# Improvements on a Cylindrical Geometry "Micro" Hall Thruster

Kevin M. Ertmer '00, MAE

Dr. Nathaniel Fisch and Dr. Yevgeny Raitses
21 September, 2000

## Abstract

This brief report summarizes the work done from 02 July, 2000 to 30 September, 2000 for the micro Hall thruster experiment at PPPL. A 2cm cylindrical geometry Hall thruster was designed and operated on the PPPL HTX's small vacuum facility in April, 2000. Based on the initial success of this basic design, further investigations were deemed necessary. A new, 3cm design was developed based primarily on improved magnetic simulations, and a closer adherence to channel dimension ratios of a larger, 9cm design. Simplicity and flexibility were influencing factors in this new design.

## Introduction

Perturbations in the orbits of satellites caused by non-sphericity of the Earth, sun-moon interactions, atmospheric drag, and solar radiation pressure necessitate the use of some corrective propulsive device. Further, because of the extremely high cost of all current space lift capabilities, weight minimization is at the forefront of spacecraft design. Therefore, a highly efficient and simple propulsion device would entail a light thruster, and more importantly, less fuel.

Traditionally, the types of thrusters used to accomplish these sorts of maneuvers were chemical in nature. However, chemical propulsion is limited by the internal energy of fuel which is available in the chemical reaction, the combustion chamber's and nozzle's heat transfer tolerances, and energy lost to internal modes of the gas. Electric propulsion (EP) bypasses these limitations. Generally speaking, by ionizing a gas and accelerating the particles directly with body forces, the only limitation is the onboard power available to such a system. Therefore, high exhaust velocities can be achieved, which, according to the famous "rocket" equation, mean less fuel (proportional to total spacecraft mass). This means more functionality for the money, and less money spent on a given spacecraft system.

This being said, the trend has still been to make *all* spacecraft components smaller, to which the terms small-, mini-, and micro- satellite refer. Smaller spacecraft entail smaller propulsion systems. A Hall thruster is one electric propulsion device that potentially exhibits good scaling to the small domains; due to their proven high efficiencies on the kilowatt level (>50%), and their relatively high thrust densities (compared to other electric propulsion devices, such as the ion thrusters.) However, experiment has demonstrated that Hall thrusters exhibit decreased efficiency at lower power and size. Further, a reduction in size has shown increased heating of channel walls, which means reduced magnetic circuit performance and reduced lifetime of the system.

To help deal with these issues, a new type of Hall thruster was developed at PPPL in the past two years. It utilizes a cylindrical geometry (vs. a coaxial geometry) to alleviate the problem of heating associated with this inner body. The body of my work deals with developing a small version (~2-3cm channel diameter) of this type of Hall thruster.

## Operating Principles and Theoretical Scaling of Hall Thrusters

Conventional Hall thruster operation is straightforward: an inert gas (usually Xenon) is introduced from the rear of a coaxial dielectric channel. A coaxial magnetic circuit creates a radial magnetic field. An axial electric field is created between an anode at the rear of the channel and a cathode at the entrance of the channel. Electrons are admitted from some electron source, drawn into the channel by the established electric field, where they are trapped by the magnetic field and forced to orbit the inner pole in the region of high radial magnetic field. These electrons ionize the Xenon, forming a quasi-neutral plasma, thus also localizing the potential drop to the region of high magnetic field. Because of the larger mass of the Xenon atoms (corresponding to a larger Larmor radius), these particles are nearly unaffected by the magnetic field, and are accelerated axially by the electric field. Very simply, momentum balance of these accelerated ions and the device yields thrust.[1]

The approach to scaling is known as photograph scaling. All dimensions of the thruster are scaled down by a factor $k < 1$. However, several quantities must remain invariant: Exhaust velocity needs to remain constant for given orbital missions, regardless of spacecraft mass, therefore, the discharge voltage must remain constant. This means that the only way to scale down the power is to scale the discharge current, since $P_d = I_d V_d$, therefore, because of quasi-neutrality, the mass flow rate. To ensure the same amount of ionization in the channel (the proportion of propellant ionized), both the mean free path of the electrons as well as the Larmor radii must also scale by the factor *k*. Therefore, according to the equation for Larmor radius $r_L = mv_\perp / eB$, implying that the magnetic field must scale as $1/k$, if the Larmor radius scales as *k*.

This constraint motivated a number of magnetic simulations in Ansys, based on a 3 cm channel diameter. The corresponding channel length and anode diameters were taken from scaling of the 9 cm cylindrical thruster. This process yielded the design seen in Figure 1.

[1] Actually, a detailed analysis shows that the ions interact with a "grid" of electrons, which interact with the magnetic circuit, which results in a net force on the device.

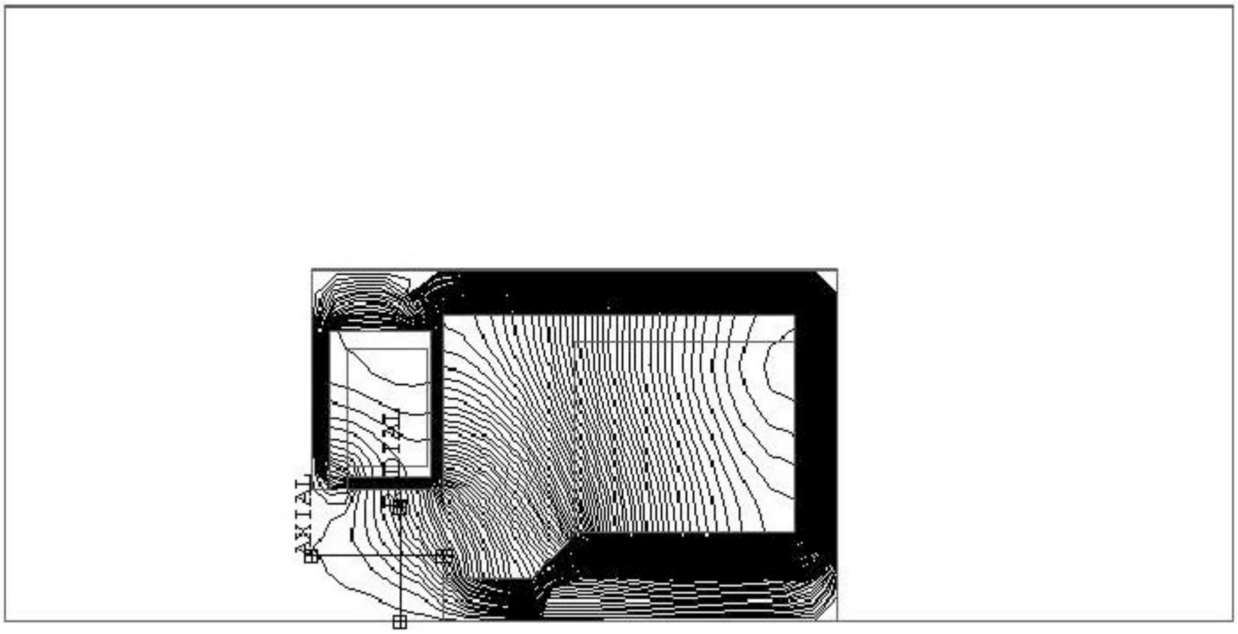
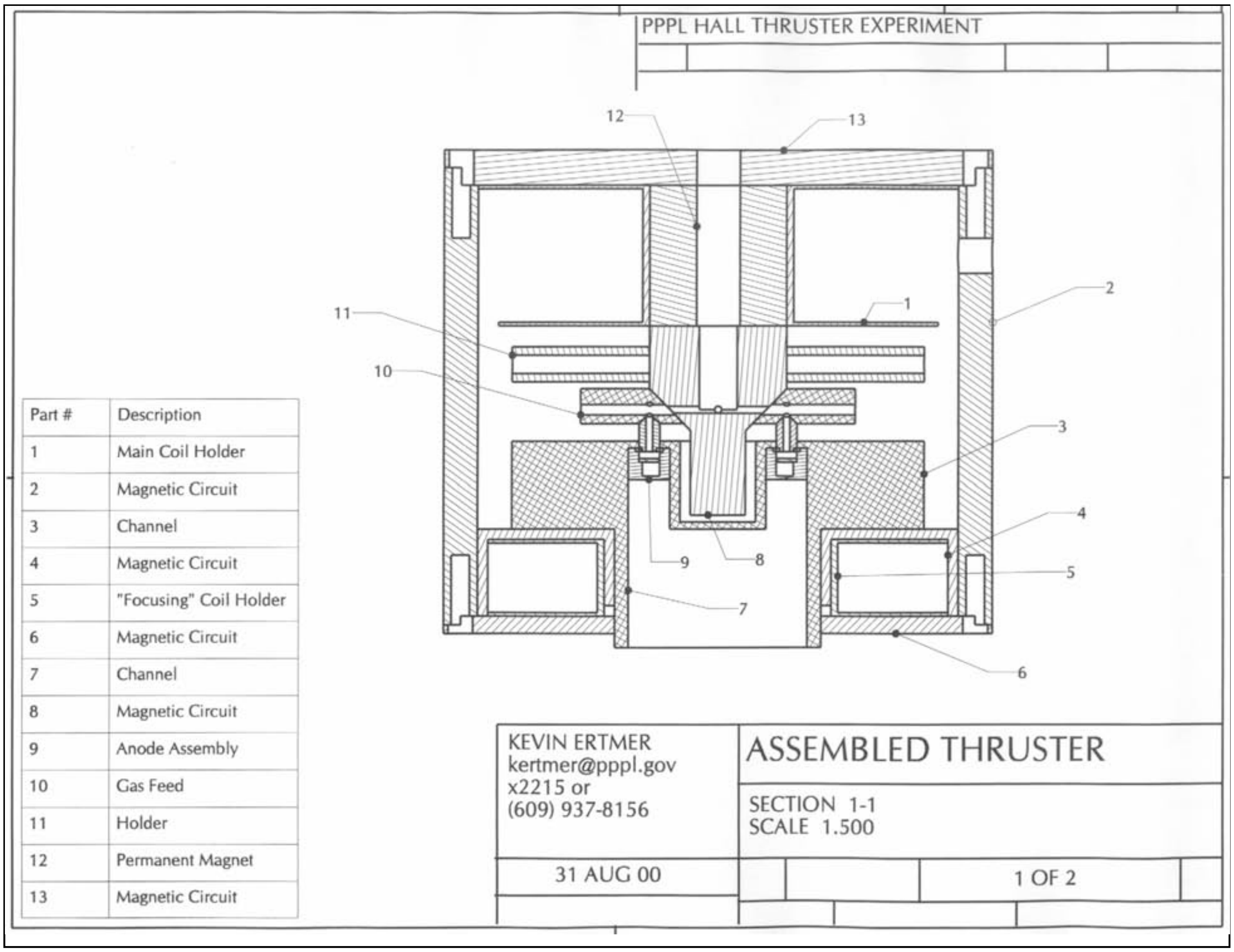



**Figure 1**

Ansys magnetic simulation of a 3cm cylindrical Hall thruster. (An axis of symmetry lies on the lower edge of this graphic) Produced by PPPL graduate student C. Andrew Burlingame.

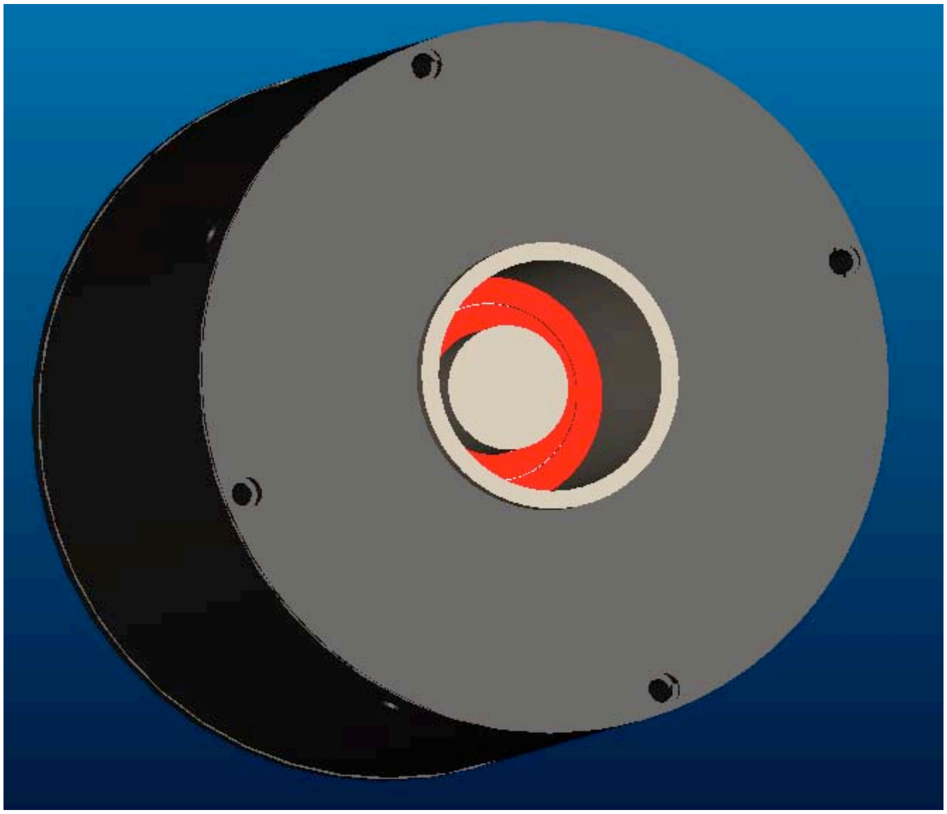
## Design of a 3cm Cylindrical Hall Thruster

Figure 2 shows a cross section of the near-final design of the 3-cm thruster. This final design was developed in a 3d CAD program (Pro-Engineer), and is almost-final version of about two-dozen designs. The majority of the design constraints developed from the gas distribution system, and the need for it not only to be coupled to the anode, but for it to produce a uniform flow of gas into the chamber, and fit into the small space available.




This design attempted to stay as close as possible to the dimensions set forth by the above magnetic simulations. Knowledge of materials and design concepts was applied from the first, 2cm thruster built earlier this year. The thruster consists entirely of soft iron and wire coils for the magnetic circuit, stainless steel for structural parts and fasteners, and boron nitride for the channel and electrical insulators. The estimated weight of this design as calculated by Pro-Engineer (without the coils) is approximately 1.1 kilograms, meaning that it will be able to be held by a very sensitive thrust stand.

A 3-dimensional rendering looking into the channel of this model is shown in Figure 3.



Although the design is not quite finished, it is nearly complete and is the culmination of much hard work by the PPPL Hall Thruster team. Machining will begin in the next few weeks and assembly should be completed within the next two months, when it will be tested in the large vacuum facility at PPPL.

## References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