Compact Permanent Magnet Hall Thrusters Development for Future Brazilian Space Missions

Laboratório de Física dos Plasmas - UnB

Universidade de Brasília

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INTRODUCTION

The main **MOTIVATION** is the world wide strong development of electric propulsion and its potential applications on future space missions of the Brazilian Space Agency (AEB), such as, the on going nano and micro satellite university programs, **SGBD**-Brazillian Geo-Estationary Satellite System for Communication and Defense and on possible future scientific missions on the solar system such as the proposed **ASTER MISSION**.

The objective of our project is to develop a Permanent Magnet Hall Plasma Thruster (PHALL) with innovative concepts with emphasis on:

- **Best and more efficient magnetic field arragement for the Hall Plasma Source.**
- **Plasma diagnostic tools development for PHALL and for relevant instruments foreseen for space plasma in situ research with space crafts.**
- **Development of proper conditions for PHALL test and space qualification and bring new human resources for the brazillian space program.**

This work describes:

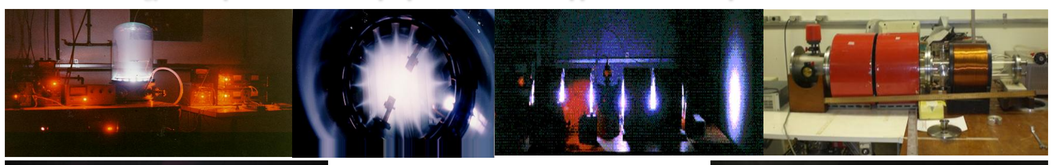
- **Activities of the Plasma Physics Laboratory in the Uniespaço Program of AEB.**
- **Some historical remarks of EPs and recent sucessfull missions.**
- **Development of PHALL and its diagnostics systems.**
- **Numerical Simulations Studies of PHALL.**
- **Applications of PHALL on foreseen future space missions.**

Activities of The Plasma Physics Laboratory of UnB

Since 2004, The PHALL project of UnB is developing critical technologies such as Electric Propulsion for space missions foreseen by The Brazillian Space Agency- AEB.

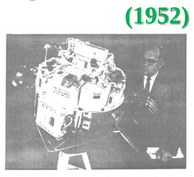
UNIESPAÇO is an AEB program born in 1998. It is designed to make Brazilian universities participate on the Brazilian National Space Activities Program – PNAE. Professors, researchers, undergraduate and graduate students from engineering, physics, chemistry, math and computer sciences from 25 Brazilian universities are involved.

Plasma technology development for electric propulsion and other applications is been performed at PPL of UNB since 1994



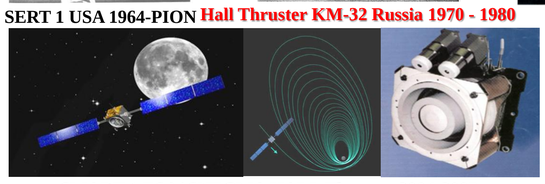
PHALL Test Vaccum Chamber at LFPP

Brazilian PION and PHALL projects are recent if compared with the 100Y history of electric propulsion. Robert Goddart (1906) e Hermann Oberth (1922), Werner Von Braun e Ernest Sthulinger (1952) Kauffman PION EUA 1960, Zhurin and Morozov HALL URSS 1962.

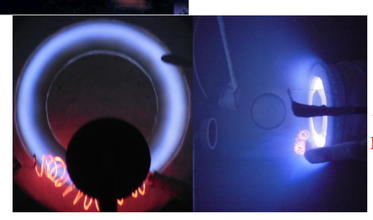


PION I II III AT LAP/INPE Brasil since 1985
***EXPECTED FOR 2018 AT LCP-INPE-**
E.Ps. LIFE TEST LABORATORY

SERT 1 USA 1964-PION Hall Thruster KM-32 Russia 1970 - 1980



SMART 1 ESA/ SNECMA HALL Thruster 2004-2005

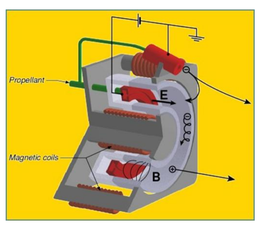


PHALL TEST AT LFP UnB

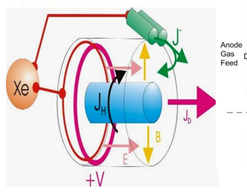
The project is been conducted BY LFP IF UnB since 2003

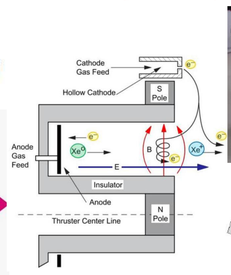
PHALL DEVELOPMENT I

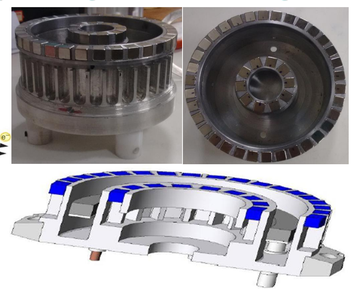
Working principles of Tradicional Hall Thrusters with Radial B Field produced by Eletromagnets or Permanent Magnets



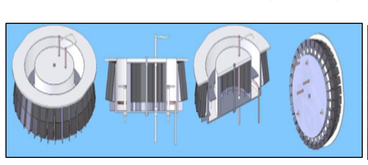
$$\frac{d}{dt}u = \frac{1}{n} J_H \times B$$

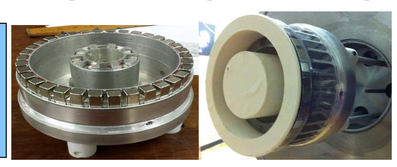


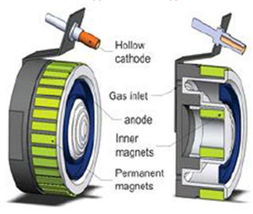




PHALL II-B with corrected (uniform) radial magnetic field configuration. SmCo magnets and ferromagnetic rings are used

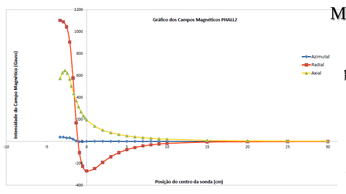






PHALL I and II arrangements of permanent magnets to produce the radial magnetic field

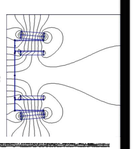
PHALL II Development (more compact D=15cm) with similar permanent magnet squares arragement with SmCo magnets.



Magnetic Field Strength and Hall Current Channel size determination for PHALL

$$r_e = \frac{m_e U_e}{eB} < L < r_i = \frac{m_i U_i}{eB}$$

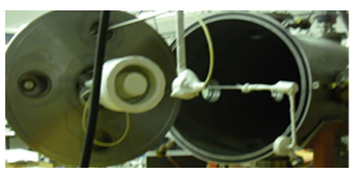
Computer Mapping of PHALL magnetic field using finite elements method and magnetic probe measurements.



Magnetic Field Strength	r_i @ 1000K	r_e @ 1eV	r_e @ 10eV
1 Gauss	5500 mm	40 mm	120 mm
100 Gauss	55 mm	0.4 mm	1.2 mm
1000 Gauss	5.5 mm	0.04 mm	0.12 mm

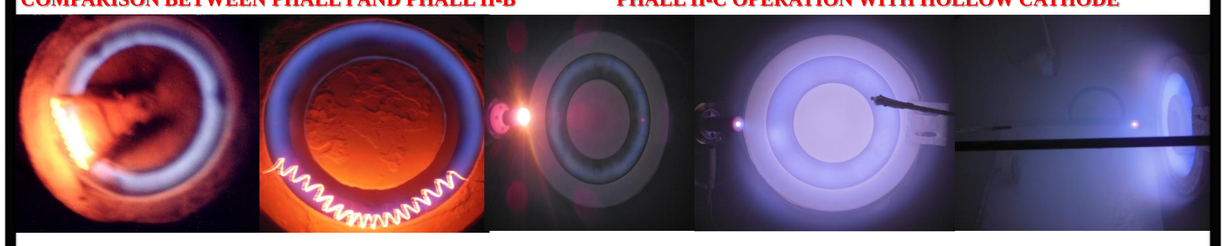
Magnetic field strengths on the order of 100 Gauss satisfy the conditions for length scales on the order of 10 millimeters. In practice, conventional kilowatt-class Hall thrusters employ peak centerline radial magnetic field strengths of **100-300 Gauss** and have channel depths of approximately 25 mm.

PHALL II working with (non uniform) high radial magnetic field configuration. I t results in Instabilities and strong magnetization of electrons and ions that have to be avoided

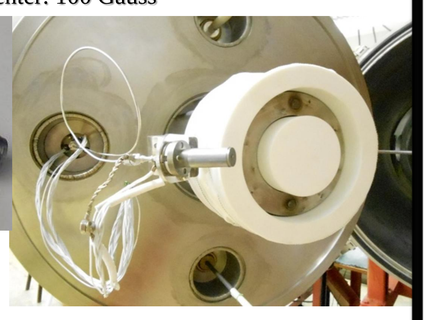


PHALL DEVELOPMENT II

COMPARISON BETWEEN PHALL I AND PHALL II-B — PHALL II-C OPERATION WITH HOLLOW CATHODE

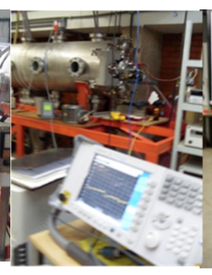


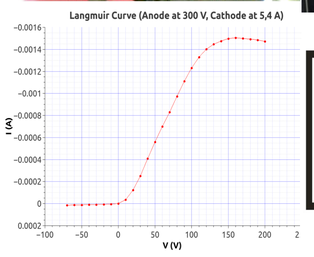
PHALL I	PHALL II-B	PHALL II-C
200-500 Volts, 0.5 A	200 Volts, 0.3 A	200 Volts, 3.05 A
$1x10^{-4}$ to $4x10^{-3}$ Torr	$5.2x10^{-5}$ Torr	$5.8x10^{-5}$ Torr, 9.03 sccm
L = 3 cm	L = 2 cm	L = 2 cm
B at Center: 260 Gauss	B at Center: 100 Gauss	B at Center: 100 Gauss

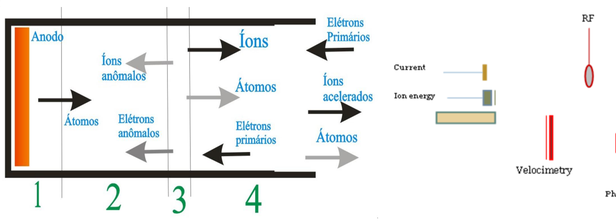


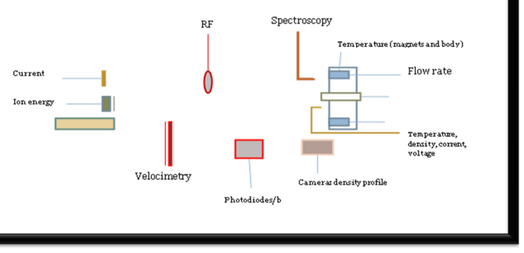
Hollow Cathode System and Propellant Gas Control System are Strategic technologies for PHALL

Development of plasma diagnostics and control methods for PHALL using Integrated Plasma Diagnostic System. This system use Langmuir probes, ion energy analyser, RF probes and faraday Cup. Spectrum analysers is used to control of *Transit-time instabilities (fc=40KHz) with low frequency band filters.*



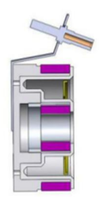


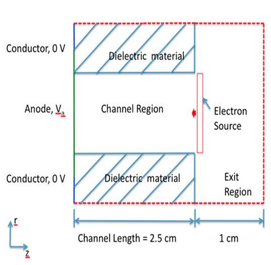


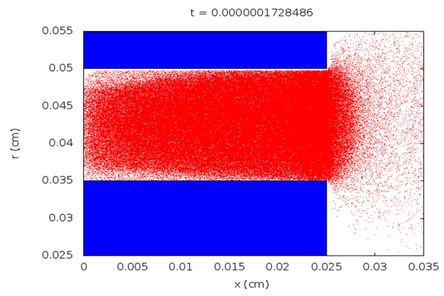


Computer Simulations and Results

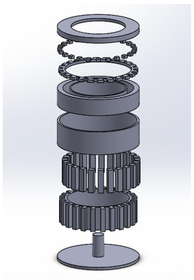
Numerical Simulation to improve PHALL II-B for improvements on plasma generation and working parameters.

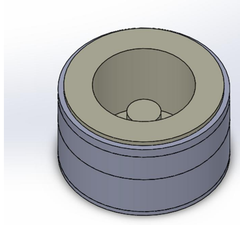


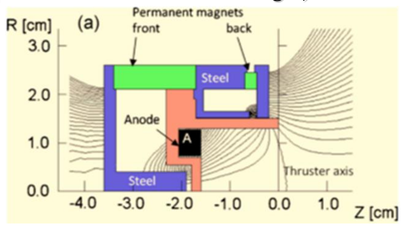


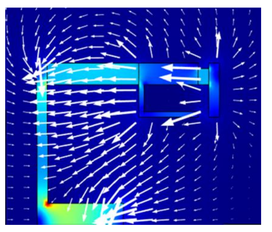


Particle-in-cell simulation of the Hall effect thruster with PHALL II-C configuration. The simulation is performed in a two-dimensional section of the thruster using cylindrical coordinates. Blue rectangles represent the ceramic channel, and red dots represent the simulated ion particles (ions are accelerated to the right).



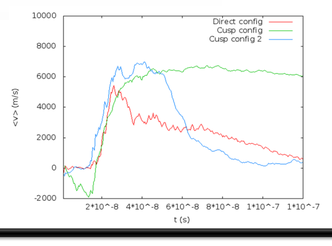


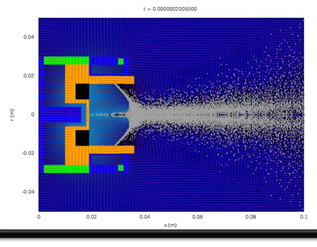




PHALL III – CHT: D = 6 cm with divergent field configurations I and II

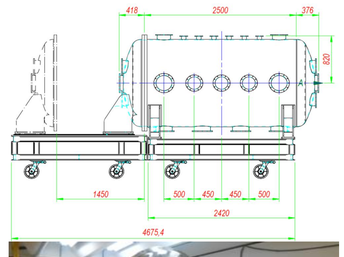
PLASMA PLUME ANALYSIS
Results for Different Cusp Magnetic Field Configurations





PHALL III - Cusped Field Configuration Results

Future Developments and Final Remarks



A VACUUM TEST FACILITY (D=1.5 m and L=2.5m) FOR DEVELOPMENT AND PERFORMANCE TESTS FOR HALL THRUSTERS IS ALSO GOING TO BE INSTALLED SOON (DECEMBER 2016) AT LFP -UNB.

With improvements on the plasma diagnostic system, on the numeriacl simulation computer system and with the new vaccum chamber space qualification teste for PHALL II and III.

We also expect to achieve in the near future a total thrust of 40 mN for PHALL II and 20 mN for PHALL III with specific impulses of 2000s for both thrusters.

REFERENCES:

José Leonardo Ferreira, Alexandre A. Martins, Rodrigo Miranda, Adriane B. Schelin, Laís de Souza Alves, Ernesto G. Costa, Herbert O. Coelho, Artur C. B. Serra and Felipe Nathan, "Permanent magnet Hall thruster development for future Brazilian space missions," *Computational and Applied Mathematics*, Vol. 35, 3, pp 711–726, 2016.