Measurements and kinetic simulations of the Alternative Low Power Hybrid ion Engine (*alphie*)

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Introduction

Electric propulsion (EP)[1] is currently employed by spacecrafts to perform multiple low-thrust high specific impulse manoeuvrers, like station keeping, orbit rising and end-of-life disposal. Due to payload limitations to fulfil these long term missions, chemical propulsion is not suitable. New disruptive technologies that could improve performance, allowing for new missions at lower cost and mass, are always required to complement existing ones.

On this regard, the new ion engine concept *alphie* (Alternative Low Power Ion Engine) [2] is a promising new technology for mid-size satellites with power requirements below 500 W. This thruster differs from classical Gridded Ion Engines (GIE) as a counter-flow of charges appears through the grid system. Measurements of the ion velocity in the plume show a well collimated two-peaked distribution, with the velocity of the high peak around $40\,\mathrm{kms}^{-1}$. Thrust measured directly is between $1-3\,\mathrm{mN}$ for gas flows of 0.2 to 0.6 sccm of Ar, which leads to specific impulses above 10^4 s.

The *alphie* plasma thruster

The Alternative Low Power Hybrid Ion Engine [2], presented in Fig. 1, is a new disruptive concept of electric thruster developed by the Technical University of Madrid (UPM). This engine employs a single external cathode for ionization and plume neutralization. In the two-grid system, a counter-flow of ions and electrons appears [3].

These electrons are exposed to the same potential drop ($V_{acc}+V_{EG}$) as the ions being extracted. Usually, a voltage difference of 400 to 650 V is maintained between the last grid and the ionization chamber. These high energy electrons are trapped by the magnetic field and interact with the injected neutral gas. Apart from ionization, electrons will exchange a large amount of energy with the neutrals, which results in the wide energy profiles shown in Sec. . After the ions have been accelerated by the potential drop between the grids they are neutralized by electrons coming from the external cathode to ensure that the thruster remain electrically neutral.

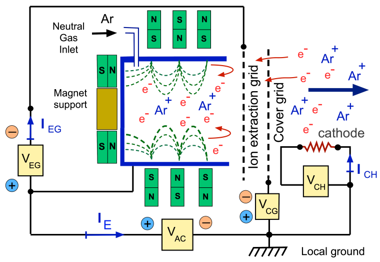

Figure 1: Electric scheme of *alphie*.

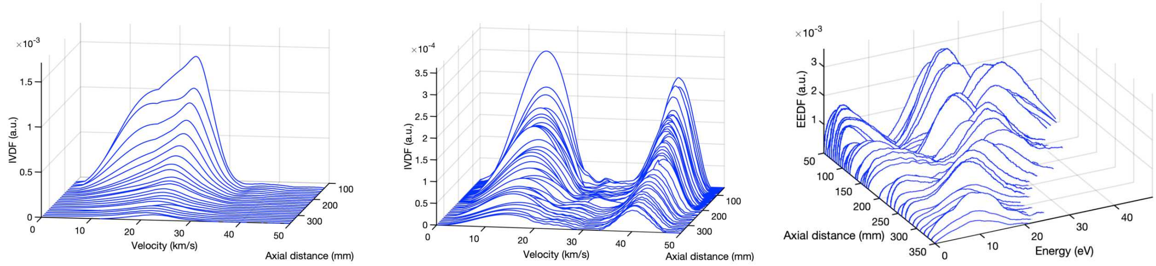

Figure 2: Energy profiles for ions at low V_{acc} (left), high V_{acc} (middle), and electrons (right) along the axial coordinate of *alphie* plume.

For the experiments presented here, the cathode was a thin tungsten wire heated up to thermionic emission by the I_{CH} current. However, other methods could be employed as a source of electrons without affecting the thruster performance.

Plasma plume measurements

The Electron Energy Distribution Functions (EEDFs) obtained with a Langmuir probe and the Ion Velocity Distribution Functions (IVDFs) are shown in Fig. 2 for positions along the plasma plume. The waterfall plots show two distinct cases for the ions. When acceleration voltage is low (left plot, 450 V), low and fast populations are indistinguishable of each other. On the other hand, for high acceleration voltages (middle, 550 V) the two populations are cleared identified. The distribution function shape remains quite constant along the plume, only decaying in value due to the expansion into the vacuum chamber.

The dynamics of electrons along the z coordinate of the plasma plume is more complex than that of ions. Along the plasma plume, it is shown that the EEDFs are the superposition of two distinct electron populations. The existence of multiple electron groups with different energies in the plasma plume expansion has been reported in previous studies with Helicon plasma sources [4] and also in particle-in-cell numerical simulations [5]. Due to their lower mass, electrons are more affected than ions by changes in plasma potential along the axial direction. The maximum of plasma potential in Fig. 3 (right) between $z = 80 - 100\,\text{mm}$ would

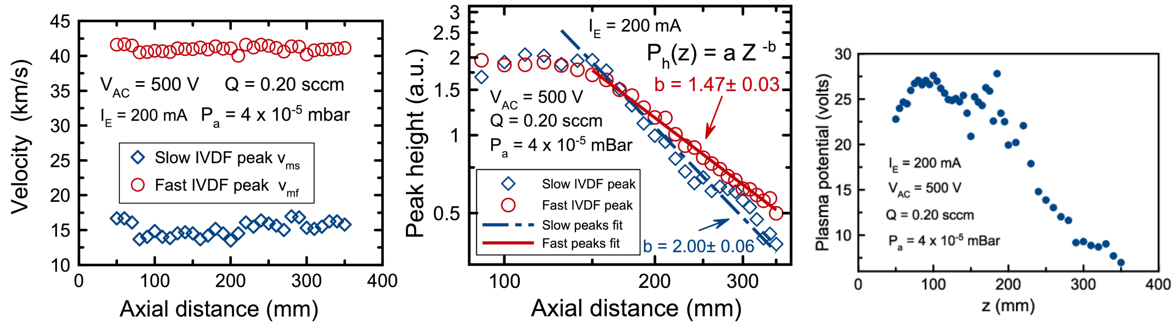

Figure 3: Velocity peak (left) and peak height (middle) for the low and fast ion groups and plasma potential (right) along the plume. Different expansion rates for each species appear.

be at the origin of the region in which a high energy population of electrons exists.

A local increase in the ion density at the exhaust raises the plasma potential, accelerating electrons that form an important group of high energy electrons [2]. After that, both electron groups merge into one as the plasma potential drops. This is not caused by collisions but by the motion of fast ions along the plume, which reduce the plasma potential and thus decreases the electron energy.

When the peaks of Fig. 2 are plotted against the axial coordinate, as in Fig. 3 (left and middle), clear distinct dynamics between the two groups appear. The velocity of the two populations remains constant along the plume, and the huge difference in velocities is clearly identified. Moreover, after ions have exited the constant plasma potential region the plasma expansion starts. It is important to notice that the two populations expand with significant different geometrical coefficients b in $P_h(z) = aZ^{-b}$. The high velocity group decays slower ($b = 1.47$ for the fast group respect to 2.00 for the low group) due to the higher ratio between axial and radial velocities.

Thrust measurements

Figure 4 depicts the direct thrust at a series of acceleration voltages (V_{acc}) and gas flows (Q). The impulse increases linearly with the gas flow and the acceleration voltage. However, for large gas flows and low voltages, thrust starts to decay. If a large amount of gas is introduced and electrons do not receive enough acceleration energy is lost due to elastic collisions before an ionization event occurs, affecting the thruster performance.

Taking into account a power intake of $200-350\,\mathrm{W}$ in typical *alphie* operation range, this leads to total efficiencies that vary between $10-40\%$. Moreover, from these thrust measurements it can be easily extracted that *alphie* has a specific impulse between 10^4 and $2\cdot10^4\,\mathrm{s}$.

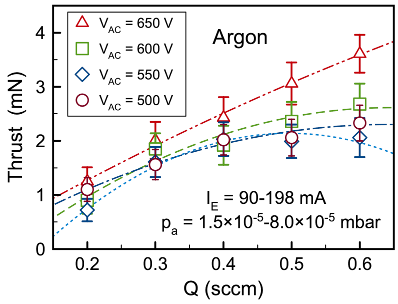

Figure 4: Thrust provided by *alphie* in a range of gas flow (Q) and acceleration voltages (V_{acc}).

Conclusions

The new disruptive ion engine named alphie differs from classical GIE as a counter-flow of charges pass through its two grid system. This means that electrons are also accelerated by the same potential drop than the ions, resulting in a self-consistent field inside the grids that is not charge-space limited. These high energy electrons are trapped by the magnetic field inside the ionization chamber and ionize a neutral gas. Apart from this ionization process, there is a significant exchange of energy between electrons, ions and neutrals, which results in wide distribution functions. The ions generated are then accelerated towards the grid system and exit the ion with an axial velocity orders of magnitude larger than the radial one.

A experimental characterization of the plasma plume dynamics has been carried out by means of a RPA and a Langmuir probe. These probes can be positioned along the plmue which allows to map it far from the exhausts.

The direct thrust provided by alphie has been measured for a series of acceleration voltages and gas flows. Although a significant impulse (> 1 mN) has been found in almost all cases studied, results show that *alhpie* achieves a higher efficiency for higher acceleration voltages, specially for high gas flows.

Acknowledgments

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