EPSC Abstracts
Vol. 5, EPSC2010-784, 2010
European Planetary Science Congress 2010

Innovative Field Emission Microthrusters for Scientific Missions

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Abstract

Field Emission Electric Propulsion (FEEP) is used for very low thrust (1 μN - 1 mN), high accuracy applications, such as fundamental physics space missions. Alta's FEEP system has been recently selected as the baseline propulsion system for the ESA LISA Pathfinder mission and is under consideration for the CNES scientific spacecraft Microscope. The thruster consists of a ionic source with a micrometer sized, elongated slit several mm to a few cm in length, where a meniscus of liquid metal is ionized and accelerated by a very high electric field. In such "linear" configuration, the applied field results in local instability of the liquid surface, generating a series of discrete ion emission sites ("Taylor cones") along the liquid meniscus merging from the thruster slit. Cesium is the propellant of choice for FEEP, due to its low melting point (29 °C), ionization potential and high atomic mass, resulting in excellent propulsive performance.

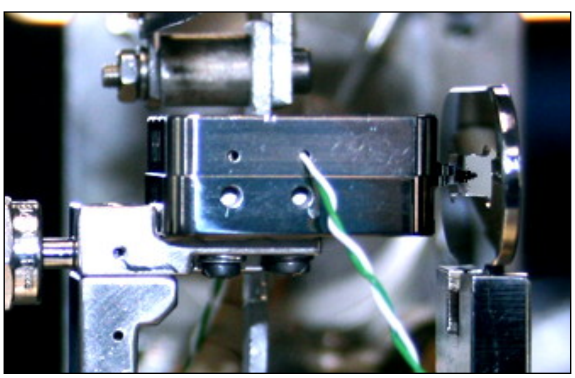

Fig. 1 - FEEP Module: emitter and accelerator electrodes

Other common field emission ion sources are based on capillaries or needles, where emission of charged particles occurs from essentially a single Taylor cone only. Such point-like sources, operated on liquid metals, are commonly used in industrial and scientific applications (LMIS - Liquid Metal Ion Sources) for microfabrication, secondary ion mass spectrometry, etc. During the last decade, the use of room temperature molten salts ("ionic liquids") as working fluids for point-like field emission sources was proposed and studied in several laboratories worldwide. Such liquids are much easier to handle than alkali metals, due to reduced or absent reactivity with air and water, very low vapour tension, low toxicity. Both space and ground operations and supporting equipment may be significantly simplified; contamination problems are much reduced. Ionic liquids have been used with success as propellants in so-called "colloid thrusters": in that case, the resulting system simplicity somehow compensates for the marked loss in specific impulse with respect to metallic propellants.

Today, space mission planners needing thrust in the 1 μN to 1 mN range can choose between clusters of point-like sources running on ionic liquids, with modest performance and considerable system complexity, or linear slit FEEP thrusters with high performance running on cesium, with the associated handling and contamination issues. In both cases, the propulsion system is rather complex and its use is only justified when very accurate and controllable thrust is required. In practice, the application of field emission thrusters is presently limited to very demanding "drag-free" scientific missions only. However, many features of FEEP (high specific impulse, low volume, room temperature operation, long lifetime and unlimited re-ignition capability) are attractive for a wide range of other spacecraft, and are specially interesting for small spacecraft or for scientific applications where thrust throttling is not strictly required.

We present a simplified FEEP system based on the linear slit technology and the use of ionic liquids as propellants. By discarding the requirement of thrust modulation, typical of scientific applications, the system may employ simple, cheap, off-the-shelf power electronics, allowing it to operate safely at constant thrust in on/off mode. The thruster is easily scalable to a nominal thrust level in the 10 μN to 2 mN range, with thrust-to-power ratio of around 50 W/mN. The use of ionic liquids allows for room temperature operation, without dedicated heaters.

A simplified FEEP system is proposed for the E-Sail project. Thruster units mounted at one end of the main tether would be used to spin-up the system initially and to provide any further spin rate change, as needed. With a delta-V of about 50 m/s and very low acceleration, the E-Sail propulsive requirements for the thruster units are fully within the range of FEEP. In comparison with other low thrust propulsion systems, a simplified FEEP would result in lower system mass due to the high specific impulse and in high operational flexibility.

A prototype simplified thruster has been tested at Alta using laboratory power supplies and a dedicated propellant feeding system. Activities underway aim at integrating the propellant tank into the thruster unit, together with the miniaturized high voltage electronics. The paper presents the test results and outlines the potential for use of simplified FEEP as a compact, low cost, high specific impulse propulsion system, addressing specifically the implementation of simplified FEEP on E-Sail.