A Summer on the Li-LFA Team: Preparing for Lithium Mass Flow Calibration

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Abstract

This report represents a summary of the progress made on the Lithium Lorentz Force Accelerator project during the summer months of the year 2000, as well as some of the individual accomplishments and future goals that came from the author's summer internship at Princeton's Electric Propulsion and Plasma Dynamics Laboratory. The predominant part of the summer was used to prepare the facilities for the calibration and firing of the mechanically fed lithium thruster. At the end of the summer, two calibration attempts were made. While the first attempt was unsuccessful and yielded no results due to unforeseen but correctable problems, the second calibration attempt was a success. Calibration data showed that the mechanical feed system of the thruster provided a smooth, steady and accurate supply of molten lithium to the thruster.

Introduction

The lithium Lorentz force accelerator (Li-LFA) is a version of the steady-state magnetoplasmadynamic thruster (MPDT). The Li-LFA uses a multi-channel hollow cathode and lithium propellant to significantly reduce the cathode erosion problem encountered by most MPDT's. The MPDT has demonstrated its capability of providing specific impulses in the range of 1500 to 8000 sec with thrust efficiencies exceeding 40%.[1] Efficiencies regarded as high (> 30%) are typically reached only at high power levels (> 100 kW).[2] When operated in the megawatt range, the MPDT has the unique capability among all developed electric thrusters of handling very high power levels in a simple, compact, and robust device that can produce thrust densities as high as 10^5 N/m^2.[3] These characteristics have made MPD thrusters particularly attractive for use in energetic deep-space missions requiring high-thrust levels.

As seen in Figure 1, the MPDT consists of a central cathode surrounded by an annular anode situated in a coaxial geometry. Connecting the cathode and anode together at the front of the thruster is some kind of electrical insulator. The MPDT simply works by introducing a gaseous propellant to the upstream portion of the interelectrode gap, where it is shortly ionized by passage through a strong, azimuthally uniform electric arc. If the arc current is high enough, its associated azimuthal magnetic will be strong enough to propel the ionized gas downstream and compress it towards the centerline of the thruster into an extremely hot plasma just beyond the end of the cathode. The ionized gas will then expand being continually propelled downstream, and thus thrust will be produced.

The Li-LFA project has been running in Princeton University's Electric Propulsion and Plasma Dynamics Laboratory (EPPDyL) for several years. The original

[1] Jahn, Robert G. and Edgar Y. Choueiri. "Electric Propulsion". Pg. 20.
[2] Jahn, Robert G. and Edgar Y. Choueiri. "Electric Propulsion". Pg. 20.

Li-LFA experimented upon in the EPPDyL had a different feed system than the mechanically driven system that we experimented with this summer. The original feed system used was simply an open-ended heat pipe where lithium was vapourized in the bottom of the pipe where through expansion and capillary action, the lithium vapour would travel to the cathode.

The issue of safety when running experiments with the Li-LFA is a crucial one since lithium is highly reactive in an oxygen atmosphere, and whose by-products are extremely toxic. Li-LFA team members had to review many safety procedures and undergo Self-Contained Breathing Apparatus (S.C.B.A.) training prior to any handling of the lithium.

Supervised by Prof. Edgar Choueiri, the Li-LFA team consisted of Leonard Cassidy, Gregory Emsellem, Andrea Kodys and myself. Gregory and Andrea had previous experience the Li-LFA while Leonard, a first-year graduate student and myself were new to the lithium project. The group's primary goals for the summer were to run a lithium mass flow calibration on the mechanical feed system of the thruster, and if successful, fire the thruster for the first time. My individual goals for the summer were to gain knowledge and experience in the field of electric propulsion that may lead to a thesis or independent work project during my senior year, and to become a valuable, contributing member of the Li-LFA team.

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[3] Jahn, Robert G. and Edgar Y. Choueiri. "Electric Propulsion". Pg. 20.

Experimental Setup

A distinct majority of the Li-LFA team's time during the summer was devoted to setting up the experiment and dealing with the safety issues prevalent with the handling of lithium.

The main experimental setup for the Li-LFA project occurs inside a cylindrical vacuum chamber, where the thruster is attached to a pivoting thrust stand. Inside the chamber also resides the entire mechanical feed system whose main component is a large piston that is mechanically driven to feed the lithium propellant to the thruster. Most of the group's time into preparing the chamber for experimental use was used for making a new feed-through face-plate for the top of the tank, revamping the water-cooling loop, rewiring most of the thermocouple connections, making sure that the tank could maintain a vacuum of 10^{-5} mTorr, and installing the feed system.

The other main piece of apparatus that is essential to the Li-LFA project is the glovebox. Under a positively pressurized argon atmosphere, this is where most of the lithium handling, preparation, and cleaning take place. Preparing the glovebox for the project included detecting and fixing leaks, preparing the glovebox's mechanical pump for quiet and efficient use, and revamping the cleaning water lines and water tray.

A diagram of the mechanical feed system for the lithium thruster can be seen in Figure 2. Preparing the feed system for operation begins with loading the reservoir with a solid lithium ingot inside the glovebox under a positively pressurized argon atmosphere. Carefully, the reservoir is transferred to the vacuum tank where it is installed at the start of the feed system loop. The vacuum tank is then sealed and pumped down to approximately 10^{-5} mTorr. At this time, the entire feed system is heated to above 200 Celsius. At this temperature, the lithium inside the reservoir will begin to melt and eventually fill the bottom of the piston cylinder. When all of the lithium has melted and reached its equilibrium level in the feed system, the first cooling valve is activated to prevent the back flow of lithium into the reservoir. The piston is then mechanically driven through the cylinder pushing the liquid lithium through the rest of the feed system to the thruster. In the case of the calibration attempts, the thruster was replaced by a collecting beaker which was situated on a weigh scale such that accurate mass flow rates could be measured.

Results

The first calibration attempt unfortunately did not result in mass flow measurements due to some unforeseen, but correctable problems. A faulty valve caused a build up of argon pressure in the reservoir. Once all the lithium in the feed system was liquefied, the build up of pressure sent the lithium pouring out the end of the feed system causing a huge mess. A picture of some of the apparatus following the outflow of lithium can be seen in Figure 3. Other problems that were corrected following the first calibration attempt some faulty heating lines as well as the absence of a thermocouple to monitor the temperature of the piston tip. This would make it much easier to monitor if the height of the lithium within the piston cylinder.

The second calibration attempt was a success. A graph of beaker mass versus piston position seen in Figure 4 shows a very linear relationship between the two measurements as there are no slope discontinuities. Figure 5, a graph of beaker mass versus time at a constant feed rate shows that the lithium feed is very smooth and possesses great accuracy. Finally in Figure 6, a graph of mass flow rate versus the rate of movement of the piston, the ability to linearly control the mass flow rate by adjusting the rate of movement of the piston through the cylinder is proven substantially.

Discussion

Although the lithium thruster was never fired during the summer, the summer can still be deemed a success as the mechanical feed system was proven to be a smooth, steady and accurate way to supply molten lithium to the thruster. The next step in the Li-LFA project is to prepare the thruster for firing.

From a personal standpoint, I have found the summer to be extremely rewarding. I felt that I have been a valuable and contributing member of the Li-LFA team. From my summer in the EPPDyL, I have gained the knowledge and experience in the field of electric propulsion that I had hoped. It is from this knowledge and experience that I plan to continue working in the EP lab this coming year fulfilling my senior independent work requirement if not a senior thesis.

There have been many smaller projects that I have worked for the Li-LFA team this summer. At the end of the summer I began to work on designing a mechanical arm that could move a probe in and out of a firing thruster with a very high measure of accuracy and precision. The difficulty with such a task is that the time frame in which the probe can survive in a greater than thousand degree plasma is very small. Although I perceive this to be a very difficult project, I am contemplating basing my senior independent work around it because I believe it would be a very rewarding challenge.

Acknowledgements

I would like to thank Professor Choueiri for giving me the chance to work at the EPPDyL for the summer. I would also like to thank Andrea for giving me work to do, Lenny for listening to my banter when there was nothing to do, and Greg for always making things interesting, and all three for making me feel like part of the group. I would also like to thank Bob Sorenson for showing me how things worked around the machine shop, and the entire lab for making this summer a fun and enjoyable experience. Go Mechanical Advantage!!!

Figures

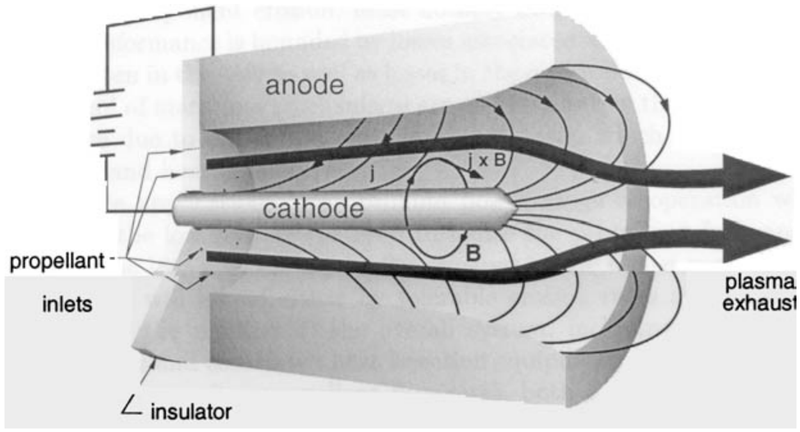

Figure 1: Diagram of a MPDT

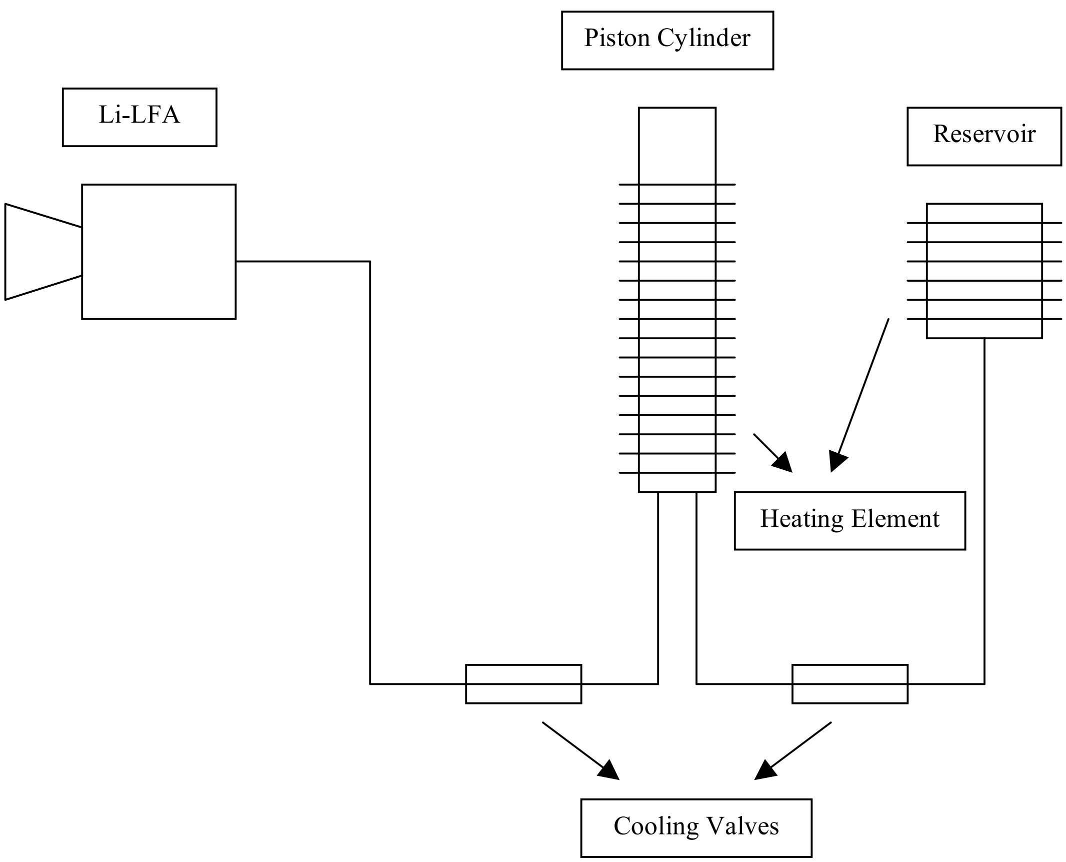

Figure 2: Diagram of the Mechanical Feed System

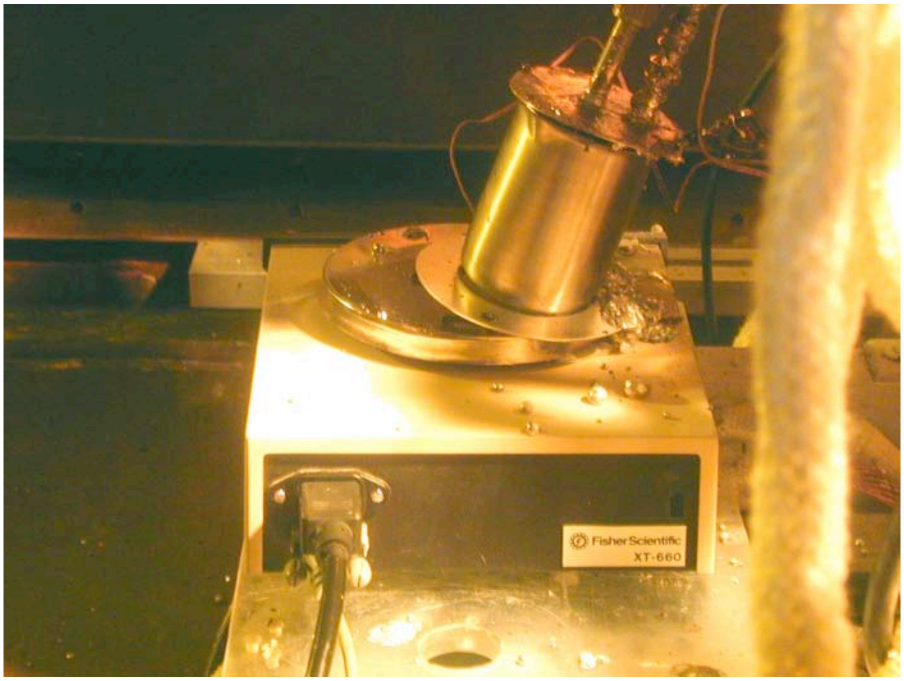

Figure 3: A Photograph of the Lithium Spill

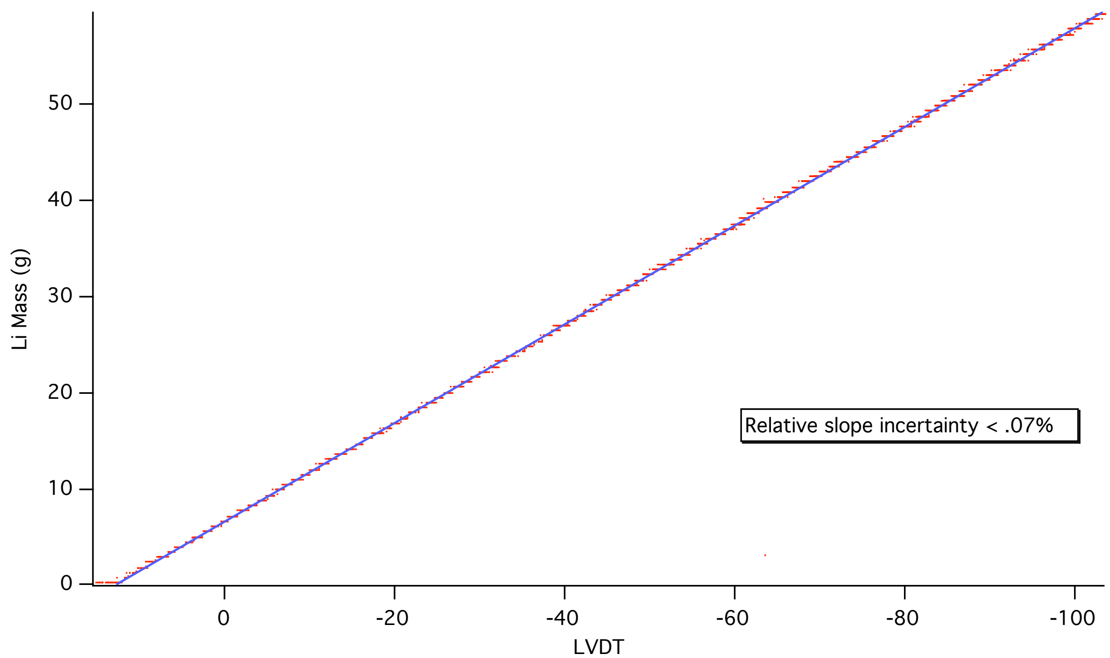

Figure 4: Graph of Beaker Mass vs. Piston Position

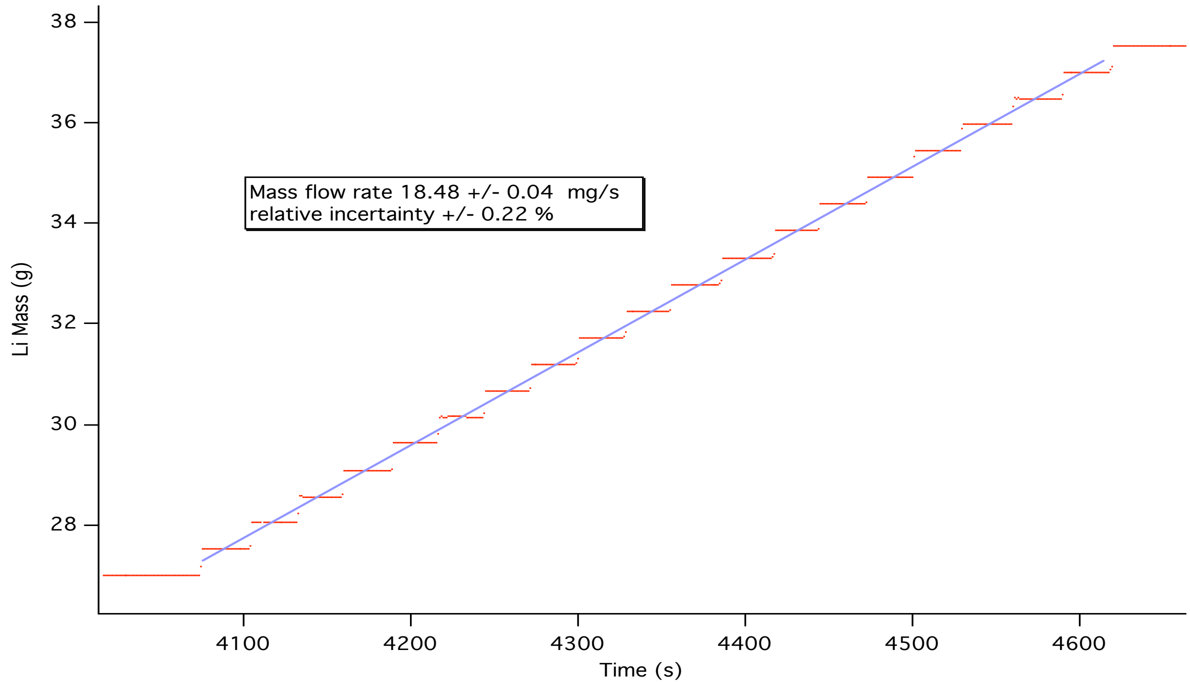

Figure 5: Graph of Beaker Mass vs. Time at Constant Feed Rate

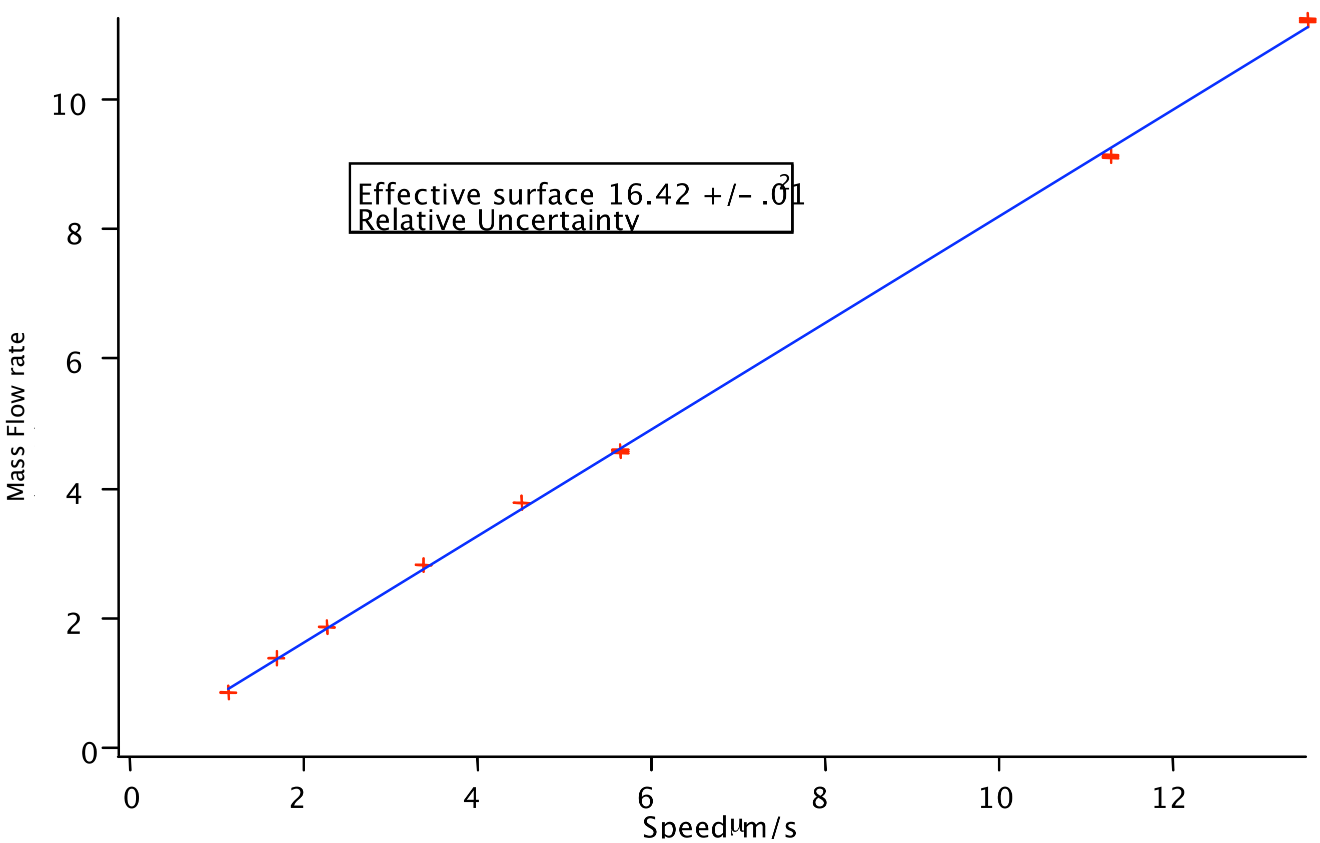

Figure 6: Graph of Mass Flow Rate vs. Rate of Movement of the Piston