

An Helicon Double Layer Type Thruster within a Double Magnetic Cusped Field Configuration

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Abstract: This work describes the development of a Helicon Double Layer Thruster and its acquisition system at the University of Brasilia Plasma Physics Laboratory. Together with the data analysis process, we are able to measure important plasma characteristics in order to compound an Integrated Plasma Diagnostics System. Experimental results can be compared with computational simulations in order to improve parameters and optimize the performance of the thruster.

Nomenclature

e	=	Fundamental charge
K_b	=	Boltzmann constant
V	=	Voltage
T_e	=	Electron temperature
i	=	Electrical current

I. Introduction

The Plasma Physics Laboratory at the University of Brasilia (UnBPPL) has been working with Plasma Thrusters designs since 2001, when the first PHALL thruster was developed and, subsequently, the models PHALL II and III were simulated, designed and tested. A Hall Effect Thruster (HET) is a type of plasma thruster in which the propellant gas is ionized and accelerated by a magneto hydrodynamic effect combined with electrostatic ion acceleration. The essential operating principle of the HET is that it uses a $\mathbf{J} \times \mathbf{B}$ force and an electrostatic potential to accelerate ions up to high speeds [1]. The Laboratory has been, also, in the after years, carrying researches in the field of characterization of Double Layer for Thrust Engines, the scope of this paper.

Helicon waves belong to the category of whistler waves, which are right-handed circularly polarized electromagnetic waves in free space [5]. They have two main properties, such as: Low frequency, leading to the electrons' gyrations slowness and therefore only their guiding center motions being kept, and they are modes of

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bounded systems, in which their purely electromagnetic character cannot be maintained. In [5], Francis F. Chen gives the theoretical basis to show that the higher than expected gain in plasma acceleration with Helicon waves in Argon gas is possible if the ionized electrons are directly accelerated by the wave interaction with the particles rather than by a “random heating process”.

Double Layers are the spatial separation of charge existent in nearly collisionless plasmas created due to perturbation of the plasma environment. This perturbation may be generated by different sources, including disruption of a neutral current sheet [2], current-driven instabilities [3] or constraint by a magnetic mirror [4]. At the UnBPPL, the Double Layer is studied by the magnetic mirror constraint principle.

More recently, the electric field embedded in the Double Layer has been proposed as a thrust producing mechanism for space propulsion, especially in light of the relative simplicity and anticipated reliability of the underlying technology [7].

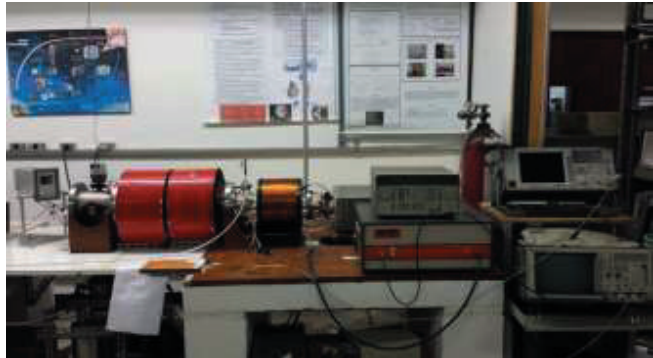


Figure 1. Helicon Double Layer Thruster at the UnBPPL.

II. Description of the Helicon Double Layer Device

on most of the Helicon Double Layer Devices on the literature [4-6][11], the HDLT (Helicon Double Layer Thruster) of UnB has three types of magnetic coils containing 730, 912 and 710 loops of 3mm diameter (10 AWG) copper insulated wire. The coils are connected in a DC voltage supply, model Tectrol TCA 15-50D-1A, which releases a maximum current of 30 Amperes per a maximum of 40 Volts to the coil system. Two vacuum chambers Pyrex made (Borosilicate) with approximately 1 meter and 10 centimeters long with several flanges ports for optical and instrumentation access constitute the device. The First and Large one is about 70 cm long and 16 cm diameter, the small one is 11 cm diameter per 40 cm long. All the connections are stainless non-magnetic made. Horizontally, from the right to the left of the Pyrex Chamber, Argon gas cylinder is connected using a Teflon hose and a leak valve, feeding the system.

The vacuum system is generated in two steps, using two distinct vacuum pumps: one mechanical pump (Edwards RV5 E2M5), being able to pump at a rate of 5.1 m³/h, used for the initial low vacuum; and a diffusion pump for high vacuum (Edwards Diffstak 63/150M) pumping at a rate of 135 L/s. With this system, a vacuum of the order of 10⁻⁶ Torr can be reached in approximately two or three hours. To track how the vacuum evolve, it is used a system of pressure gauges – two Edwards APG-M NW16 for the low vacuum, and a Edwards AIM-S-NW25 for the high vacuum – and a controller where it is shown the information collected by the gauges – Edwards TIC Instrument Controller 3 Head RS232/RS485. When the system reaches the necessary pressure, approximately 5x10⁻⁶ Torr, it is started the process of Argon release into the chamber the pressure increases to approximately 5x10⁻³Torr.

After the right pressure conditions are achieved, the RF system is turned on. A signal generator, model hp 8648A, is used to generate RF wave with a frequency of 29,959 MHz and an amplitude of -7,5 dBm. This signal is measured with the help of an oscilloscope, model hp 54540A, and amplified by a 25 WATTS amplifier, model Amplifier Research 25W1000M7. The coupling with the antenna is made using a capacitive impedance matching circuit for maximum power transfer.

The RF antenna is made using a ring shaped copper bar. This inductive-capacitive ring is used to excite the plasma by electromagnetic radiation. All the connections in the RF assembly are made with coaxial cables.

Once the RF is turned on, the electromagnetic waves heat the Argon gas, ionizing it and creating the plasma environment. The ionization by electromagnetic radiation is a process in which electrons are pulled out of the atoms by interaction with the field. By absorbing the photons, electrons gain energy enough to disrupt the atomic bound and by collision increase the rate of ionization. The difference between Normal RF waves and helicon waves, described in [6], rests upon the fact that the latter has a higher penetration power, and when coupled with the magnetic field, generates an efficient production of a controllable fast electrons population.

After the Plasma is created, the Coils are turned on and the Magnetostatic field of an maximum of 500 Gauss on the axis is generated, squeezing the plasma and then, if adjusted with the right conditions, generating the ambipolar field.

Interesting to notice that, the property of the expanding magnetic field gives strong conditions for the ambipolar field appearance and consequently the drop of the potential inside of the plasma, creating the Double Layer region.

The expansion of the Magnetic field lines and its action upon the ions and electrons creates a charge separation on the plasma. This charge separation generates a Electric field that accelerate ions in the direction of the axis, giving the impulse necessary for a propulsion principle. As demonstrated by [5], there may be found a direct connection between the use of Helicon waves with magnetic fields and the increase of power deposited on the plasma from electromagnetic fields, justifying the use of such system configuration.

III. Finite Element Magnetics Simulation (FEMM)

Magnetostatic simulations of the profile of the devices' surroundings were made with the help of the program. For plasma constrained by a magnetic mirror, the position of the double Layer is linearly tied to the magnetic field at a position close to the maximum in the gradient and half the maximum of the field [6], stressing so the importance in modeling the magnetic field profile of the device.

With the help of the program, it is also possible to plot a graph showing the intensity of the Magnetic field in the axial direction. This graphic is relevant for helping to find the position established in [6]. In the case of the UnBPPL, the Double Layer must be found approximately at the position 0,60 meter, where the magnetic field lines expansion occurs.

A conclusion section is not required, though it is preferred. Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions.

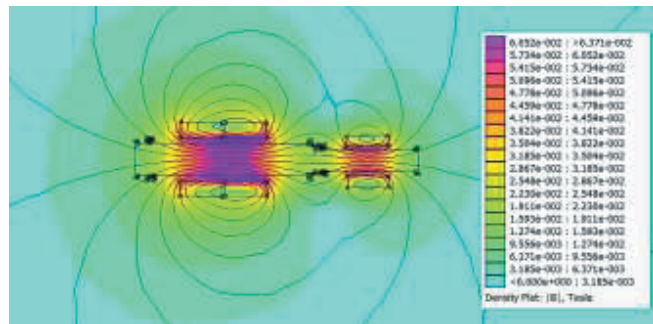


Figure 2. Magnetic Field distribution simulated in FEMM.

IV. Acquisition System

A. Probes

Probes used in the Laboratory are basically separated in two groups: Langmuir (electric probes), and the Energy Analyzer, to be explained in next section.

An electric probe is a cylindrical metallic device (generally tungsten or molybdenum) insert in the plasma and posteriorly biased with a potential, in order to discriminate ions and get the curve from which the Temperature, floating potential and Plasma potential can be inferred.

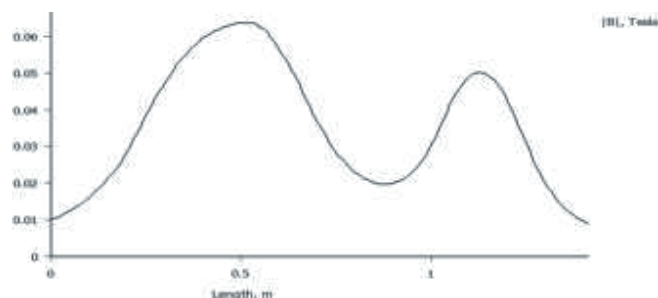


Figure 3. Axial magnetic field.

The edge of the probe is firstly negatively biased, in order to generate an ionic saturation section. Slowly, the potential is increased. At the Plasma Space Potential, the electron saturation occurs and the Plasma temperature can be measured [10]. The Langmuir method is well known and highly effective in Plasma Diagnostics.

B. Energy Analyzer

The energy analyzer is composed of three parts: 2 grids and a plate. The first grid, the one in contact with the plasma, is left at the plasma floating potential, so that it let the ions pass through it but do not let the electrons pass, i. e., the first grid select the ions. The second grid, which is between the first grid and the plate, is charged positively, letting only the high-energy ions pass through it, i. e., the second grid selects the high-energy ions. The plate is called collector, it is charged very negatively, collecting the ions that were able to pass through the second grid and eliminating the few electrons that were able to pass through the first grid. So, it is possible to develop experiments in order to measure the Ion Temperature, to observe the ion beams and measure the decay of the charged exchange cross-section of the ion beam, and measure, also, the ion distribution function.

The UnBPPL is designing one energy analyzer for the Helicon Double Layer Thruster. A cup of Teflon holds the analyzer altogether and then it is put the collector plate on the background, but in between the plate and the second grid, and in between the second and first grid, there is a Teflon ring that will isolate the grids and the plate from each other. The Teflon is dielectric but it is not enough resistant for the plasma environment, so, it was necessary to make a case to protect it. A stainless steel case was constructed in order to protect the Teflon.



Figure 4. Energy Analyzer designed and produced at the UnBPPL.

C. Power Supplies and Circuit Design

For the Langmuir probe, a DC voltage power supply, model Agilent 6035A, is used to create the desired potential on the probe's edge. The terminals are connected to a relay circuit, responsible to invert the polarity from the negative to positive voltages. The probe is linked using a coaxial cable to the relay circuit and the bench multimeter, model hp 34401A, is connected to the ground and to the other exit of the relay circuit. The relay is controlled by a signal from the control program. The figure bellow illustrates the circuit.

D. LabView Acquisition and Data Treatment

The control program is created using the LabView platform by National Instruments and it is responsible for controlling the voltage of the power supply and recording the voltage data from the multimeter. The test usually goes from -20 to 80 volts. When the voltage of the power supply reaches zero, the relay circuit is triggered and the polarity of the power supply is inverted. This next figure illustrates the block diagram of the control program.

First the control program requests a filename where the data will be saved in a *txt* format. The control values for the power supply (minimum and maximum voltage), the VISA address for the power supply and the multimeter are settled. The figure bellow illustrates the front panel of the control program. The routine starts by pressing RUN. All the communications are made using GPIB protocols. The power supply starts at the minimum voltage and steps towards zero, one volt at a time. The program then reads five values from the multimeter and stores them in a *txt* file for each voltage level. Two graphs are plotted using these points.

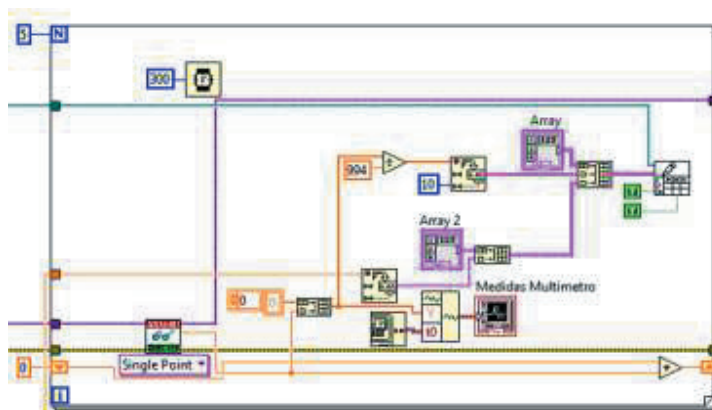


Figure 6. Section of the Block Diagram of the control program.

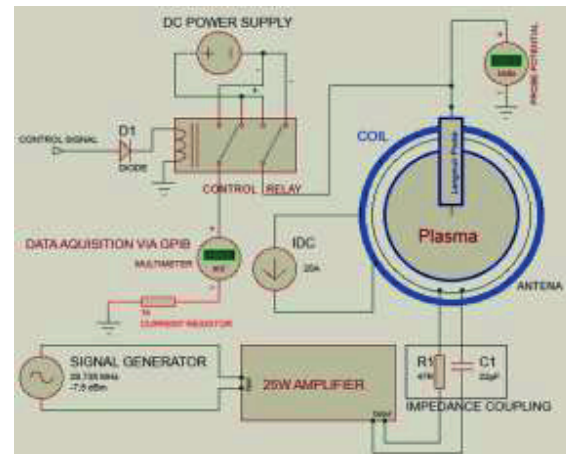


Figure 5. Acquisition system circuit design.

When the power supply reaches zero, the relay circuit is triggered and the connection polarity is inverted. This is necessary to cover a range from negative to positive voltages. With the polarity inverted, the power supply goes from zero to the maximum value.

At each voltage level, the program reads five values and calculates the average. Simultaneously two graphs are plotted, one with every value from the multimeter and another with the average of those five points per voltage level. The user can choose which collection of data (the raw data, the average values or both) to be saved on the *txt* file.

When the routine reaches its stopping condition, or the user stops the execution of the routine, the control program for safety reasons turns off the power supply automatically. With the previously generated txt file Fig. 8 can be plotted using a suitable program.

The data treatment is done with the help of the program QtiPlot in a Linux environment. A data treatment and diagnostic is being conceived on LabView environment so the plasma parameters can be more easily and faster calculated.

V. Applications and Developments for Future Brazilian Space Missions

Using method [10], the data generated can be properly derived and analyzed.

The data used to generate Fig. 8 can be used,

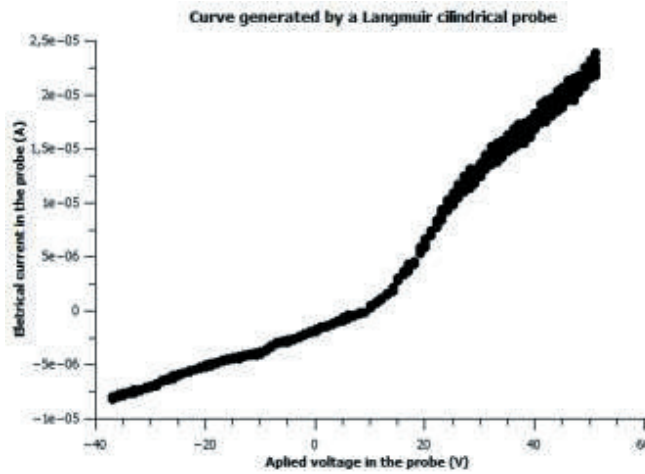


Figure 8. Langmuir Curve.

The aim of the Helicon Double Layer project at the UnBPPL is to find evidences of the Double Layer in an expanding magnetized plasma and show its feasibility

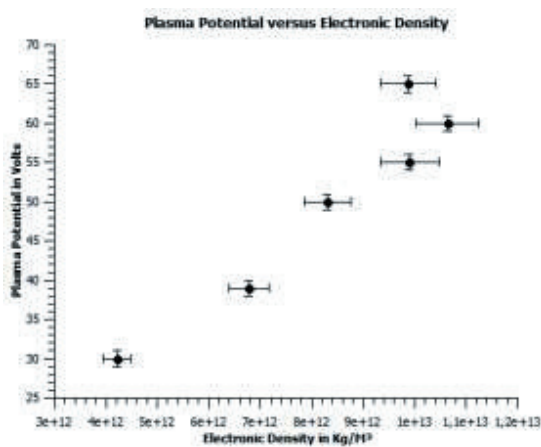


Figure 9. Plasma Potential vs. Electronic Density.

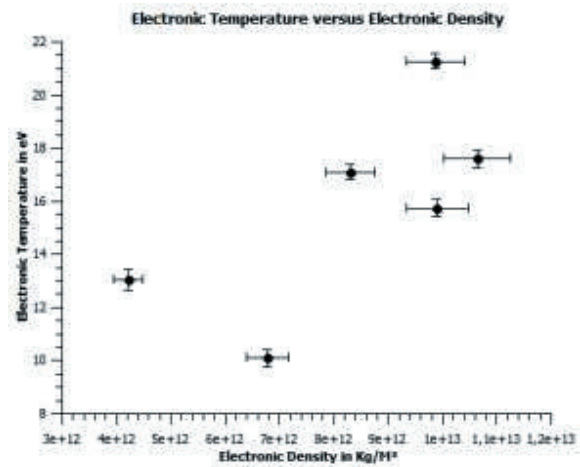


Figure 10. Electronic Temperature vs. Electronic Density.

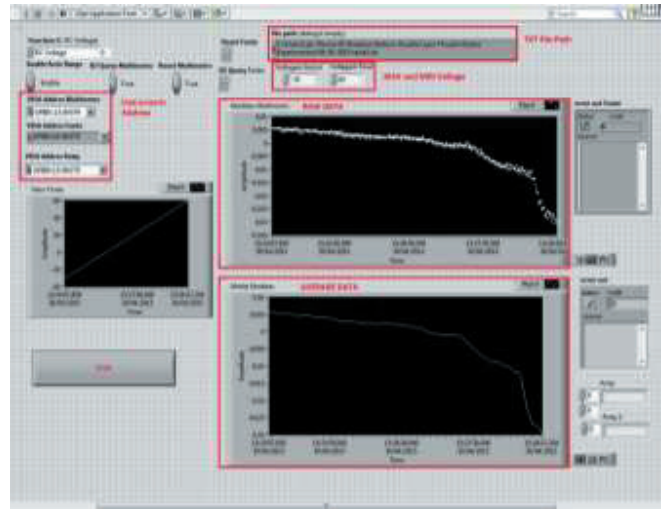


Figure 7. LabView front panel.

with the help of QtiPlot, for data treatment, and the derivative of the linearized Langmuir curve may be obtained:

$$\frac{d\ln(i)}{dV} = \frac{e}{K_b T_e}$$

Based in [10], the electronic temperature and the electronic density can be measured.

In Fig. 9 and Fig. 10, a change in the plasma potential and temperature in function of the density is observed being so inferred a linear relation between the plasma electronic density and potential, Fig. 9, and the electronic density versus temperature, Fig. 10.

VI. Conclusion

when compared with other thruster models.

Improvements need to be done in the measurement apparatus in order to achieve an axial analysis of the plasma potential. A mechanism, aimed to cross the plasma axially, using a movable probe, is being constructed in order to measure such a potential profile. An improvement in the RF system may also be created. Chokes for blocking higher-frequency alternating current in the electrical circuit are in construction. The magnetic coils are being reconfigured in order to increase the magnetic line expansion. A faster algorithm in LabView is being implemented in the system for more precise data analyses and treatment.

Further analysis ought to be done when the complete apparatus is settled.

Acknowledgments

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