A particle test Monte-Carlo model to understand electron-wave interactions in a Hall Effect Thruster

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A Hall Effect Thruster (HET) is an ion source of a few centimeters length used for spacecraft propulsion. The use of a magnetic field barrier permits to locally decrease the electron conductivity giving rise to an electric field that accelerates ions for thrust. Despite several decades of research, there remains some unknown concerning the transport of the electrons across the magnetic barrier. A Particle-In-Cell code has been developed showing that an electron-drift azimuthal instability exists. At this conference, the interactions of the electrons with the calculated azimuthal wave using a test particles Monte-Carlo model will be analysed and discussed.

Hall-effect thruster (HET) are ion sources used for space propulsion [1-2]. A DC plasma is generated in a channel between two coaxial cylinders. Electrons are emitted by an external hollow cathode near the exhaust plane (see Fig.1). The anode through which the gas is fed is located at the other end of the channel. The main characteristic of the HETs is the use of a magnetic field which has two purposes. It traps the electrons and allows for a longer residence time of the latters in order to increase the ionization rate. The trapping greatly reduces the conductivity and consequently induces an electric field that penetrates inside the quasineutral plasma. This field in turn, provides enough energy to accelerate the ions and to create the thrust. In general, across a magnetic field, the conductivity of electrons is classically ensured by collisions which break their cyclotron orbit, kicking them from one magnetic field line to another towards the anode. In the Hall thruster however, due to a strong ionization of the neutral gas, the measured and simulated collision rates are far too low to satisfy the classical conductivity.

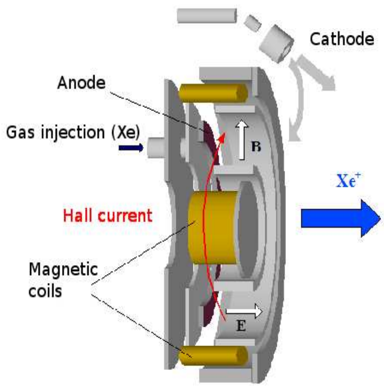

Fig. 1: schematic view of a HET.

The understanding of the de-trapping process is one of the major issues of understanding the operation of the device. This phenomenon is usually called the “anomalous electron transport,” because we need to consider others processes to explain the transport of electrons from the cathode to the anode [3]. This also point out the lack of theory on this subject. It was first attributed to electron-wall interactions [4-5] but it now seems that plasma turbulence may also play a major role in this anomalous transport, especially outside the channel where the walls no longer exist. Experimental evidence of fluctuating signals in the azimuthal direction has been observed through antenna [6], probes [7] and Thomson scattering, [8] diagnostics.

In order to bring some light about the electron transport in a HET, a Particle-In-Cell (PIC) model has been developed by Adam *et al.* [9] using an implicit scheme. This model describes a flattened sector of cylinder in the azimuthal (y-axis) and axial (x-axis) directions. Elastic and ionization collisions are treated. The B-field is in the z-direction. In the y-direction the boundaries are periodicals. One of the major results is shown in fig. 2. This is a map of the azimuthal electric field which exhibits a fluctuating behaviour. Its amplitude rises to its maximum in the right-hand side of the map which corresponds to the exit of the thruster where gas density has already reached its minimum. It is of importance to state that, unlike models which describe the x-z direction, in this case, no artificial parameter is added in order to maintain current continuity. Hence, the transport is assured self-consistently and electrons need to interact with the field to be transported toward the anode.

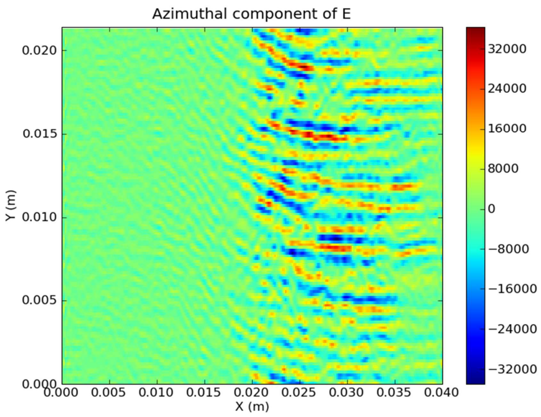

Fig. 2: Azimuthal electric field. The unit is V/m.

This interaction process between the electrons and the wave requires a deeper analysis. A particle test Monte Carlo (MC) model has consequently been developed, where the inputs such as the electric field and neutral density profiles come from the PIC code. It provides more flexibility and allows a simplification of the problem in order to reveal the fundamental phenomenon responsible for the electron transport. We will show that freezing the electric potential on a scale equals to the transit-time of electrons has a weak influence on the electron transport. We will also show that the interactions occur for some particular modes which are space-dependant and clarify the type of interaction responsible for electron transport.

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References

[1] V.V. Zhurin, H.R. Kaufman, and R.S. Robinson, *Plasma Sources Sci. Technol*. 8, R1-R20, (1999).
[2] R. G. Jahn and E.Y. Choueiri, *Electric Propulsion in* Encyclopedia of Physical Science and Technology, Third Edition, Volume 5 (The Academic Press, San Diego, 2001).
[3] G. J. M. Hagelaar, J. Bareilles, L. Garrigues, and J.P. Boeuf, *Journal of Applied Physics* **93**, 67 (2003).
[4] A. I. Morozov and V. V. Savelev, *Plasma Physics Reports* **27**, 607 (2001).
[5] A. I. Bugrova, A.V. Desyatskov, A. I. Morozov, and V. K. Kharchenikov, *Plasma Physics Reports* **4**, 302 (1996).
[6] A. Lazurenko, V. Vial, M. Prioul, and A. Bouchoule, *Physics of Plasmas* **12**, 013501 (2005).
[7] A. A Litvak, Y. Raitses, and N. J. Fisch, *Physics of Plasmas* **11**, 1701 (2004).
[8] S. Tsikata, N. Lemoine, V. Pisarev, and D. M. Grésillon, *Physics of Plasmas* **16**, 033506 (2009).
[9] J. C. Adam, A. Héron, and G. Laval, *Physics of Plasmas* **11**, 295 (2004).