27th EPS Conference on Contr. Fusion and Plasma Phys. Budapest, 12-16 June 2000 ECA Vol. **24B** *(2000) 81 -84*

Investigation on a New Type of MPD Thruster

V.B. Tikhonov*, N.N. Antropov*, G.A. Dyakonov*, V.A. Obukhov*,
F. Paganucci**, P. Rossetti**, M. Andrenucci**.
** RIAME MAI, 125080 Moscow, PB 43, Russia*
***CENTROSPAZIO, Via Gherardesca, 5, 56014, Pisa, Italy*

Introduction

The most attractive features of Magneto-Plasma-Dynamic Thrusters (MPDT s) for space applications are the high thrust density (up to 10^4 N/m^2), the design simplicity, the robustness and the possibility, in principle, to use a large variety of propellants (gases, polymers, alkali metals). These features allow the MPDT s to be favourably considered for high power (0.1 1 MW), primary missions, ranging from orbit-raising of large satellites to cargo interplanetary transfer. For this last class of missions, MPDT s represent almost the unique electric propulsion option, provided an exhaust velocity of 40-60 km/s, a thrust efficiency larger than 50% and a lifetime of 5-10 thousands hours are exhibited [1]. However, the achievement of these performance is generally hampered by the occurrence of detrimental phenomena, usually referred as ”onset phenomena”, taking place when a critical current is exceeded, depending on thruster geometry, propellant and mass flow rate. Onset phenomena involve arc voltage fluctuations, power losses and, eventually, strong erosion or melting of thruster components (anode in particular). Several experiments show the critical current is close to the full ionization current, at which all the propellant is ionized and exhausted at the critical Alfven velocity and the near-anode zone is the most involved region in onset phenomena [2, 3]. This last occurrence is attributed to the joint action of pinch and Hall effect, which tends to compress the plasma to the thruster axis and, consequently, to reduce plasma density in the anode region. The relevant increase of the Hall parameter in the anode layer yields an increase of the anode potential drop and electron temperature. This occurrence is favourable for the development of ion-sound microinstability, which, in turns, increases plasma thermalization and heat transferred to the anode. Direct injection of neutral propellant in the anode region has proved to alleviate and/or delay the onset phenomena [4]; nevertheless no decisive results have been obtained, since the ionization length in MPDT s exceeds the anode layer extent (of the order of the electron Larmor radius): an injection of ionized propellant in the anode region seems thus more appropriate to modify the anode layer condition, as shown in [5]. To assess the effectiveness of this last solution, a new MPDT (called Hybrid Plasma Thruster - HPT) has been proposed [6], developed and tested in the framework of a joint activity between RIAME of the Moscow Aviation Institute (RU) and Centrospazio (Pisa, I). On the basis of the results of a performance model [7], two almost identical prototypes have been developed and are currently under testing in each laboratory. Some of the experimental results gathered so far are illustrated in the following.

The Hybrid Plasma Thruster

The HPT, shown in Fig. 1, is an axisymmetric MPD thruster with an applied magnetic field, a central acceleration chamber and a peripheral ionization chamber. Each prototype developed consists of:

- a central hollow cathode (copper, 20 mm in dia), through which 80-90% of a gaseous propellant is injected in the main discharge chamber;
- an anode, consisting of a cylinder (aluminum, 200 mm in inner dia) and eight straps, made of copper, which divide the central chamber from the ionization chamber. To optimize the

acceleration processes in the central chamber, the straps are shaped to be parallel to the local magnetic force lines;
- eight peripheral hollow cathodes (copper, 12 mm in dia each), through which 10-20% of the propellant is injected;
- a solenoid, capable of producing an induction field up to 100 mT at the thruster axis.

Since the prototypes operate in a pulsed, quasi-steady mode (pulses 1-5 ms long with instantaneous power of 100-800 kW), the insulators between the electrodes are currently made of Plexiglas™.

The aim of the peripheral chamber is the ionization of 10-20% of the propellant by means of a secondary, low power (5-40 kW) discharge between the peripheral cathodes and the anode. The ionized propellant then flows in the acceleration chamber, increasing plasma density near the anode. A relevant onset phenomena reduction is expected. In [7] an anode voltage drop reduction up to 10 V at the critical condition is estimated, due to the added ionized gas.

The acceleration processes taking place in the HPT are mainly electromagnetic. In the region close to the central cathode, the thrust is mainly generated by the interaction between the radial current and the self-induced, azimuthal induction field. In the anode region of the acceleration chamber, where the electron Hall parameter should be moderately higher than 1, the main contribution to thrust comes from the interaction between the azimuthal Hall current and the applied magnetic field, similarly to an SPT operation. [7] indicates the Hall effect contribution to thrust is always significant up to the critical current and can represent the main contribution, especially at low mass flow rates and currents.

Preliminary Experimental Results

Electrical characteristic and thrust measurements performed at Centrospazio with argon are shown below. The thruster is mounted on a thrust stand inside a vacuum chamber, capable of maintaining a back pressure during the pulse better than 1×10^{-3} mbar. The electric power to the HPT is supplied by a Pulse Forming Network (PFN), connected as shown in Fig. 2, capable of deliver quasi-steady current pulse 2.5 ms long. The propellant is injected by two gas feeding systems, one for the central cathode and the other for the peripheral cathodes, based on fast acting solenoid valves, which provide gas pulses with long plateau after few milliseconds from valve activation [2]. When a steady state mass flow is reached, the electric circuit is closed by switching an ignitron on and the discharge takes place. The solenoid is supplied by a DC generator, switched on few seconds before the discharge. Figs. 3 and 4 show typical current and voltage signals respectively. Each data point of the electrical characteristics has been obtained as an average of current and voltage on a window 100 microseconds long taken in the middle of the pulse. The overall voltage and current accuracy is within ±4% and ±3% of the data points respectively.

Thrust (T) measurements have been carried out with a ballistic method [2], which allows instantaneous thrust to be obtained with an overall accuracy within ±10% of the data points. Figs. 5 and 6 show the electrical characteristics measured for 660 mg/s of argon, with an applied magnetic field with a maximum induction on the axis of 40 mT (calculated). Three cases have been investigated: all the propellant injected from the central cathode without activation of the ionization chamber, 600 mg/s from the central cathode and 60 mg/s from the peripheral cathodes with and without activation of the ionization chamber. A reduction of the primary arc voltage (about 5 V) with the activation of the ionization chamber was observed for 660 mg/s below the estimated critical current (see below). No significant reduction was observed for higher currents.

Fig. 7 shows the thrust data obtained at 660 mg/s with and without the external magnetic field. The HPT operation without applied magnetic field seems to be well represented by the model $T=bI^2$ for $I \geq I_{fi}$ and $T=bI_{fi}I$ for $I \leq I_{fi}$ [2], where I_{fi} is the critical or full ionization current at which all the propellant is exhausted at the Alfven velocity (about 8.7 km/s for argon; for $b=1.8 \times 10^{-7}$ N/A^2, and 660 mg/s, I_{fi} is 5600 A). The applied magnetic field seems to improve the thrust up to the critical current, no matter the ionization chamber is activated, while for $I \geq I_{fi}$ no significant thrust augmentation seems to occur. Since the Hall effect contribution to the thrust is mostly generated in the anode region, we believe this region is poorer and poorer of propellant by increasing the current, due to pinch effect, and consequently the Hall effect contribution to thrust decreases and is almost negligible for $I \geq I_{fi}$.

As a conclusion, tests carried out so far with argon have shown the substantial effectiveness of the applied magnetic field as well as of the ionization chamber for $I < I_{fi}$, while no significant effects have been observed at higher currents. Better results should be obtained by increasing the propellant fraction elaborated by the ionization chamber and/or using a different propellant. Moreover, a deeper insight on HPT operation could be obtained from plasma diagnostics in the anode region, foreseen in the next testing activity.

References

[1] R. H. Frisbee, N. J. Hoffman, Electric Propulsion Options for Mars Cargo Missions , AIAA paper, 32nd Joint Propulsion Conf. (JPC), Lake Buena Vista (FL), July 1996.

[2] M. Andrenucci et al., "Scale and Geometric Effects on the Performance of MPD Thrusters", AIAA 92-3159, 28th JPC, Nashville, TN, July 1992.

[3] M. Andrenucci, F. Paganucci, A. Turco, MPD Thruster Plume Diagnostics , IEPC-93-141, 23rd International Electric Propulsion Conference (IEPC), Seattle, WA, Sept., 1993.

[4] F. Paganucci, M. Andrenucci, MPD Thruster Performance Using Pure Gases and Mixtures as Propellant , AIAA-95-2675, 31st JPC, San Diego, CA, July 1995.

[5] N. V. Belan, V. Kim, A. I. Oransky, V. B. Tikhonov, Stationary Plasma Thrusters , Kharkov, 1989, (in russian).

[6] V.B. Tikhonov, G.A. Dyakonov, MPD Thruster with External Magnetic Field and Ionization Chamber , IEPC-95-121, 24th IEPC, Moscow, 1995.

[7] V. B. Tikhonov, V. Obukhov, G. Dyakonov, Development and Tests of a Hybrid Plasma Thruster , Review Report no. 1, Centrospazio Contract no. 03650, 1997.

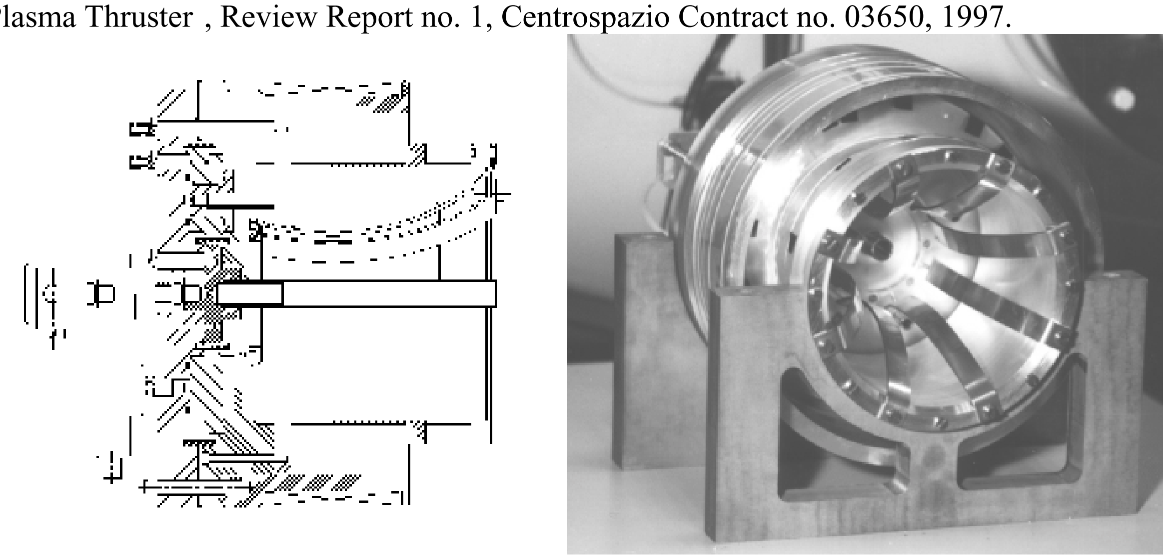

Fig. 1 Centrospazio's HPT

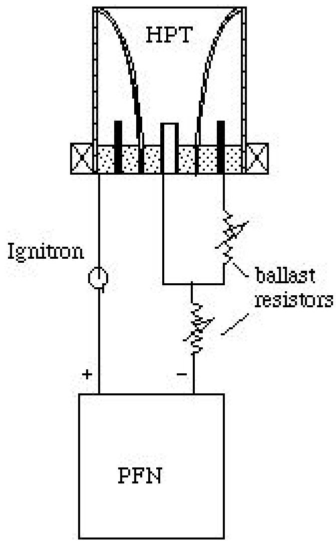

Fig.2 Main electric circuit arrangement

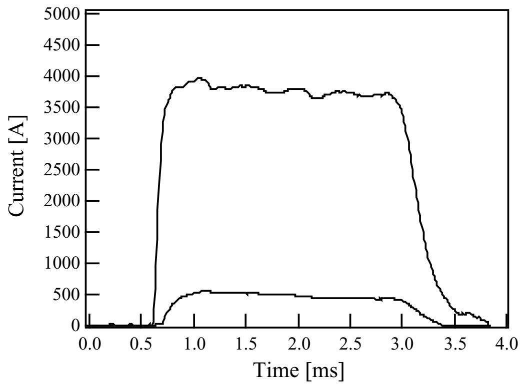

Fig. 3 Current signals (high: primary current, low: ionization chamber current)

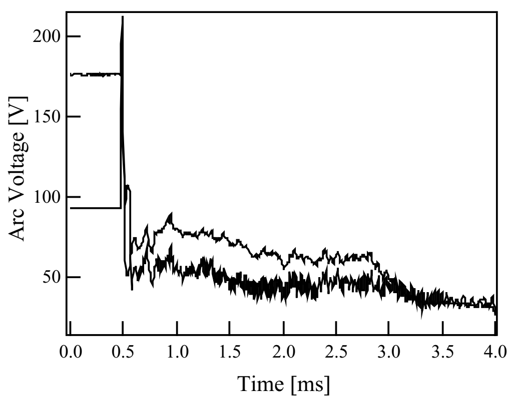

Fig. 4 Voltage signals (high: primary voltage; low: ionization chamber voltage)

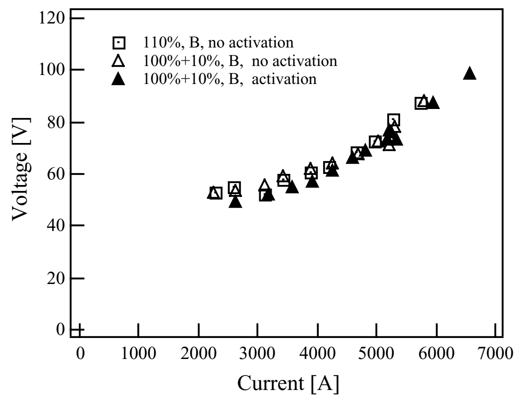

Fig. 5 Electrical Characteristics (660 mg/s, argon)

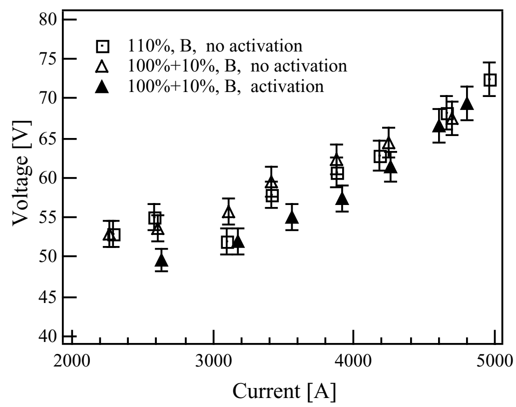

Fig. 6 Electrical Characteristics (660 mg/s, argon, zoom)

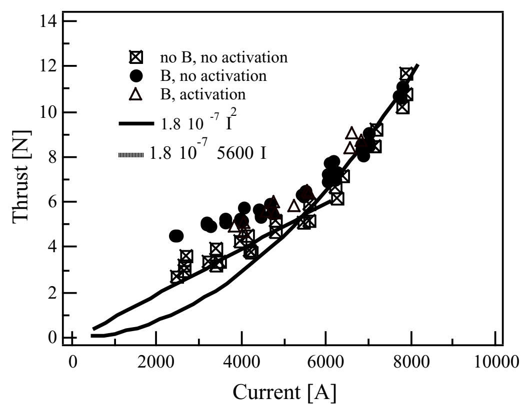

Fig. 7 Thrust vs Current (660 mg/s, argon)