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PARTICLE-IN-CELL NUMERICAL SIMULATION OF THE PHALL-IIc HALL THRUSTER

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Abstract. *In this work the performance of two types of Hall thrusters are compared, namely, the SPT-100 and the PHALL IIc, the latter being developed by the Plasma Physics Laboratory at the University of Brasilia. The comparison is carried out by performing particle-in-cell simulations. Thruster parameters are computed such as thrust and specific impulse. This data can contribute to the design of future Brazilian space missions.*

Keywords: *Numerical simulation, Electric propulsion.*

1. INTRODUCTION

Hall thrusters are a type of electric propulsion systems used in deep-space missions and for station-keeping purposes due to their high exhaust speed, high specific-impulse, and high propellant efficiency. Basically, they operate as follows. Electrons travel from a hollow cathode to an anode in the rear end of the thruster, are trapped due to a magnetic field, and start drifting along the annular chamber. The motion of the electrons generates a Hall current, and ionizes a gas, usually Xenon. The ions are then electrostatically accelerated out of the discharge chamber, which generates thrust.

Electric propulsion was first elucidated by Robert Goddard in 1906 and later described by Tsiolkovskiy in 1911. After that, its application was developed by the Hermann Oberth in 1929 and by Sheperd and Cleaver in 1949. During the 60's the United States and the Soviet Union made important contributions and investments in spatial applications for the Hall Thruster.

There are basically two types of Hall thruster technology, namely, the Stationary Plasma Thruster (SPT), and the Thruster with Anode Layer (TAL). The main difference between the TAL and the SPT is that an anode layer is installed in the acceleration channel of the SPT instead of the original dielectric material. The first Hall thruster was launched in 1971 by the Soviet Union. The most important achievement by Hall thrusters was the mission SMART-1 by the European Space Agency (ESA) in 2003. In this mission the PPS-1350-G was the first electric propulsion thruster to leave the geosynchronous earth orbit.

The Plasma Physics Laboratory of University of Brasilia (LFP-UnB) is developing a SPT-type thruster called PHALL which differs from the traditional SPT-100 thruster in channel dimensions, operating parameters, and the mechanism to generate the required magnetic field. While the SPT-100 employs coils, the PHALL uses permanent magnets. This work shows a comparison of performance between the SPT-100 and PHALL IIc with Xenon as propellant via numerical simulations. This extended abstract is organized as follows. Section 2describes the computational model and the operating parameters of the SPT-100 and the PHall IIc. The numerical results are presented in section 3. and the conclusions are presented in section 4.

2. METHODOLOGY

Cylindrical coordinates are chosen and variations in the azimuthal direction are neglected to adopt a two-dimensional representation of the upper-half of a Hall thruster. The geometry of the simulation domain is shown in Figure 1. This allows a reduction in the computational effort.

The simulation is solved using the particle-in-cell approach, in which the position and velocities of particles are obtained from the equations of motion due to the electric and magnetic fields. From the distribution of the positions of particles the charge density can be obtained. The Poisson equation can be solved from the charge density to obtain new values of the electric potential and the electric field. These fields are then used to obtain the velocities and positions of the particles, and the cycle is restarted. The magnetic field is assumed to be static. Table 1 shows the operating parameters of the SPT-100 and the PHall IIc.

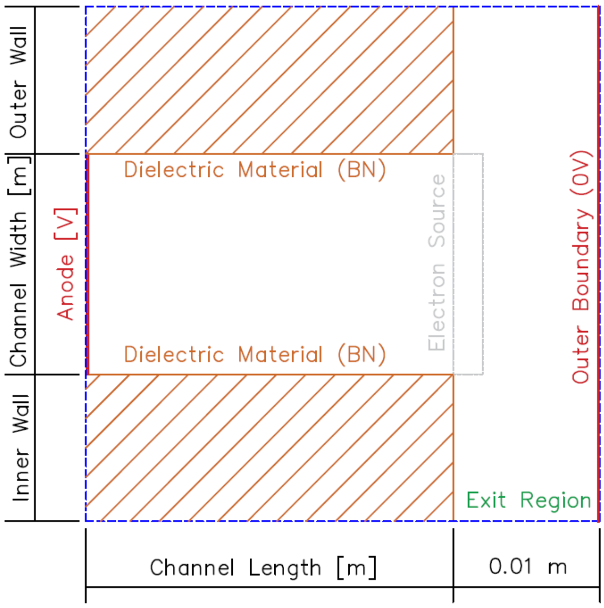

Figure 1. Two-dimensional model of a Hall thruster.

Table 1. Operating parameters of the SPT-100 and the PHall IIc thrusters.

Thruster	SPT-100	PHall IIc
Channel length (m)	0.025	0.0235
Channel width (m)	0.015	0.025125
Exit length (m)	0.01	0.01
Anode (V)	300	105.5
Cathode (V)	0	0
Electron emission current (A)	4.5	4.46
Initial electron energy (eV)	25	5.61
Maximum magnetic field (T)	120×10^{-4}	100×10^{-4}
Maximum xenon density (m^{-3})	10^{21}	10^{21}
Shrink factor	50	50

3. NUMERICAL RESULTS

The simulation's first step is defining an initial Xenon gas distribution and introducing electrons through the exit region. The electrons ionize the gas via Monte Carlo Collisions, producing Xenon ions. Figure 2 shows the distribution of superparticles representing Xe^+ ions over the simulation domain at the end of the SPT-100 and the PHall IIc simulations. Each superparticle represents 1×10^5 real particles. The Xe^+ ions are accelerated toward the exit region due to the electrostatic potential.

The particle-in-cell approach allows to compute the electrostatic potential ϕ and the associated electric field self-consistently from the charge density, which is obtained from the distribution of charged particles over the simulation domain. Figure 3 shows the resulting ϕ for the SPT-100 and the PHall-IIc, represented by a color scale. The spatial profiles of the electrostatic potential of the SPT-100 and the PHall IIc are similar, however the maximum value of ϕ of the SPT-100 is higher than that of the PHall IIc. This is due to the higher potential applied to the anode (see Table 1).

Since the velocity of the ions greatly exceeds the velocity of the Xe neutral particles in the exit region, the thrust T can be written as (Goebel and Katz, 2008)

$$T = \dot{m}_i \langle v_i \rangle \tag{1}$$

where $\dot{m}_i$ is the ion mass flow and $\langle v_i \rangle$ is the average ion velocity. A discretized form of Eq. (1) can be written as (Miranda *et al.*, 2017)

$$T = N_p \frac{m_i}{\Delta t} \langle v_i \rangle \tag{2}$$

where N_p is the number of particles represented by a superparticle, and Δt is the time step.

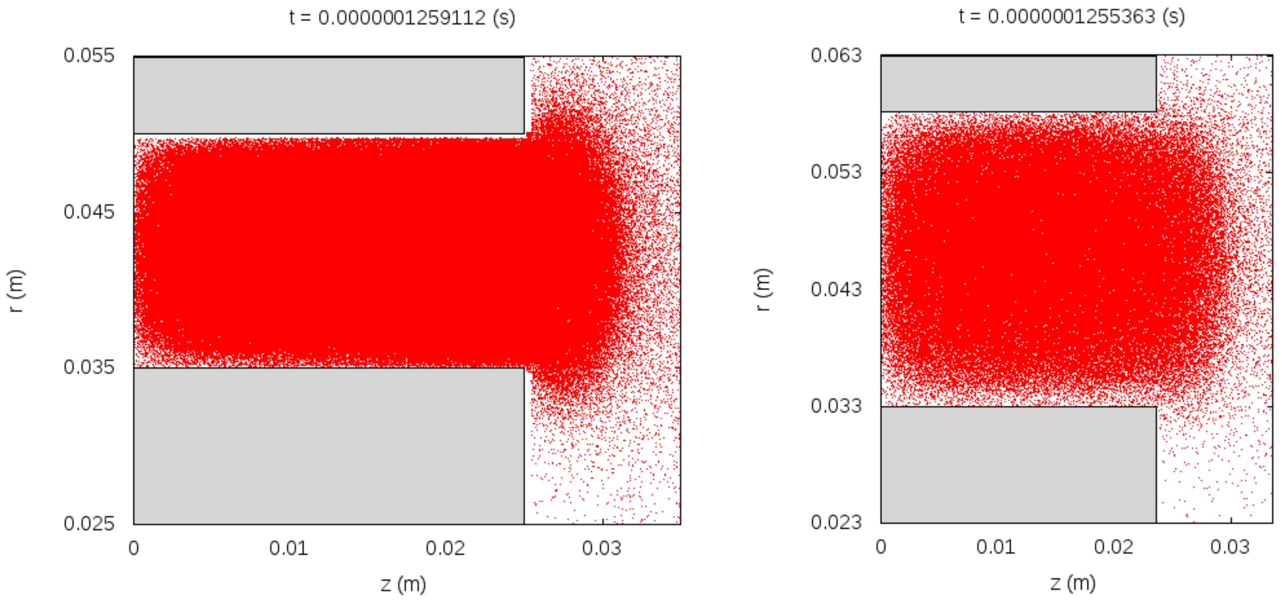

Figure 2. Distribution of superparticles representing Xe^+ ions (red points) at the end of the SPT-100 thruster simulation (left panel) and at the end of the PHall-IIc simulation (right panel). The grey rectangles represent dielectric walls.

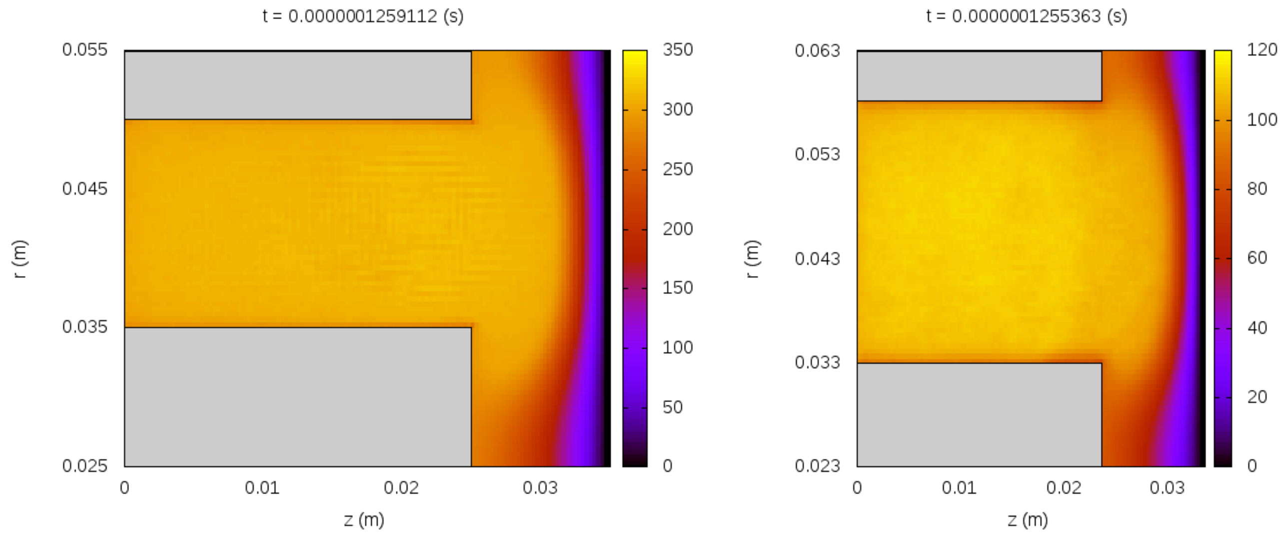

Figure 3. The electrostatic potential ϕ represented by a color scale at the end of the SPT-100 simulation (left panel) and the PHall-IIc simulation (right panel).

The specific impulse I_{sp} is related to the thrust by

$$I_{sp} = \frac{T}{\dot{m}g} \tag{3}$$

where $\dot{m}$ is the neutral mass flow rate, and $g = 9.8m/s^2$ is the Earth's acceleration of gravity. If the propellant is xenon, Eq. (3) can be written as (Goebel and Katz, 2008)

$$I_{sp} = 1.02 \times 10^5 \frac{T}{Q} \tag{4}$$

where Q is the xenon mass flow rate in mg/s.

The T and I_{sp} are computed using Eqs. (2) and (4), respectively, from the numerical simulations of the SPT-100 and the PHall IIc. The average velocity of ions $\langle v_i \rangle$ is computed by selecting the superparticles near the end of the exit region. The results are shown in Table 2. The thrust of the SPT-100 obtained is lower than the expected value of ~ 0.080 N (Choi *et al.*, 2012; Goebel and Katz, 2008). Since the channel exit in the computational domain has a length of 1 cm, the value of T computed tends to be underestimated (Cho *et al.*, 2013). Table 2 also indicates that the thrust and the specific impulse of the PHall IIc are lower than those of the SPT-100. These results are expected since the PHall IIc thruster operates at a lower power than the SPT-100.

Table 2. Computed thruster parameters.

	SPT-100	PHall IIc
Thrust (N)	0.048 ± 0.00083	0.019 ± 0.00031
Specific impulse (s)	1636.24 ± 28.42	650.92 ± 10.65

4. CONCLUSION

In this work numerical simulations of two types of Hall thrusters are performed, namely, the SPT-100 and the PHall IIc being developed at the Plasma Physics Laboratory at the University of Brasilia. A 2D axisymmetric model is used to represent the thruster geometry, and the particle-in-cell method to model charged particles and solve the field equations self-consistently. The results indicate that the thrust and the specific impulse of the PHall IIc attain lower values than the SPT-100. These results are expected since the PHall IIc operates at a lower power in comparison with the SPT-100. This data can be useful for designing new Hall thruster prototypes for future Brazilian space missions.

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6. REFERENCES

Cho, S., Komurasaki, K. and Arakawa, Y., 2013. “Kinetic particle simulation of discharge and wall erosion of a Hall thruster”. *Physics of Plasmas*, Vol. 20, No. 063501.

Choi, Y., Mahalingam, S. and Likhanskii, A., 2012. “Predicting hall thruster operational lifetime with computational models”. In *Aerospace Conference, 2012 IEEE*. IEEE, pp. 1–13.

Goebel, D.M. and Katz, I., 2008. *Fundamentals of electric propulsion: ion and Hall thrusters*, Vol. 1. John Wiley & Sons.

Miranda, R.A., Martins, A.A. and Ferreira, J.L., 2017. “Particle-in-cell numerical simulations of a cylindrical Hall thruster with permanent magnets”. *Journal of Physics: Conference Series*, Vol. 911, No. 012021.

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