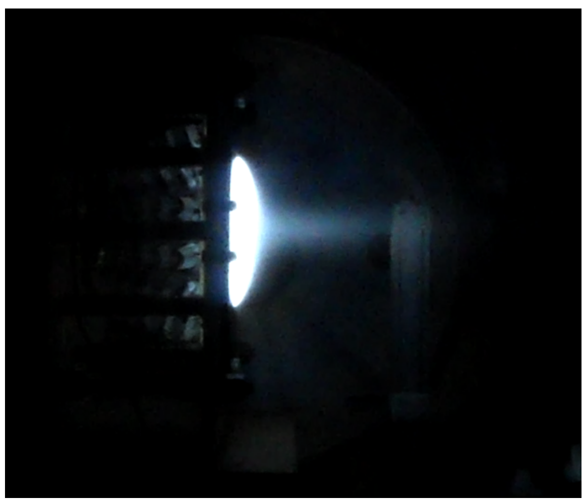

FIG. 1: The preionization stage of the MAD-IPA viewed from the side, the thrust vector points to the right.

III. RESULTS AND DISCUSSION

The different inductive coil geometries affect pulsed inductive plasma acceleration by changing the location, shape, and electrical properties of the plasma current sheet. The semi-empirical model for the current sheet position and commensurate inductance as a function of time helps to explain the complex interplay between these various factors. The results of the model are compared with thrust stand measurements to gauge agreement.

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