Design of a plasma shield for vacuum tank windows

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Abstract
The purpose of this project was to build a shielding device for a vacuum tank in which plasma thrusters are tested. The thruster that is tested in this tank is a Lithium Lorentz Force Accelerators (LiLFA). The window shield prevents the coating of the windows with Lithium, so that optical access can be maintained during experiments, by rolling up a plastic film at a controllable speed in front of the window.

Introduction
In Princeton University's Electric Propulsion and Plasma Dynamics Lab, several kinds of Plasma thrusters are currently being developed and tested. One of them is a Lithium Lorentz Force Accelerator. It creates and accelerates a lithium plasma to create thrust. The thruster is being tested in a vacuum tank, which has a number of windows through which the thruster can be watched and spectroscopic data can be taken.

During previous tests with the thruster, a problem occurred that made it impossible to take spectroscopy data through the windows of the tank. The lithium plasma condensed on the windows of the tank, and completely coated them after approximately five minutes. In order to get all the spectroscopy data needed, the visibility through the windows needs to be good for at least 30 minutes.

The visibility through the window can be kept good by placing a piece of plastic in front of the window, which is renewed several times during the firing. The purpose my research was to design a device that performs this task. This project required a material, which has good optical qualities, can withstand the heat in the tank, and does not react with lithium.

There were two possible concepts for how the plastic in front of the window could be exchanged during the firing of the thruster. One of them was that a set of sheets of the plastic could be used and exchanged automatically, the other one included rolling up a roll of film in front of the window. The roller concept was the one that was finally chosen, since a system that exchanges sheets of plastic would take up more space inside the tank and the roller system was less complicated.

Design of the window shield
The materials considered for use in the window shield included transparent Teflon, Mylar, Polyethylen, PVC, and Ardel. All of these materials have good optical qualities, meaning a light transmittance rate of about 90 percent and a low haze, less than 2 %. They differ in melting point and cost. Transparent Teflon has the highest melting point, but it is expensive and hard to obtain. Mylar was eventually chosen as the material to be used, because it has a higher melting point than most other plastics, and can be ordered from various companies for a reasonable price.

The device consists of two rollers, a supply and a take-up roller. The supply roller is placed below the window and initially holds the roll of plastic. The take-up roller is

placed above the window and is attached to a motor, which spins it, so that the plastic film is pulled up from the supply roller and rolled up on the take-up.
The device is mounted on an aluminum frame, which also shields the motor and the rollers from the lithium. On the one hand, this makes the device a lot easier to clean after firing. On the other hand, some of the parts of the device are made out of plastics, which have lower melting points than aluminum, and often also react with lithium. Unlike the plastic film, these parts shouldn't have to be replaced after very experiment, so they have to be protected from the plasma.
The front part of the aluminum frame, as seen from the inside of the tank, is a rectangular ¼ inch thick plate, with a circular whole in it, which has the same radius as the center part of the tank window.
The motor that drives the take-up roller operates with DC-currents up to 24 V. By adjusting the voltage supplied to the motor, the speed of the roller can be controlled. This way the motor can be run at a high frequency while spectroscopy data is being taken, and at a lower frequency while no data is taken, which minimizes the amount of plastic film needed.
After every experiment, the covers of the device can be opened, and the motor has to be disconnected from the shaft, so that the roll of film can be taken off the roller and be disposed. The design of the device makes this relatively easy to do.

Testing and Discussion
Small samples of the plastic films (Mylar, Polyethylen, transparent Teflon, PVC and Ardel with various thicknesses) were placed in the tank near the plume of the thruster in order to test their resistance to the lithium plasma. The attached pictures show that none of the film could withstand the extreme heat at that point of the tank. The temperatures in the plume get up to 700º C, which is higher than the melting points of all the plastics tested. Since the temperatures are much lower at the windows, this did not mean that the plastics could not be used for the window shield. These plastic films can be used if the window shield is placed on one of the windows in the back of the tank, where the temperatures are considerably lower.
Since the window shield was built, the LiLFA has been fired several times for short periods of time. During these short tests, the window shield worked properly. The window that was shielded stayed clear, while the other windows of the tank were starting to get covered with lithium. The motor was run at 6 volts, but the optimal voltage at which the motor should be run is yet to be determined. Test for this will include measuring the visibility through the window by placing a laser in front of the window, whose beam then hits a photo diode placed behind the window, so the visibility through the window could be determined at different speeds of the film.
While no data is being taken through the window, the motor will still have to be run at a certain speed, which is yet to be determined. This speed depends on how long the plastic film can withstand being exposed to the lithium without tearing.
The performance of the window shield will be tested in more detail the next time the plasma thruster is fired. If it proves to be effective, it will be used in future experiments to take optical data through the windows of the plasma tanks in the Electric Propulsion and Plasma Dynamics Lab. The optimal operating conditions (i.e. optimal film speeds)

have yet to be determined and will require longer firings. For further details of the design please refer to the attached pictures and sketches of the device.

Acknowledgements
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Figure 1: The Window Shield without covers

Figure 2: The Window shield with covers

Figure 3: Plastic film samples after exposure to Lithium plasma

Figure 4: More Plastic film samples after exposure to Lithium plasma

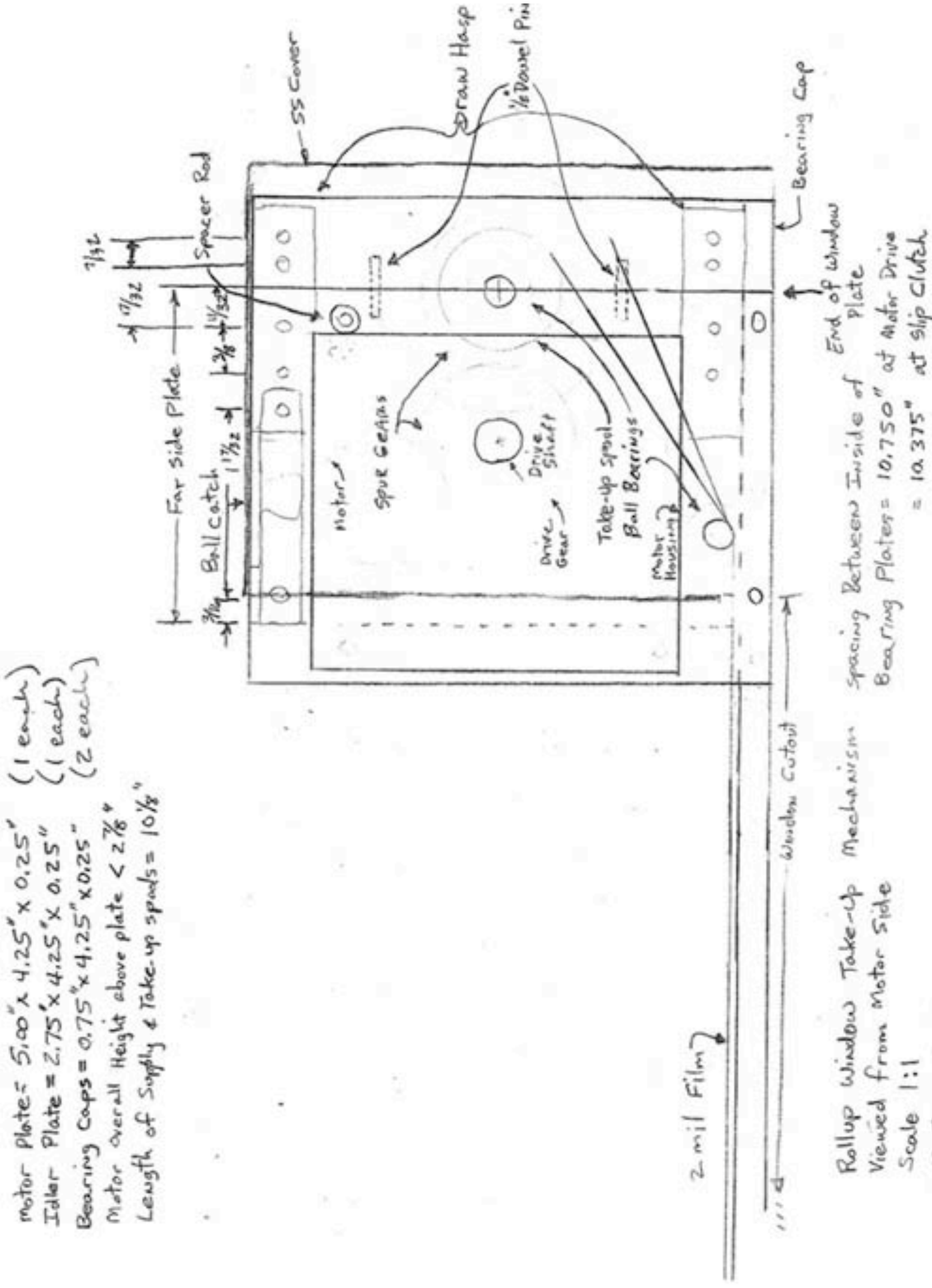

Figure 5: Sketch of the Window Shield (drawn by Robert Sorenson)