# ELECTRIC PROPULSION IN ITALY: STATUS AND PERSPECTIVES

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## Abstract

The main actors in the Italian EP scenario are Centrospazio/Alta and LABEN-Proel. The two companies carry out research and development in a variety of propulsion-related fields under the sponsorship of the Italian Space Agency and are involved in most of the ESA-supported programmes in the EP field. This paper presents an overview of Italian EP activities and outlines the planned development lines.

## Introduction

Italian Electric Propulsion (EP) activities are concentrated in Pisa, at Centrospazio - Alta, and in Florence, at LABEN - Proel Tecnologie Division (LABEN/Proel). The two companies are active in research, development and support activities related to most of the major EP fields, including thruster development (HET, gridded ion, FEEP, MPD, arcjet), components (cathodes, feed lines, tanks), testing, system and mission design. Several Italian research institutes contribute to plasma diagnostics and modelling investigations. The two companies have recently established a joint program for advanced development in the EP field, aimed at the development of a variety of propulsion capabilities covering different fields of application. After a brief recollection of the background of the two companies, the following sections present the ongoing programmes and the envisaged future activities.

### LABEN/Proel

Proel Tecnologie, established in 1986, is a Hi-Tech Organization located in Florence, operating in the field of electron (EGA for the TSS-1and TSS-1R missions), ion and plasma sources for space applications, and relevant spin-off technologies. Proel Tecnologie was initially set up as an independent Company owned 100% by LABEN S.p.A. since the Company birth. In December 1995 the Company was incorporated to LABEN S.p.A. (currently a FINMECCANICA Company co-ordinated by ALENIA SPAZIO) as a detached division, assuming the denomination of LABEN Proel Tecnologie Division (or, more briefly, LABEN/Proel). The Company experience in the Space Field ripened and received a significant boost thanks to the participation to the Tethered Satellite System program (TSS-1 launched in 1992 and TSS-1R in 1996), within which a very particular and challenging Electron Generator (EGA) was designed and manufactured (and successfully in flight operated in both the mentioned missions). LABEN/Proel has identified EP as the main strategic development line. In this field the very first achievements have been the neutralizer (ESA contract) for the RIT-10 ion thruster (part of the Ion Propulsion Package on ARTEMIS satellite) and, as a technology spin-off, the development of a first prototype of a “Plasma Contactor” device (ASI contract). Starting from 1992 LABEN/Proel initiated the development of an innovative Ion Thruster (RMT), under ASI contract, for thrust levels in the mN range (this thruster, described in the following, has now achieved the Engineering Model development status). LABEN/Proel activities presently include the development of the RMT Ion Thruster in the millinewton range, cathodes/neutralizers for EP in the 0,2-5 kW power range, in-flight diagnostics of EP sub-systems (ARTEMIS, STENTOR, SMART-1), xenon feedlines and flow control units, plasma contactors for the electrostatic charge control on spacecrafts (PLEGPAY experiment on the ISS) and support technologies/facilities for the manufacturing of Hall Thrusters and propellant tanks (the latter by using an advanced process for composite materials polymerization through electron beam irradiation).

### Centrospazio / Alta

Electric propulsion (EP) activities in Pisa date back to 1970, with the first theoretical MPD thruster studies carried out within the Faculty of Engineering of the University of Pisa[1]. First experimental studies were initiated in 1980 on Teflon-fed pulsed Magneto-Plasma-Dynamic (MPD) thrusters, then on Field Emission Electric

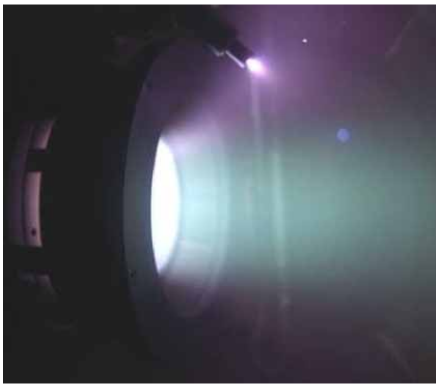
Propulsion (FEEP) in 1983. In 1987, the growing EP laboratory was moved to Consorzio Pisa Ricerche, a non-profit applied research institution promoted by the University of Pisa. By the time of its official opening in May 1989, Centrospazio - the space technology laboratory of Consorzio Pisa Ricerche - was equipped with three vacuum chambers of different sizes and speeds, where experiments on arcjets, MPD and FEEP were run under several R&D contracts by ESA and ASI[2]. In the first half of the 1990's, EP activities worldwide went into a slow but steady transition from the laboratory to industry as a result of the increasing onboard electric power availability and of the growth of the telecommunication satellite business. At Centrospazio, activities with an increasing industrial content were gradually growing along with pure research. The increasing interest for Hall effect thrusters (HET) stimulated internal activities on the subject, leading to the realization of prototypes[3].

Alta S.p.A., a privately own industrial company, was founded in 1999, ten years after the opening of Centrospazio. Alta's mission is to make use of Centrospazio's know-how and expertise to exploit application opportunities on the space technology market. The major business lines of Alta include products (FEEP systems) and services (high power EP testing), as well as applied research (MPD and HET, system and mission studies). A full micronewton FEEP propulsion system is being developed for the MicroScope spacecraft, a scientific mission by CNES aimed at verification of the Equivalence Principle. FEEP is also being considered for ESA's SMART-2 technology demonstration mission, as well as for the intended scientific spacecraft GG by ASI. The ASI-funded STEPS facility will be placed on an external site on the International Space Station to work as a long-duration testbed for EP systems. ASI co-funds the development of a very large testing facility (5.7 m internal diameter) for high power EP testing up to 50 kW.

Alta is presently equipped with eight vacuum facilities. IV1 is a 0.6 m diameter, 1.6 m long stainless steel vessel with cryogenic pumping ($10^{-8}$ to $10^{-9}$ mbar) dedicated to FEEP. IV2 is a 0.8 m diameter, 1.5 m long electromagnetically transparent fiberglass chamber where MPD studies are performed; the high current needed for pulsed MPD operation is generated in a dedicated pulse forming network capable of 5 MW for 10 ms. IV3 is a 1.2 m diameter, 2 m long plus 1 m diameter, 4 m long steel vessel with 12,500 l/s pumping speed at $10^{-4}$ mbar, well suited to arcjet and pulsed high power applied field MPD thruster testing. IV4, a high pumping speed 2 m diameter, 3.2 m long facility is illustrated below. IV5 is a 0.3 m diameter, 0.5 m long ultra-high vacuum chamber for test of components and small parts. IV6, IV7 and IV8 are three identical facilities for FEEP and other low power thruster testing, 0.5 m diameter and 1 m long. IV9 is 1.2 m diameter, 2.5 m long, and will be used for FEEP testing. Additional EP testing chambers are in preparation, including the large facility (5.7 m diameter) for high power thrusters.

## Low Thrust Ion Propulsion (RMT)

The RMT[4] (Radiofrequency with Magnetic field ion Thruster), developed by Proel, uses a RF, VHF plasma discharge in conjunction with a low level (about 100 Gauss) static magnetic field. Resonance phenomena in the plasma are exploited in order to enhance the ionization process in the low gas flow rate regime (corresponding to low thrust levels). The ion beam is extracted and accelerated through a 3-grid ion optics (Fig. 1). The RMT, whose engineering phase is now successfully completed (including the performance/characterization validation) under ASI contract, has been specifically conceived to provide a thrust level in the mN range (2-12 mN), with real time thrust throttling capability. The achievable specific impulse range, corresponding to the mentioned thrust range, is 2300-3700 sec. The thrust throttleability is considered of primary importance in missions where a drag-free control or a very tight orbital height control is required.



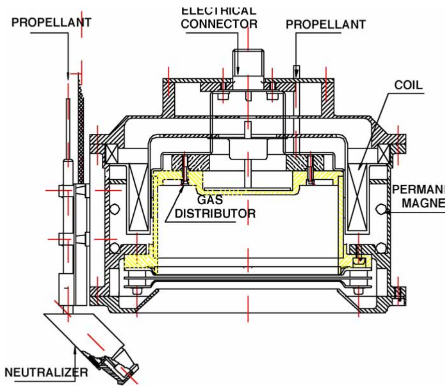



**Fig. 1 - RMT Ion Thruster: under test at LABEN/Proel, left; cross section drawing, right.**

The RMT thruster can be used in a variety of missions based on small satellites (200-1000 kg),[5, 6] e.g.:

- Drag compensation/ Drag-free control of LEO satellites (altitude ≤ 500 km)
- Control of orbital parameters of LEO satellites belonging to a constellation (altitude in the range 500-2000 km)
- Mutual position control/ gap filling of satellites belonging to a constellation/formation
- Orbit raising from the launcher deployment orbit to the operational orbit (within the 300-500 km range)
- End-of-life orbit disposal
- Station keeping of GEO/MEO satellites
- Magnetospheric mapping with spiral up spacecraft.

The RMT thrust throttleability within the 2-12 mN range, while maintaining the maximum efficiency, can be achieved by varying the coil power, the RF power, the xenon mass flow rate. Either the coil or the RF power, alone, can be varied to achieve the fast (> 1 Hz) thrust variations around the selected thrust level. The specific impulse can be adjusted, according to the mission optimization criteria, by controlling the beam voltage and the propellant utilization efficiency. The RMT is well suited to be an actuator of an integrated system for the autonomous navigation in which GPS receivers are used as position and velocity sensors. The RMT technical features, verified on the thruster EM model manufactured under ASI contract, are summarized in Tab. 1.

| *Parameter* | *Value* | *Comments* |
|---|---|---|
| Total Gas Flow rate (mg/s) | 0.1- 0.4 (xenon) | including neutralizer |
| Neutralizer flow rate (mg/s) | 0.025 | |
| Specific Impulse (sec) | 2200 - 3600 | including neutralizer |
| Thruster throttling range (mN) | 2-12 | Optimal performances achieved around 10 mN |
| Thruster efficiency | 0.3 - 0.5 | including neutralizer |
| RF input power (W) | 20 - 80 | |

**Tab. 1 - RMT Technical Features**

Neutralizers/Cathodes

LABEN/Proel positioning within the European market for these components has significantly consolidated in the last years. A family of hollow cathode[7, 8] neutralizers/plasma contactors has been developed and qualified with the purpose to make available to the European EP system manufacturers off-the-shelf components (as far as possible) for their needs.

The low current neutralizer (reference neutralization current of 300 mA) for the German thruster RIT 10 (flown on ARTEMIS satellite in year 2001) has been successfully qualified by ESA for a lifetime of 15000 hrs (Fig. 2). A larger version of the RIT 10 neutralizer (neutralization current up to 3 A) has been developed and engineered for the ESA-26 ion thruster, developed by ESA.

**Fig. 2 -Neutralizer for the RIT 10 thruster on ARTEMIS, left; cathode for the PPS 1350 Plasma Thruster, middle; cathode for the PPS X000 (usable also for the RIT-XT on Alphabus), right.**

A new 4.5 A cathode/neutralizer (ESA contract co-funded by ASI) has been developed and qualified, in cooperation with SNECMA and PLANSEE, for the PPS 1350 (80 mN) Hall Effect Plasma Thruster. This new design incorporates the oxygen absorber in the cathode body. The latest development in this field (ESA contract

funded by ASI) concerns a High Power Cathode (HP-HCA) for currents up to 20 A in view of application with PPS X000 (SNECMA) and with RIT-XT (Alphabus version).
As a spin-off of the cathode/neutralizer technologies, hollow cathode plasma sources have been developed by LABEN/Proel (under ASI contracts) for applications as Plasma Contactors. Typical use of these devices concern:

- Control /prevention of the electrostatic charging of big space infra-structures
- Electrodynamic experiments based on Tethered Space Systems.

A plasma contactor (based on the PPS 1350 cathode design) will be in-flight tested, as a device dedicated to the alleviation of the spacecraft electrostatic charging, in the frame of the PLEGPAY technology demonstration experiment (ASI contract) on the EuTEF (European Technology Exposure Facility) of the ISS.

Ion / plasma diagnostics packages

LABEN/Proel has acquired a leading position in Europe for what concerns the in-flight diagnostic instrumentation to assess/monitor the impacts of the EP systems operation on board telecommunication and scientific satellites.

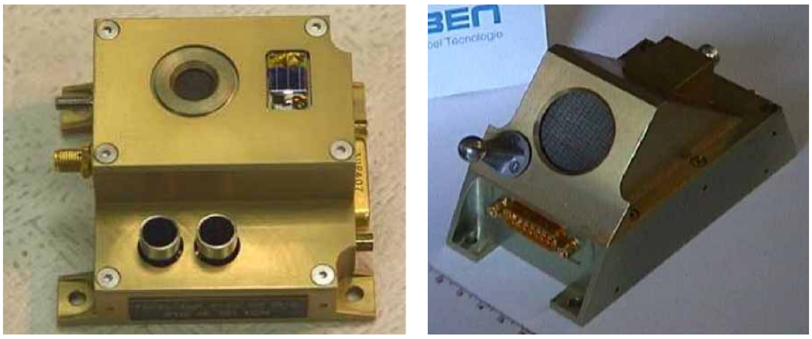


**Fig. 3 -Ion Propulsion Diagnostic Sensor for ARTEMIS, left;**
**Plasma Probe Assembly for STENTOR and SMART-1, right.**

Within ARTEMIS program (ESA) LABEN/Proel has developed, qualified and delivered a Ion Propulsion Diagnostic Sensor (IPDS, Fig. 3) dedicated to the characterization of the charge exchange ions generated by the operation of the Ion Propulsion Package (composed by 2 RIT 10 thrusters and 2 UK 6 thrusters). Successively LABEN/Proel has manufactured and delivered (ALCATEL/CNES contract) a more complex Plasma Diagnostic Package[9,10] (PDP, Fig. 3) dedicated to the characterization of the Electric Propulsion (based on the Stationary Plasma Thrusters) on the French STENTOR satellite (CNES).
The latter developed product (ESA contract) in this field is the Electric Propulsion Diagnostic Package[11] (EPDP), for monitoring the plasma interactions related to the operation of the PPS 1350 Thruster (SNECMA) on the SMART-1 satellite. The EPDP flight hardware has been delivered in spring 2002.
Near terms perspectives in this application area concern the development of a Plasma Package for the FEEP propulsion within the SMART-2 mission (ESA) and the co-operation with Alta for developing the Diagnostic Package dedicated to the facility STEPS (Spaceborne Testbed for EP Systems) on the ISS.

Gas Feedline and Flow control Units

In the frame of products/component for EP systems LABEN/Proel is active in the European scenario developing Gas Feedline and flow Control Units (GFCU) for the management of the propellant (namely xenon) supply to the thruster/s. LABEN/Proel has gained experience in this field by developing GFCU for the RMT Ion thruster (Fig. 4) and for the Plasma Contactor Experiment (PLEGPAY) on the ISS[12]. These GFCU's have been developed and assembled using the traditional technology based on electro-mechanical components (on/off valves, plenum, flow restrictors, piping, etc). The developed GFCU's include the Front-End and Control Electronics for the unit operation. More recently, LABEN/Proel has started new developments in this field proposing an approach based on the introduction of innovative solid state (e.g. magneto-strictive, silicon) components. In this context LABEN/Proel has been awarded a contract by ESA (with ASI financial support) for developing an innovative GFCU with the design goal of realizing a compact and cost effective unit directly interfaceable to the high-pressure tank (100-200 bar). The proposed equipment makes use of a ROOV (Regulation and On/off Valve), placed upstream a MFS (Mass Flow Sensor) which acts as the actuator of the closed-loop control in which the controlled parameter is no more the upstream pressure (as in the traditional approach) but directly the mass flow rate (Fig. 4). The new unit will contain a dedicated electronics accommodated in the same box, rendering the GFCU an independent and self-contained unit.

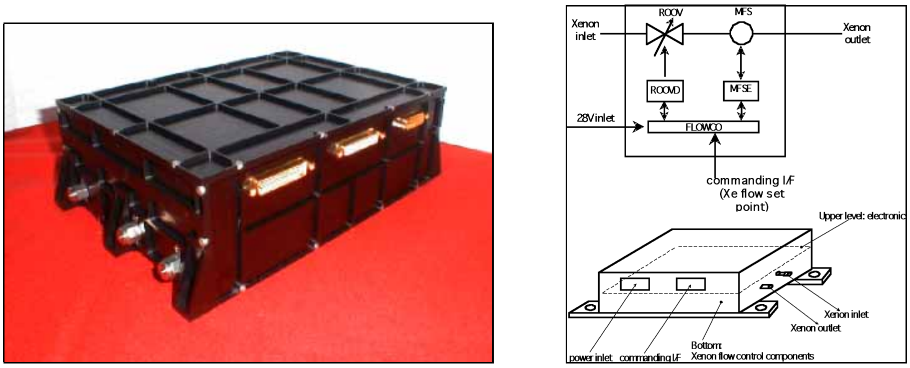



**Fig. 4 -GFCU EM developed for the RMT thruster, left; proposed configuration for the innovative GFCU, right.**

<u>Tanks in composite material</u>

In this field LABEN/Proel has patents for an innovative and cost/effective process for the realization of composite materials through electron beam irradiation[13] of the composite matrix. This process uses a low energy (≤ 500 keV) electron beam to achieve the curing of the product during the phase of deposition, around the mandrel, of the resin impregnated fibers (Fig. 5). In this way the composite is polymerized and grown layer-after-layer, until the desired thickness is achieved. This technology is very interesting for space applications, when coupled to the filament winding composite realization technology, in particular for the realization of the external shell (which it is wound around the internal metallic liner) of a tank for an EP system. Filament wound composite tanks are considered key components for the satellite on board propulsion systems.


**Fig. 5 - Low Energy Electron Accelerator for layer-by-layer composite curing, left;**
**laboratory prototype of small tank prior to be submitted to electron irradiation for polymerization, middle;**
**conceptual scheme of the proposed double stage Hall thruster, right.**

The preliminary validation of the process has been accomplished, using a laboratory pilot e-beam plant, in the frame of a technology contract with ASI - FIAT Avio. Within this activity samples suitable to validate the technology for the realization of solid propellant tanks have successfully manufactured and tested. The process is now investigated and proposed for the realization of small tanks for electric propulsion sub-systems and also, in co-operation with qualified European partners, for the realization of cryogenic propellant tanks.

The technical co-operation between LABEN/Proel and Alta has been recently consolidated through several joint programs. One of the most significant is the ESA contract on “Development of a Double Stage Hall Effect Thruster (DS-HET)”. The contract foresees the development and technology validation of a new generation HET in which decoupling between the ionization region and the accelaration region is implemented and achieved by the introduction of an intermediate electrode. This solution allows for operation of the thruster within a wide range of specific impulse (namely 1500-3500 sec) and, at the same time, increases the overall thruster efficiency. The preliminary proposed DS-HET scheme, to be verified by suitable experimental activities, foresees the use of a simple dual coil system in conjunction with a double metallic anode (Fig. 5, right). The workshare between LABEN/Proel and Alta foresees for LABEN/Proel the general program responsibility, the definition of requirements and the concept selection, the detailed DS-HET prototype design, the DS-HET manufacturing & assembly, the test results analysis; and for Alta, the review and assessment of the DS-HET technology, the DS-HET prototype preliminary design, the DS-HET functional test and performance mapping, and contributions for the test results analysis.

## FEEP

A number of experimental activities were carried out during the last two years to assess various aspects of the thruster performance. Fig. 7 shows the plume of a 100 μN thruster fed with rubidium and a thruster module. The envisaged arrangement of such modules in all of the near-term missions is in “clusters” of two or three ion emitters. A two-emitters test was recently carried out to assess possible interactions between incident ion beams from adjacent thrusters. The two thrusters were arranged at about 5 cm from each other, with parallel slits (Fig. 8, left), such that the ion beams were to overlap immediately downstream of the exit plane.

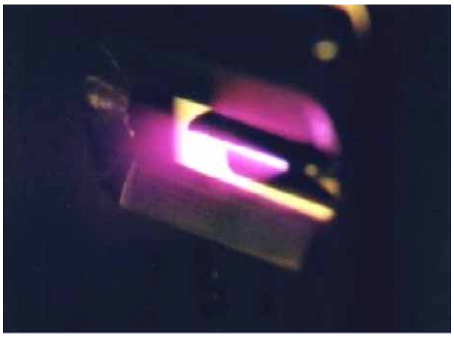
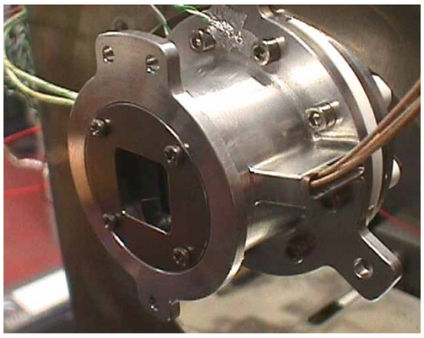



**Fig. 7 - Rb-fed FEEP thruster plume, left; 100 μN thruster module, right.**

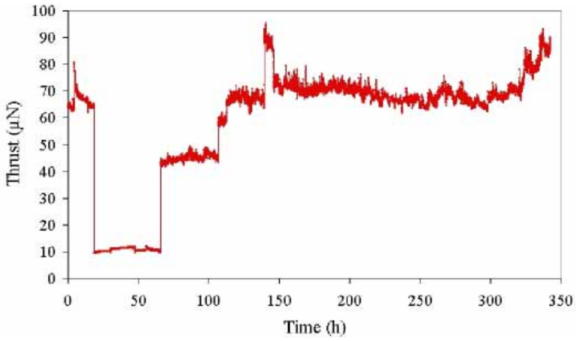




**Fig. 8 - A twin-emitter FEEP cluster, left; thrust profile over 340 hours, right.**

The beam profile resulting in combined operation is essentially coincident with the sum of the singly-operated individual profiles, showing that there is no significant interaction and demonstrating the feasibility of closely-packed clusters of FEEP emitters. Using the same experimental arrangement, one of the emitters was fired for a total of more than 500 hours. The thruster was fired at different thrust levels in open-loop mode, i.e. with no thrust control, in order to characterize the intrinsic behaviour of the ion source. Fig. 8 (right) shows the recorded thrust profile over 340 hours. During the test, power efficiency was always higher than 90%, reaching values as high as 98%. Post-test inspection showed complete absence of electrode erosion, confirming a predicted lifetime largely exceeding 10,000 hours. Actually, the test was intentionally terminated due to other scheduled work using the same vacuum facility.

In the past, possible contamination of the propellant emerging from the slit by residual atmosphere in LEO was perceived as a potential failure mechanism in alkali-metal fed FEEP. To assess this issue, a long duration test was carried out in mid 2001 exposing the thruster to very severe environmental conditions. The atomic oxygen (ATOX) flux encountered in a 200 km altitude Earth orbit was simulated by means of a dedicated ATOX source. A 50 mm slit, 1 mN FEEP thruster was exposed to direct impingement of atomic oxygen. Ion emission quality was monitored using scanning electrostatic probes. No significant degradation of the thruster performance was

observed after as long as 384 hours total exposure to severe atomic oxygen flux and to an intense molecular oxygen background[14].
Other recent achievements include preliminary thrust measurement with a high-sensitivity torsional pendulum in the 20 - 50 μN range; compatibility test with a carbon nanotube field emission cathode by the Busek Company (USA) as a neutralizer, showing no significant effect of Cs vapour and charge-exchange ions on the neutralizer performance; successful restarts of a Cs-fed FEEP thruster after repeated exposure to atmosphere, demonstrating a large degree of robustness and tolerance with respect to possible propellant degradation after chemical attack by air and moisture; and full 3-D simulation of the ion beam, including neutralization and charge-exchange effects, using a hybrid PIC/multigrid code.
In 2001, Alta was selected in a competitive tender for the provision of the FEEP system for the CNES mission Microscope. Scheduled for launch in 2007, this ambitious mission is dedicated to the verification of the Equivalence Principle using a set of high accuracy inertial sensors mounted on a small spacecraft in LEO. The FEEP system will be used to continuously compensate for non-gravitational, perturbing forces acting on the spacecraft, enabling it to fly drag-free to an unprecedented $10^{-10}$ $ms^{-2}Hz^{-1/2}$.
Power conditioning and control units (PCU's) development is underway at Carlo Gavazzi Space (I), for the Microscope spacecraft, and at Galileo Avionica (I), for ESA's SMART-2 technology demonstration mission. In both cases, a single PCU is able to drive all of the thrusters in a cluster of three. The PCU's have built-in health check and partial failure recovery routines, as well as in-flight re-calibration capability.
In support of the intense development effort underway, a set of new vacuum facilities was developped, including a cryo-pumped chamber 1.2 m diameter and 2.5 m long and three support facilities, each 0.5 m diameter, 1 m long (Fig. 9). The larger facility is dedicated to lifetime and qualification testing of FEEP systems for ESA missions.

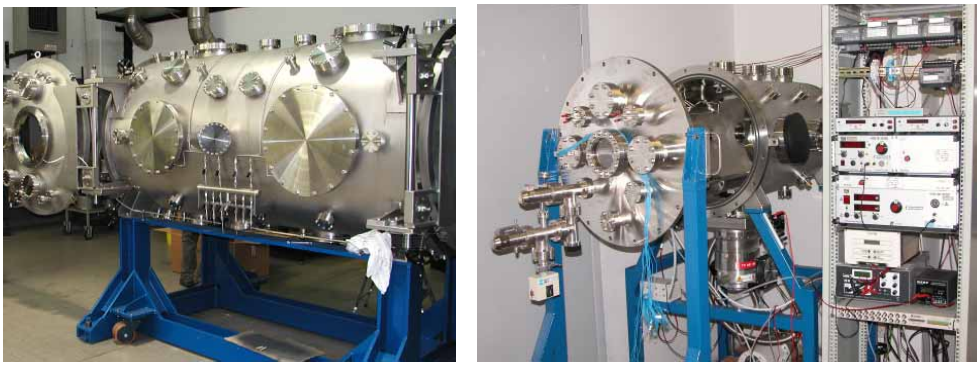


**Fig. 9 - The FEEP lifetime and qualification test facility, left; one of three identical support test chambers, right.**

Planned future research in the FEEP domain is driven by the needs of applicative missions. More exhaustive beam characterization will be carried out to fully understand thruster/spacecraft interaction issue. Accurate thrust measurement at sub-micronewton level is still an open issue, requiring refinement of the existing torsional balance. Finally, advanced fabrication techniques are being considered to lower the system cost and enhance miniaturization.

## MPD

Centrospazio has a consolidated experience in studying, developing and testing gas-fed MPD thrusters, operating in pulsed quasi-stationary mode. Typical current pulse duration is 1-5 ms at instantaneous power levels of 0.1 - 5 MW. In order to simulate thruster thermal conditions typical of the steady state regimes, since 1992 a very efficient cathode heating system has been developed.
First experimental studies were aimed at investigating the effects on thruster performance of the geometry and scale, of the type and injection mode of the propellant and of the cathode temperature. Since 1995, most of the research effort was concentrated on the study of cathode phenomena in MPD thrusters, in order to identify basic criteria for designing long-life cathodes.
Current MPD activities involve the study, development and test of an innovative applied-field MPD thruster, called Hybrid Plasma Thruster (HPT), in collaboration with RIAME-MAI of Moscow, under ASI funding; theoretical and experimental investigations on hollow cathodes, also funded by ASI; and investigations on the onset phenomena by means of systematic plasma characterization at different operating conditions.

The HPT design implements the idea of injecting a certain amount of pre-ionized propellant throughout the anode. According to several studies, this could be an effective solution for attenuating, up to completely suppressing, the onset of plasma instabilities, which are responsible of performance deterioration in MPD thrusters. The HPT (Fig. 10) consists of two stages (chambers) divided by a half-transparent anode. The first stage serves for the preliminary ionization of part of the propellant and the second one is used for ionization and acceleration of the total plasma flow. Two HPT prototypes with an applied magnetic field (up to 100 mT) have been developed and independently tested at RIAME and Centrospazio (Fig. 11, left), using nitrogen and argon as propellants respectively[15, 16]. Current research at Centrospazio is focused on the optimization of the HPT design; in particular, a new version of the acceleration chamber has been designed, featuring an high-emissive hollow cathode-heater assembly.

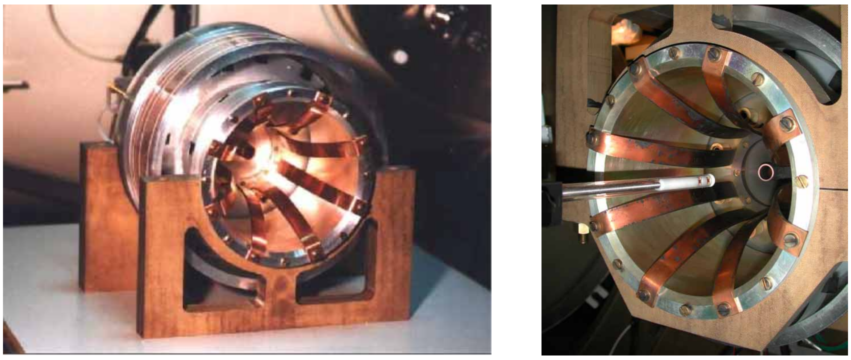


**Fig. 10 - Centrospazio's HPT prototype: on the bench, left; with a magnetic probe assembly, right.**

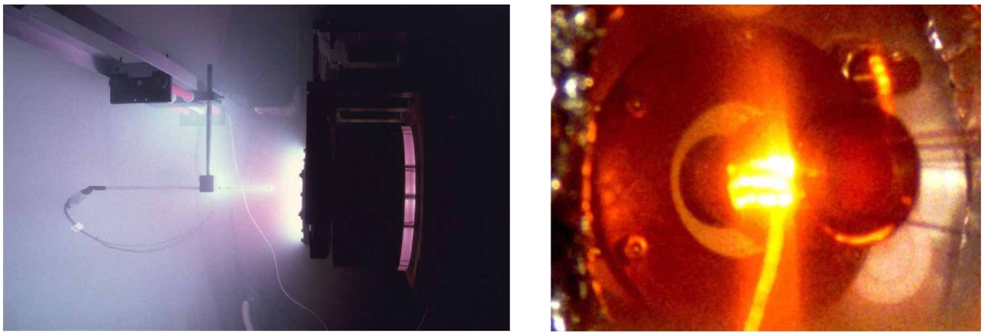
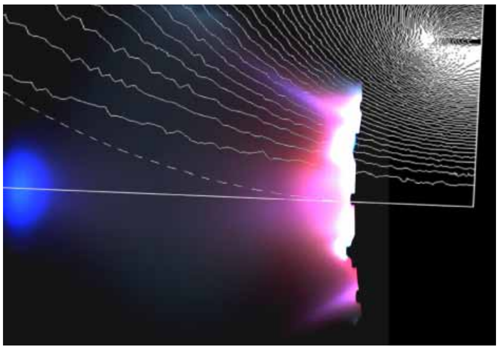


**Fig. 11 - The HPT during testing, left; hollow cathode prototype for tests on the heating system, right.**

Because of the high operating currents in MPD thrusters, the cathode experiences a high erosion rate. Recently, a hollow cathode model has been elaborated at Centrospazio describing plasma-cathode interactions in a single channel configuration, during MPD thruster continuous or pulsed-quasi-stationary mode operation[17]. The model is being modified for being applied to the multiple-channel configuration, particularly interesting for MPD thrusters. On the basis of the numerical results, a single-channel hollow cathode with the heating system has been designed for the new HPT (Fig. 11, right), while a multi-channel hollow cathode is under development and will be tested with the Li-fed Lorentz Force Accelerator (LFA) available at Princeton University, in the framework of a collaboration with Princeton's Electric Propulsion and Plasma Dynamics Laboratory.
As regards plasma characterization for the study of onset phenomena, Centrospazio acts as program co-ordinator for a number of collaborative activities with highly skilled Italian laboratories involved in plasma physics (RFX, Padua - nuclear fusion, Department of Electric Engineering, University of Bologna - magneto-hydro-dynamic systems)[18, 19]. In a future step of this collaborative research, possible application of turbulence control systems developed for nuclear fusion experiments to MPD thrusters will be studied. Fig. 12 show pictures of experiments carried out in the frame of a project sponsored by the Italian Ministry of Scientific Research, aimed at understanding the basic phenomena relevant to the so-called onset regime of MPD thrusters. Extensive plasma diagnostics activity was carried out both with intrusive (electrostatic/magnetic probes) and not-intrusive (spectroscopy, plasma imaging) diagnostic techniques. A class of instabilities was identified which are likely to be of magneto-acustic origin. With an applied magnetic field, the imaging technique highlighted the presence in the plume of rotating plasma structures, probably plasma filaments.



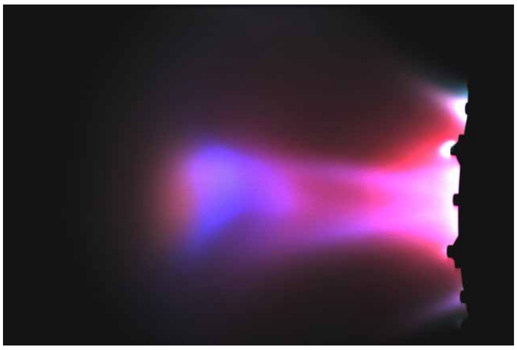


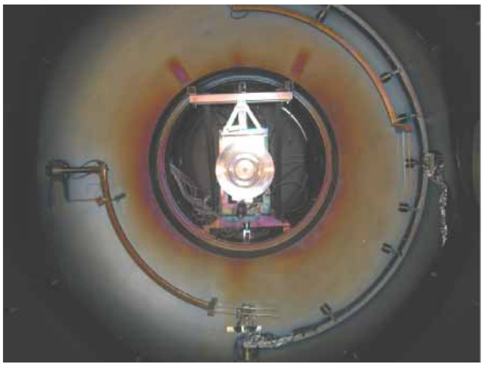
**Fig. 12 - Picture of the HPT plume with calculated superimposed applied magnetic field, left; a plasma "clot" after expulsion, right.**

<u>HET</u>

Among the EP system concepts studied and developed at Alta, an important place is for Hall Effect Thrusters (HET's), possibly the most interesting plasma propulsion system presently in use on space vehicles. Alta's heritage in Hall thruster development dates back to Centrospazio's activities in 1994-1996, when the first prototype HET (a first generation 0.7 kW system, with a classic multipole arrangement) was designed, realized and tested[3] in the IV-3 facility. In the following years HET activities continued under sponsoring from ASI, addressing the many scientific and technological issues related to such devices. Fundamental investigations addressed such topics as the plasma dynamics in the ionization channel, the interaction of HET plumes with spacecraft, the surface modifications and erosion of materials exposed to impinging high energy ions (both for clarifying the ionization channel erosion mechanisms and the issue of plume/test facility interactions), the development of a scalable family of high accuracy thrust stands for the appropriate characterization of thruster performance, the identification and implementation of extensive diagnostics for full plasma investigation.

Alta and Centrospazio are presently focusing on the development of higher power HET's, multi-kW technology demonstrators for fully understanding the key technologies to future industrial products. In this respect, two main activities have a key role in Centrospazio's and Alta's strategy as a HET technology and test service provider: the testing of Astrium's ROS-2000 HET and the development of a 5 kW HET prototype for ASI.

Centrospazio and Alta are also developing a 5 kW HET prototype (HTP-5) under sponsoring from ASI. This thruster was designed in order to provide a flexible test-bed for implementing a wide range of possible solutions. The 5 kW prototype (Fig. 13) is the first item in a series of increasing power devices: the development of a 10 kW (HTP-10) thruster was started in 2002 and is presently underway. The parametric exploration of devices designed using the same methodology and sizing relations will allow for a better understanding of scale effects in increasing power HET's.



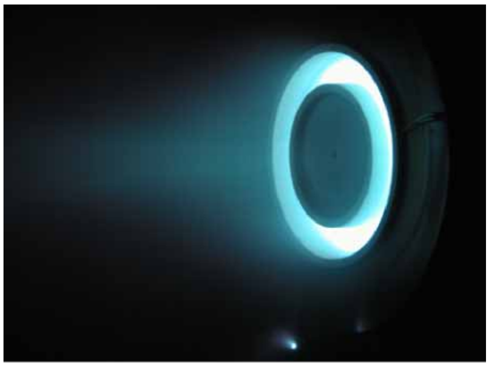


**Fig. 13 - Alta's 5 kW Hall thruster in facility IV4.**

Although nominally operating at 5 kW, the HTP-5 prototype is sized in order to run at up to 8 kW input power. The prototype features an axially symmetric magnetic coil arrangement, with three separate windings in order to achieve a plasma focusing effect possibly decreasing the plume divergence. After magnetic and thermal characterization, the thruster was extensively tested in late 2002. Maximum recorded efficiency, including cathode and magnetic circuit, was 49% at 3.6 kW, with a thrust of 200 mN and a specific impulse of 1850 s.

Testing services

Since 1999, Centrospazio and Alta are providing test services and support in the framework of ESA's ROS-2000 HET development program, in partnership with Astrium Ltd (UK), Qinetiq Ltd (UK), Inasmet (E) and Keldysh Research Center (RU). A new vacuum facility (IV4) was designed and realized in order to undertake this task, providing a suitable environment for high quality tests and full qualification on a nominally 2 kW thruster (Fig. 14).
The IV4 facility is among the most performing European facilities for advanced EP systems testing: with a maximum pumping speed in the order of 140,000 l/s [Xe] for short duration tests (up to 10 hours) and 70,000 l/s [Xe] for long duration tests (thousands of hours), the IV4 facility is now fully operative for qualification tests on HET's up to 2.5 kW (gridded ion engines - GIE's up to 1 kW) and performance tests on HET's up to 5 kW (GIE's up to 2 kW). Astrium's ROS-2000 thruster first ignition was successfully performed at Alta in July 2002.

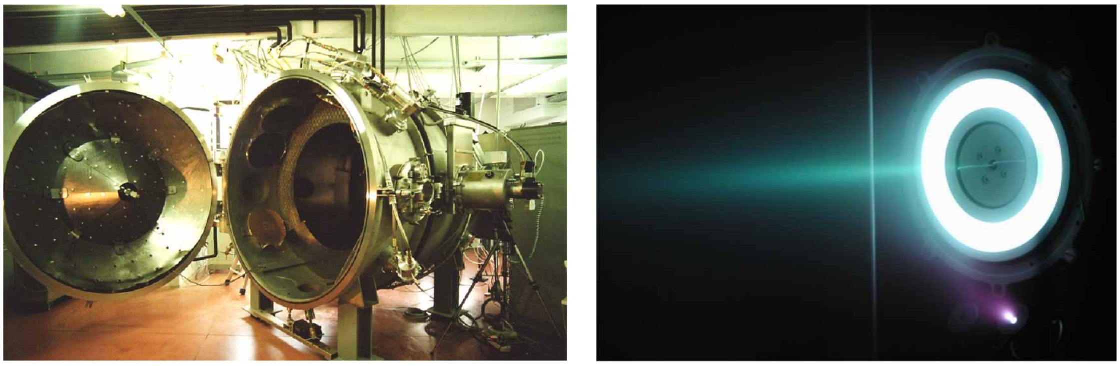


**Fig. 14 - Alta's IV4 test facility: 2 m diameter, 3.2 m long, with an additional 1 m diameter, 1 m long lock chamber; a 1 m diameter gate valve connects the two. At right, Astrium's ROS-2000 HET fired in Alta's IV-4 facility.**

In preparation for the next generation of high power EPS, Alta has undertaken the design and realization of a new large test facility[20], with 5.7 m diameter and a total length of up to 13 m, suitable for testing HET's up to 50 kW and GIE's up to 15 kW. With a maximum pumping speed exceeding 1,000,000 l/s [Xe], the new facility (Fig. 15) will be Europe's most powerful and advanced test bench for EP, allowing the end-to-end space simulation of multiple propulsion systems.

**Fig. 15 - Alta's new large test facility during the final assembly stages.**

A re-usable platform for testing of EP systems in space, based on an International Space Station (ISS) external site, is under development at Alta under ASI funding. The STEPS facility (Spaceborne Testbed for Electric Propulsion Systems) will enable in-orbit testing of small, miniaturized EP systems, as well as extended investigations on higher power devices (Fig. 16). The STEPS programme is now entering Phase C, aiming at a first flight in 2007.

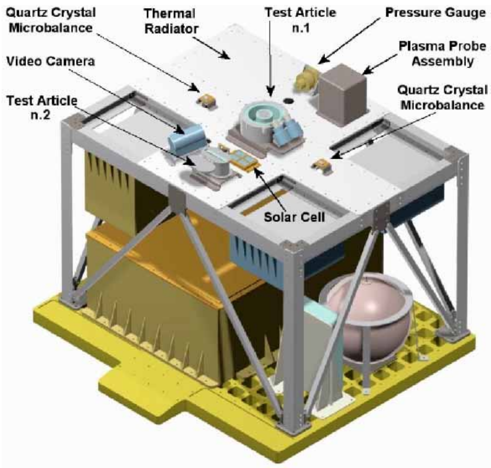



**Fig. 16 - The STEPS facility.**

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