Low and High-Power Inductive Pulsed Plasma Thruster Development Testing at NASA-MSFC

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I. Abstract

The inductive pulsed plasma thruster (IPPT) is an electromagnetic plasma accelerator that has been identified in NASA roadmaps as an enabling propulsion technology for some niche low-power missions [1] and for high-power in-space propulsion needs.[2] The IPPT is an electrodeless space propulsion device where a capacitor is charged to an initial voltage and then discharged producing a high current pulse through a coil. The field produced by this pulse ionizes propellant, inductively driving current in a plasma located near the face of the coil. Once the plasma is formed it can be accelerated and expelled at a high exhaust velocity by the electromagnetic Lorentz body force arising from the interaction of the induced plasma current and the magnetic field produced by the current in the coil.

Thrusters of this type possess many demonstrated and potential benefits that make them worthy of continued investigation. The electrodeless nature of these thrusters eliminates the lifetime and contamination issues associated with electrode erosion in conventional electric thrusters. Also, a wider variety of propellants are accessible when compatibility with metallic electrodes in no longer an issue. IPPTs have been successfully operated using propellants like ammonia, hydrazine, and CO_2, and there is no fundamental reason why they would not operate on other in situ propellants like H_2O. It is well-known that pulsed accelerators can maintain constant specific impulse ($I_{\rm sp}$) and thrust efficiency ($\eta_{\rm t}$) over a wide range of input power levels by adjusting the pulse rate to hold the discharge energy per pulse constant. It has also been demonstrated that an inductive pulsed plasma thruster can operate in a regime where $\eta_{\rm t}$ is relatively constant over a wide range of $I_{\rm sp}$ values (3000-8000 s). Finally, thrusters in this class have operated in single-pulse mode at high energy per pulse, and by increasing the pulse rate they offer the potential to process very high levels of power using a single thruster.

There has been significant previous research on IPPTs designed around a planar-coil (flat-plate) geometry. [3] The most notable of these was the Pulsed Inductive Thruster (PIT),[4] with the PIT MkV presently representing the state-of-the-art in pulsed high-power IPPT technological development. In this paper, we focus on two planar-geometry devices that operate at significantly different power levels. Most work performed at NASA-Marshall Space Flight Center (MSFC) has, to date, focused on lower power thruster operation ($\approx$ 10s to 100s of J/pulse, up to 2-2.5 kW average power throughput) and previously described in Refs. [5,6]. The most recent work aimed to assemble a device that could be tested in cyclic mode on a thrust-stand, and which could augment the existing data set for IPPTs. [6] In addition, the thruster was designed to serve as a test-bed for solid state switching circuitry and pulsed gas valves, with the modular design of the device allowing for variation in or upgrades to test configuration.

Recently, MSFC obtained on loan from the Georgia Institute of Technology (Atlanta, GA) the PIT MkVI, [7] successor to the PIT MkV. The MkV and MkVI are similar in design with much of the hardware from the former, specifically the capacitors and spark-gap switches, being reused in the latter. The coil is simliar in geometry but has bent copper rods used in the latest iteration in place of the Litz wire windings found in the MkV. The MkVI master switch for the spark gaps is located in the vacuum chamber contained within a sealed, pressurized vessel fastened to the back of the thruster. This is different from the MkV where many capacitor charging lines and spark gap-triggering delay lines ran to the thruster from a master trigger located outside the vacuum chamber. The MkVI was damaged during testing soon after its fabrication was completed. The thruster arrived at MSFC still-damaged and mostly disassembled into many individual pieces. The device has been repaired, with a few additional design changes implemented after discussions with the late Prof. Lovberg regarding the initial testing results and issues encountered.

In the present work, we present results from testing of both the small IPPT and the larger MkVI thruster. The smaller device (Fig. 1) is tested on a thrust stand on multiple gases to demonstrate its capability to operate in a repetition-rate mode and serve as a IPPT technology-development testbed. The larger MkVI (Fig. 2) is operated

for the first time in its newly reconstituted state, demonstrating full-power pulsed operation and, for the first time, repetition-rate operation of a high-power IPPT. The additional upgrades required for synchronous operation of all the pulsed systems in single-pulse and repetition-rate mode are described in detail.

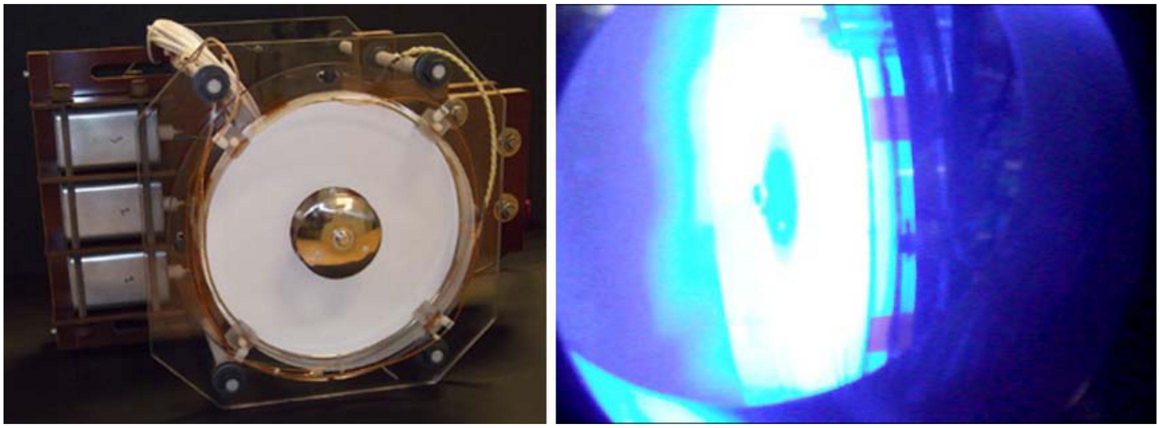

Figure 1. (left) The assembled small IPPT and (right) the small IPPT operated in single-pulse mode at a charge of 2 kV.

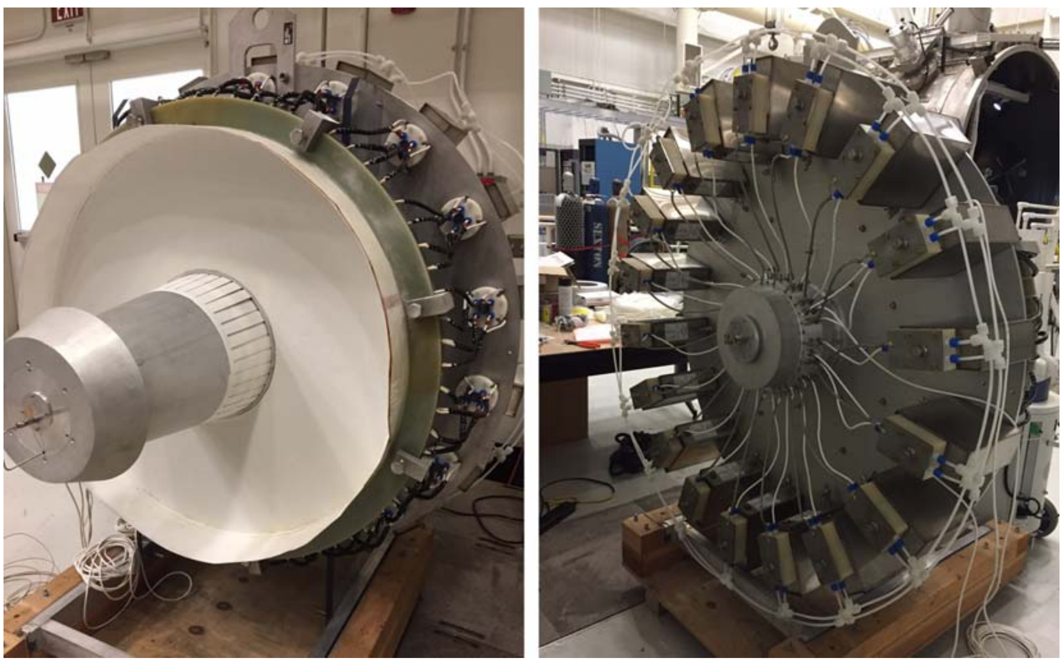

Figure 2. Front and rear views of the PIT MkVI thruster during the re-assembly process.

References

[1] J.W. Dankanich and K.A. Polzin, "Mission assessment of the faraday accelerator with radio-frequency assisted discharge (FARAD)," in *44*$^{\text{th}}$ *AIAA/SAE/ASME/ASEE Joint Propulsion Conference*, Hartford, CT, July 2008. AIAA Paper 2008-4517.

[2] In-Space Propulsion Systems Roadmap: Technology Area 02, National Aeronautics and Space Administration, Office of the Chief Technologist, NASA Headquarters, July 2015.

[3] K.A. Polzin, "Comprehensive Review of Planar Pulsed Inductive Thruster Research and Technology," *J. Propuls. Power*, Vol. 27, No. 3, pp. 513-531. May-June 2011.

[4] C.L. Dailey and R.H. Lovberg, *The PIT MkV Pulsed Inductive Thruster*, NASA CR-191155, Lewis Research Center, Cleveland, OH. July 1993.

[5] K.A. Polzin, A.K. Martin, R.H. Eskridge, A.C. Kimberlin, B.M. Addona, A.P. Devineni, N.R. Dugal-Whitehead, and A.K. Hallock, *Sum-*

mary of the 2012 Inductive Pulsed Plasma Thruster Development and Testing Program, NASA TP-2013-217488, Marshall Space Flight Center, Huntsville, AL. Aug. 2013.

[6] A.K. Martin, A. Dominguez, R.H. Eskridge, K.A. Polzin, D.P. Riley, and K.A. Perdue, "Design and Testing of a Small Inductive Pulsed Plasma Thruster," in *30th International Electric Propulsion Conference*, Hyogo-Kobe, Japan (2015). IEPC Paper 2015-50.

[7] D. Russell, J.H. Poylio, W. Goldstein, B. Jackson, R.H. Lovberg, and C.L. Dailey, "The PIT Mark VI Pulsed Inductive Thruster," in *AIAA SPACE 2004 Conference*, San Diego, CA, Sept. 2004. AIAA Paper 2004-6054.