05/3202 Advanced Concepts of Electromagnetic Generation, Confinement and Acceleration of High Density Plasma for Propulsion

Type of activity: Medium Study (4 months, 25 KEUR)

Background

Plasma–based propulsion systems have found increasing interest in the past twenty years. Their conception and design derives directly from magnetic confinement fusion research, particularly of open magnetic “mirror” devices. Recent advances in plasma-based concepts have led to the identification of electromagnetic (RF) generation and acceleration systems as able to provide not only continuous thrust, but also highly controllable and wide-ranging exhaust velocities. This is of particular advantage in manoeuvring applications such as planetary missions involving planetary orbit insertion/transfer and deep space cruise phases. Another key feature of RF based plasma systems is their ability to produce energetic exhaust flows starting from light gases (H_2, D_2, He) giving very high specific impulse (up to 30,000s) to heavier noble gases (Ar, Kr, Xe) with lower specific impulse but higher thrust; a side benefit of these RF-based designs is that they are electrode-less, with the related long device lifetimes since sputtering problems due to ion impingement on grids is avoided. Furthermore, they are scaleable from low-power (few kW) to high-power (>100 kW), thus making them suitable for a variety of mission applications. It is also to be stressed that these plasma thrusters have terrestrial applications in other sectors such as surface science, high-energy physics, and waste disposal.

The typical conceptual design of an RF plasma thruster is composed of an RF plasma source, an open-ended magnetic confinement device, an RF acceleration unit, and a “magnetic nozzle” (that might not be distinct from the confinement device). The plasma source is composed of an RF driven helix-like antenna (“helicon”) that energizes a flow of initially neutral gas, into magnetised plasma with high ionization fraction. The plasma outflow is confined into an elongated column by an intense magnetic field system, and then accelerated by a second RF driven device before exhaust flux through the “magnetic nozzle” structure of the magnetic field produced by the confinement coils near the acceleration region. The plasma source and the acceleration unit employ distinct RF systems and frequencies; the ubiquitous choice for the acceleration is to employ the Ion-Cyclotron Resonance Frequency (ICRF), a proven technology in fusion experiments for efficiently transferring large RF powers to magnetized plasmas, and exploited by the NASA VASIMR (VAriable Specific Impulse Magnetoplasmadynamic Rocket) propulsion system [1]. However, despite their distinct advantages in terms of performance of other forms of electric propulsion, some major challenges need to be overcome. These are primarily related to reducing the presently high specific mass and the large geometry of the system, as well as improving the thrust efficiency (at present the specific power is very high).

Study Objectives

The primary objective of this activity is to address these major challenges by performing a detailed modelling of the above concept and optimizing its design through investigation of a number of RF and magnetic field options, associated technologies and geometries. A secondary objective is to estimate the resources needed for its development and testing. The activity will focus on the most critical electromagnetic RF issues, and on the electromagnetic (RF) plasma interactions, with less emphasis on the detailed magnetic field structure.

Task Description

- Study the RF-plasma interaction in the critical ICRF acceleration region by setting up a convenient Electromagnetic (EM) model. The model will consider the antenna geometry (possibly simplified) interacting with the magnetized plasma column; the dependency on geometrical, magnetic and plasma parameters will be investigated, in order to optimize the acceleration device.

- Analyse the helicon device with a separate EM model, considering the low-density (initial) and high-density regimes. Magnetic field confining structures will be separately assumed, and their influence analyzed. Scaling laws outside the scope of the present research will be derived from the available literature, as much as possible from measured results.

- Set up a global, approximate electromagnetic model of the plasma device to provide an appreciation of its performances. This will be a tool to establish the conceptual design of the RF antennas, matching circuits and generators, and the ensuing evaluation of the required power, mass and other physical parameters, including magnetic field for confinement. In particular, the feasibility of a low-power (a few kW) system will be investigated, and the scaling to high power addressed.

- The resources required for its physical realisation shall be finally estimated in terms of power, dimensions, mass etc. Finally, critical technologies shall be identified and necessary development steps outlined.

Deliverables

- Final report
- Final presentation at ESTEC
- Numerical modelling tools developed

References

[1] J.P. Squire, F.R.C. Diaz, T.W. Glover, V.T. Jacobson, D.G. Chavers, R.D. Bengtson, E.A. Bering, R.W. Boswell, R.H. Goulding And M. Light, "*Progress in experimental research of the VASIMR engine*". Fusion Science and Technology **43**, 111-117 (2003).