PRELIMINARY RESULTS FROM A PERMANENT MAGNET HALL THRUSTER EVALUATION

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Abstract

This work shows the first results from a Hall Thruster designed with an innovative magnetic field source within an array of permanent magnets. It's basic design was adapted from the SPT 100, but the channel acquire new dimensions to support the magnets. The magnetic induction profile is very similar to the well known closed drift thrusters, however in the plume region the field is stronger. The thruster operates with discharge current going from 0.5 A to 1.5 A and 450 volts in pure Argon gas . The thrust is between 45mN to 80mN although ionization efficiency are low. Typical plasma temperature, density and magnetic field space profiles are shown. Ion energy measurements and its relation with plasma drift from the Hall Thruster will also be presented.

1. Introduction

Long duration space missions often require a long period of acceleration capability. Electric propulsion with plasmas has proved to be an efficient method to obtain these requirements by reducing propellant mass and generating high exhaust velocities. The closed drift thrusters, so called Hall Thruster are now been developed in USA and France based on an original design made in Russia in the beginning of space exploration on the sixties years. Some of the most important features are steady state operation at moderate power levels, external sources of electrons and externally applied magnetic field. A remarkable characteristic is the simpler design and working principles compared with the grid electron bombardment thruster successfully developed in the USA.

In this work we will show the preliminary results of a new closed drift thruster with one stage magnetic layer that is been developed at the Plasma Laboratory of UnB. The new feature of this thruster is a magnetic field generated by permanent ceramic magnets (ferrite). The main advantage of using permanent magnets instead of electromagnet coils is the possibility to save about 200W in energy consumption, while keeping the same thrust obtained in the SPT family. It is also possible to simplify the thruster transponder and power electronics by using the proposed arrangements of permanent magnets for Hall current generation.

2. Plasma Source and Diagnostics Description

A standard glass bell jar vacuum system with volume of 0.2m^3 , fore pump with pump velocity of 35 m^3 /h and diffusion pump velocity of 500 l/s is able to maintain 10^{-4}torr to 10^{-5}torr of working pressure in the vacuum chamber. In order to clean the system between working periods, a cryogenic trap is used to decrease the bell jar background pressure to 10^{-6} torr.

The Hall thruster plasma source is positioned at the bottom of the bell jar in order to allow a plasma drift length of 0.7m. On fig. 1A a side view of the Permanent Magnet Hall Thruster (PMHT) working is shown. The plasma plume near the channel is clearly similar to the SPT but it is also possible to see a plasma beam going away from the plasma source indicating an extra ion acceleration in the PMHT. The plasma source chamber is made of stainless steel with ionization channel cover by a thin ceramic layer within 2mm thickness. The anode ring is 2 cm wide and 1mm thick it is also made of stainless steel and it is positioned

3.8cm from the exit of the channel. Behind the anode ring the fuel gas is uniformly distributed in the chamber by using a isolated cupper circular tube with several small holes.

Hall thruster schematics, on fig. 1b, shows a cross section view of the thruster with permanent magnet locations, anode ring , thermionic cathode, gas feed tube, electrical supplies and plasma diagnostics. The plasma is generated by a discharge between the anode ring and a negatively polarized directed heated cathode. This simple thermionic cathode is made of a 5.5cm long and 2mm thick tungsten wire cover by BaO in order to increase electron emission. By using this type of cathode it is possible to move it and choose its best position outside the ionization channel, which is 3.0cm outside the channel exit.

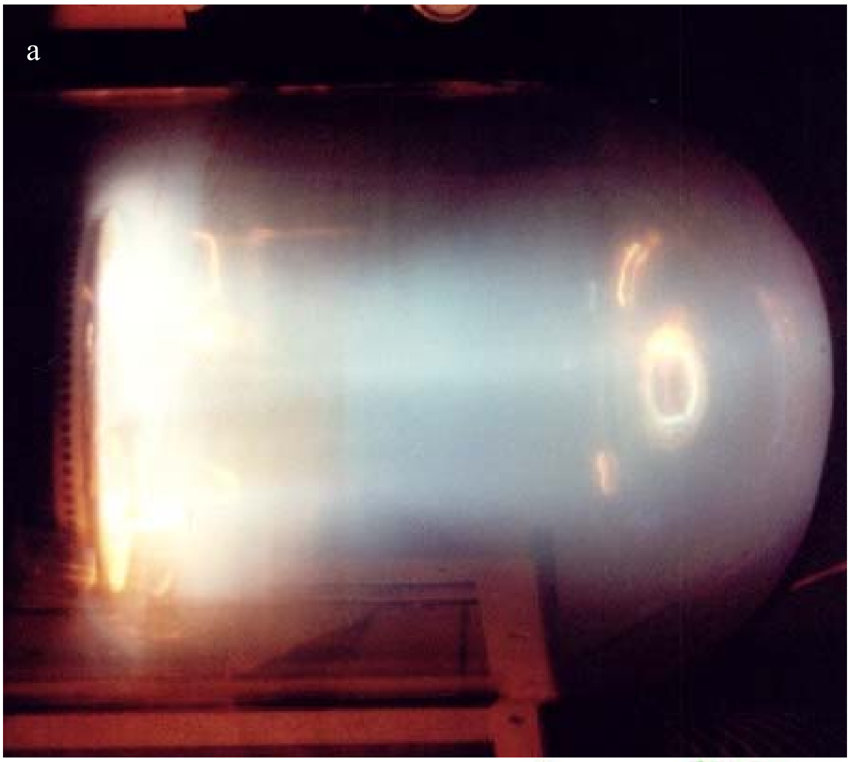
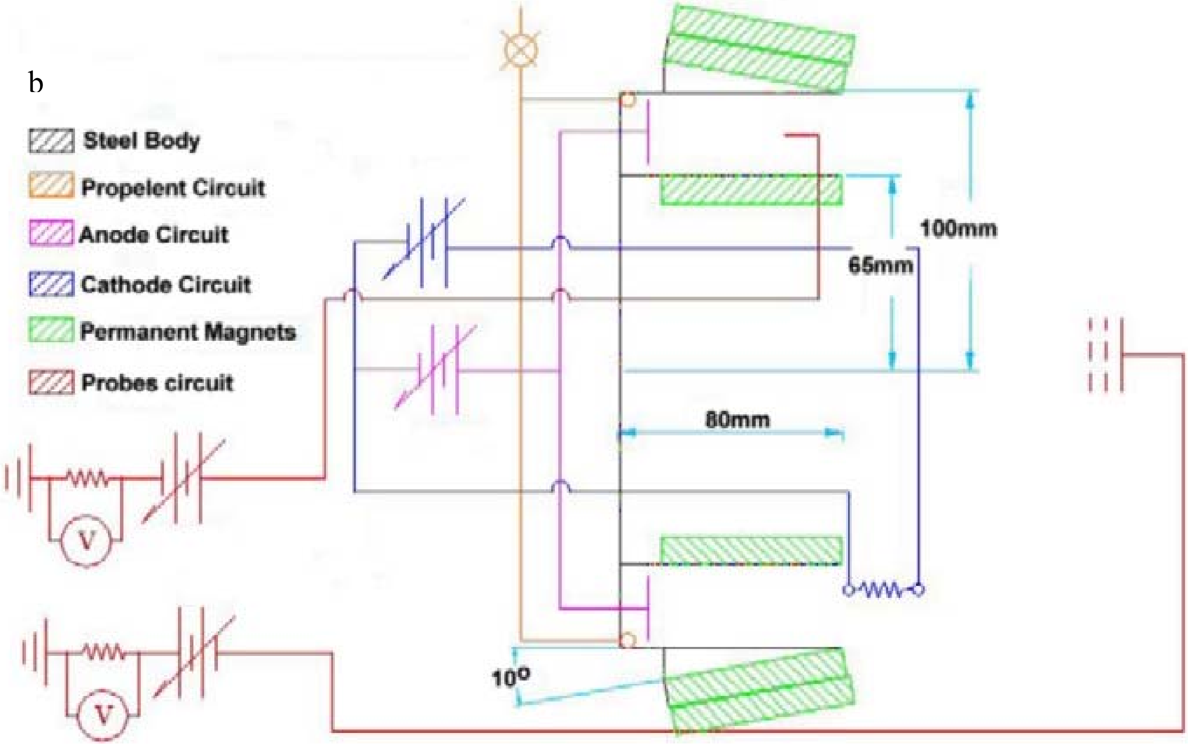


Fig.1 – (a) Photo of the PMHT working in the low thrust mode.
(b) Schematics of the PMHT, showing Permanent Magnets geometry, circuits, and diagnostics probes.



On fig. 2a Hall thruster computer simulated magnetic field lines for two concentric circles of 76 permanent magnets bars (16 on the internal cylinder) with 6.0 cm length and cross section of 1.0 cm x 2.0 cm. The radial component of the magnetic field for several distances from the source axis is shown on fig. 2b . The magnetic field space profile along the channel has a maximum value of 350 gauss, near the channel exit and 0.5cm from the external wall. At the center of the channel a magnetic field gradient **dB/dz > 0** was obtained within this magnet arrangement. It is important to point out that within this arrangement, others magnetic field components (axial and poloidal) are also present in the thruster channel. They might contribute to generate better plasma conditions in the ionization channel and higher plasma drift flux and Hall current in the plasma source.

Plasma diagnostics inside and outside the source were made by using a movable Langmuir probe and an ion energy analyzer. The cylindrical Langmuir probe (0.25mm x 3.5mm) can be orientated parallel or perpendicular to the thruster axis in order to provide plasma density, plasma potencial and temperature space profiles. A two grid ion energy analyzer is positioned 35 cm distance from the plasma source. It is able to measure the drifting plasma flux current space distribution and the correspondent ion energy.

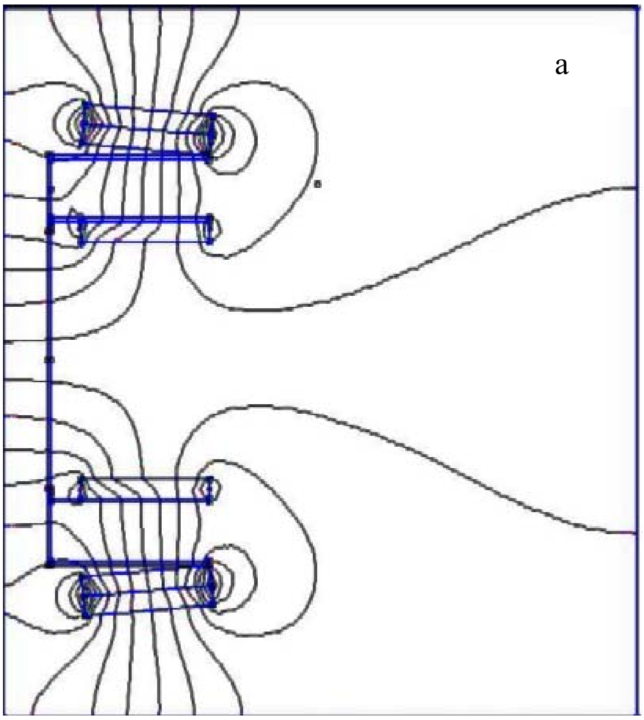
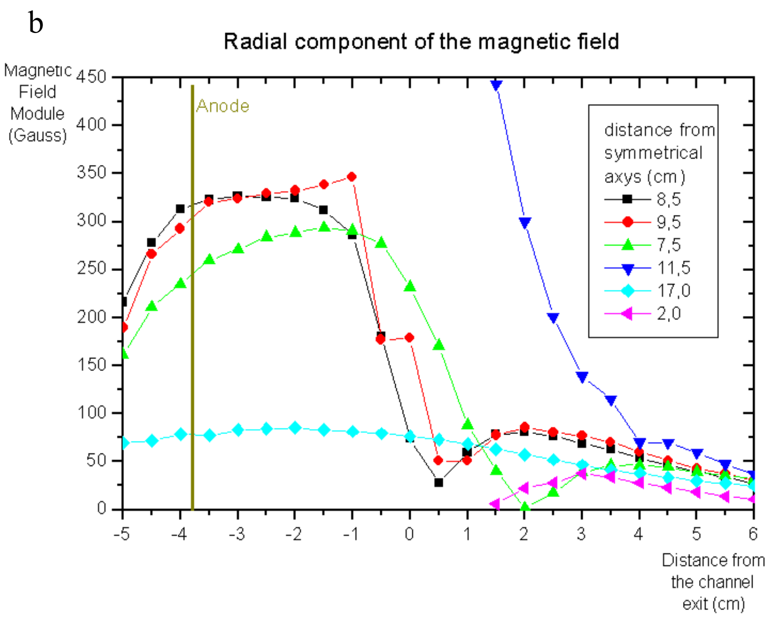


Fig. 2 – (a) A finite element simulation of the magnetic field generated by permanent magnets for the geometry of he Hall Thruster.
(b) Magnetic field Hall probe measurements for the radial component of the PMHT magnetic field. The fig. shows the profile for several distance from the thruster center. Please note that the channel radius is between 6.5cm and 10cm. The zero in the horizontal axis means the position of the channel exit.



3. Experimental Results

The PMHT can be easily operated with anode bias voltage going from 150 volts to 700 volts. The discharge plasma current for most of the experimental conditions are between 0.1 to 1.5 amps within argon gas pressures smaller than10^{-2}torr and greater than 10^{-4}torr. In this work, we call the 0.1amp discharge the low thrust regime, and the 1.5amp discharge (with 150 to 200 volts), the high thrust operational regime. The tungsten wire covered with BaO hot cathode works with temperature of 900°C emitting 1A/cm2 of primary electrons to generate the discharge.

In the highest pressure conditions an electron plasma density and temperature space profiles inside the plasma source channel are respectively in the range of 2.0 - $2.5x10^{10}$part/cm^{-3} and temperature from 35eV to 65eV (see figs. 3 a and 3b). Plasma potential space profile (fig. 4) shows that inside the plasma source the anode determine the plasma potential maintaining the average anode bias voltage inside the plasma channel. Outside the channel the potential decrease drastically mainly due to the plasma neutralization made by the thermionically emitted electrons.

a

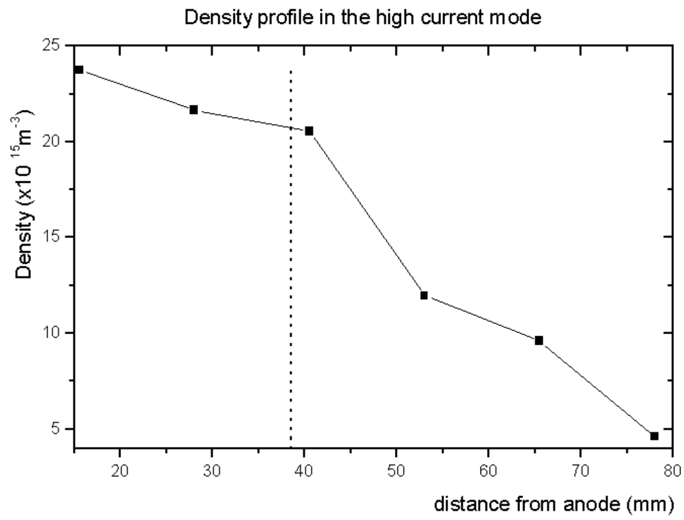
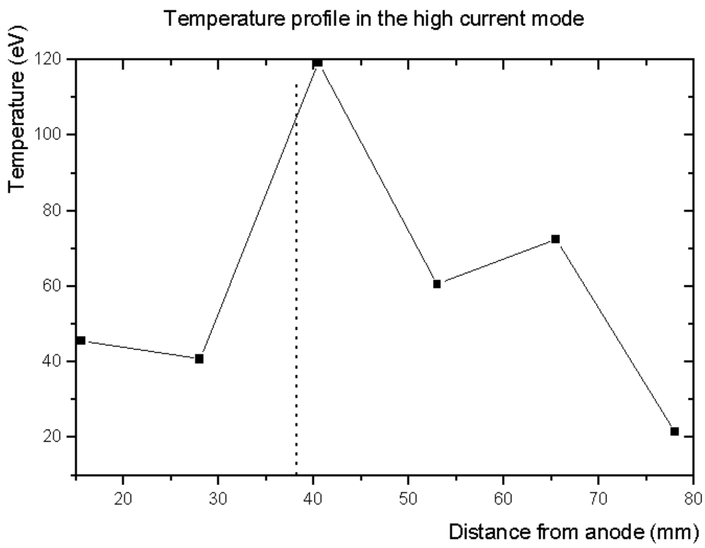


Fig. 3 – (a) Density space profile of the PMHT working in the high thust mode.
(b) Temperature space profile also for the high Thust mode.
Both curves are measured with a Langmuir probe.
The doted line means the channel exit plane.

b



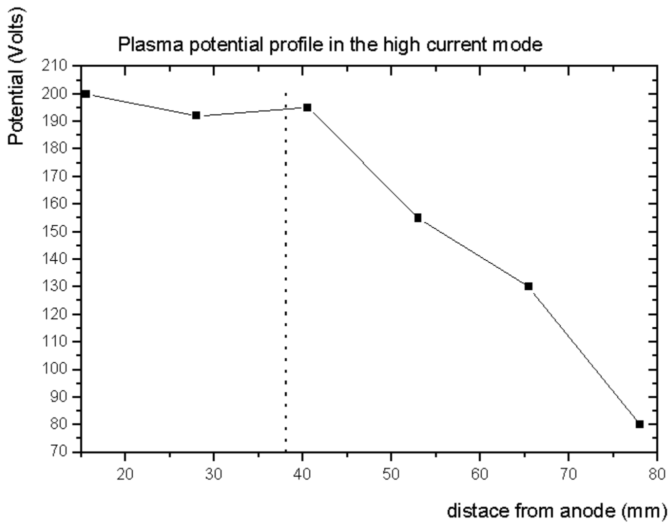


Fig. 4 – Plasma potential space profile, for the high thrust operation mode. Note that inside the channel, the plasma sustain the voltage applied in the anode, only outside the channel (dotted line) we have the plasma potential drop, and so on, the acceleration.

The plasma acceleration is measured using an ion energy analyzer. The ion energy distribution. As a derivation of analyzer characteristics curve, clearly shows two peaks indicating that ion energies are about 350eV and 600 eV, for a 650 volts discharge (see fig. 5).

For measure the plasma beam profile, we changed the ion energy analyzer to be a “faraday cup”. Positioning the faraday-cup 35cm from the acceleration channel exit, we moved than to obtain the angular distribution of the plasma, and so the beam profile. This data are showed in the fig. 6, where we can see some asymmetry that occurs because the utilization of a hot filament cathode just above the channel exit. In fig. 6, the relative cathode position is in the -10^o vertical line.

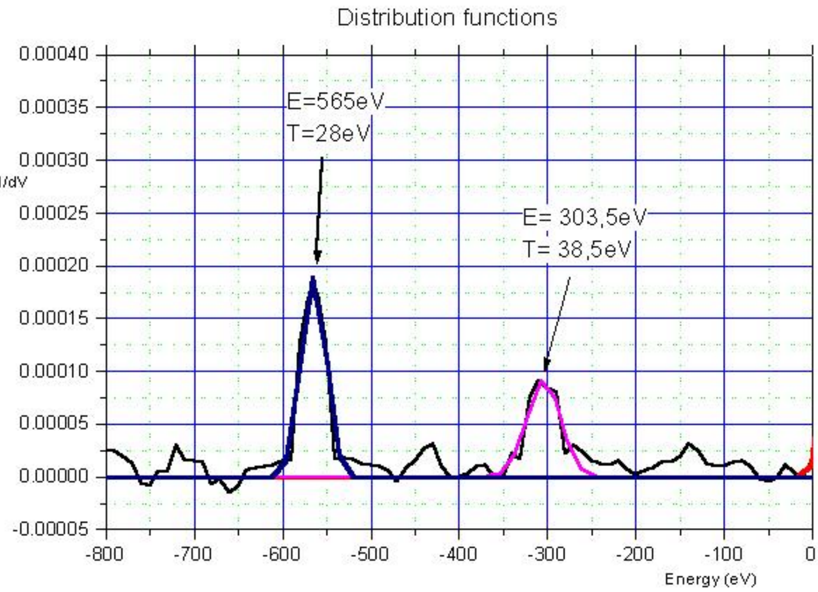


Fig. 5 – The ion distribution function, as we derivate from the ion energy analyzer. Note that exists several peaks, but the most expressive are about 300eV and 565eV. For this curve, we work with the low thrust operation mode, with a discharge about 600volts. In the horizontal axis, the minus sign in the label only shows that we are working with ions.

The total thrust calculated from the ion collector current is in the range of 18mN to 39 mN indicating that the PMHT is working with 27% of efficiency as expected for this first experimental model. If the total thrust is calculated from the total input power in the Hall discharge the thrust goes from 44mN to 80mN . So the thrust obtained on the PMHT is only 43% of the maximum thrust that can be obtained from this discharge. These thrust values can at least be scale up to the thrust values of the SPT 100.

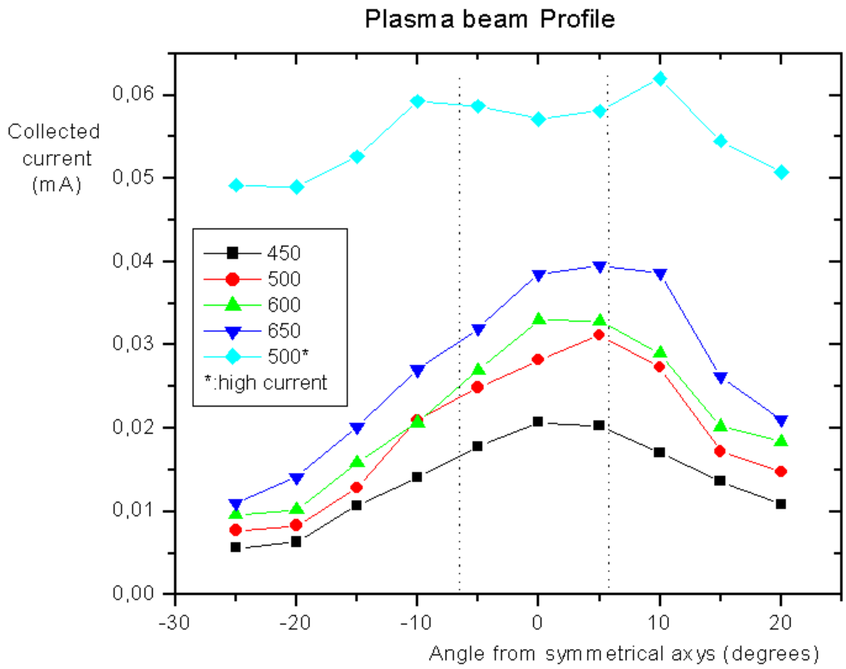


Fig. 6 – The plasma beam profile, measured by a faraday-cup at 35cm from the channel exit. Each curve was obtained from a different discharge voltage, as legend show. The high current means high thrust operation mode.

4. Conclusion

A new conception of closed drift Hall thruster using permanent magnets was developed. The results obtained on the magnetic field geometry and strength, on plasma density temperature and thrust measured by ion collector probe and ion energy analyzer are very much encouraging. In spite of the use of simple materials easily found on brazillian industrial market , the new PMHT Hall thruster is able to produce remarkable working characteristics. The economy on satellite energy consumption is the mainly advantage of this new design.

References:

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