Low Current Pulsed Ablation Plasma Thruster

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Theme

A NEW type of ablation plasma thruster has been investigated which delivers small impulse bits of 10–100 μN-sec at a msec pulse duration. The high impedance of the device is such that operation from a low-weight electrolytic capacitor is possible. Though the plasma exhaust velocity is high (9 km/sec) the dominant accelerating mechanism is not of the $\bar{j} \times \bar{B}$ type. The performance of the device is limited by electron heat conductivity.

Contents

One type of pulsed ablation plasma thruster has shown capability for certain control functions of satellites.[1] This thruster type utilizes self magnetic field acceleration and is a high-current (10 ka) low-impedance device which delivers impulse bits at a msec time duration. These thruster characteristics imply a high-voltage capacitor for energy storage which has to be closely mounted to each thruster. In order to reduce energy supply constraints a new low-current pulsed ablation thruster has been designed and investigated which can be operated from a small weight electrolytic capacitor, possibly common to a number of thrusters.

The basic thruster arrangement is shown in Fig. 1. A plasma discharge occurs between a brass cathode and a copper anode which are permanently connected to an electrolytic capacitor. Close to the anode a solid fuel block is placed which consists of an insulating material such as PbI_2, CsI, or Teflon. Ignition of the discharge is provided in the usual way[1] by a triggering element. During the discharge an ablation area exists at the fuel surface. This area is a ring concentric to the anode if no magnetic bias field is applied. With a magnetic bias field an ablation spoke forms which is attached to the anode. Varying the magnetic field configuration it turned out that ablation occurs only at an area where $\bar{j} \times \bar{B}$ (of the ablating surface current and the bias field) is oriented towards the fuel surface. Consequently the location of the ablation area is determined by the anode and the direction of the applied magnetic field.

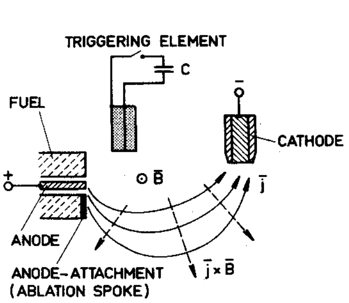

Fig. 1 Basic thruster arrangement.

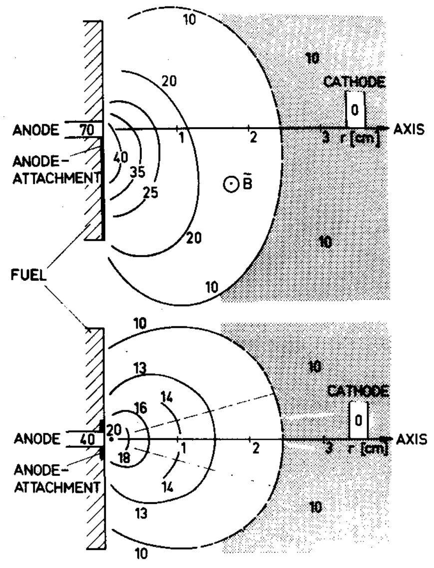

Fig. 2 Contours of equal floating potential (volt with respect to cathode); upper part: with magnetic field of 400 gauss, lower part: without magnetic field.

Numerous plasma diagnostic measurements[2] have revealed some understanding of the accelerating mechanism. The ablating area acts as an ion source from where the ions move nearly collisionless through a potential field (Fig. 2). This field is originated by the applied voltage and specially shaped by plasma space-charge. The ions passing through this potential field are accelerated to an energy which corresponds closely to the applied voltage. The potential contours and the ablative anode attachment for a magnetic field of 400 gauss are shown in the upper part of Fig. 2.

Considering plasma acceleration in an electric-magnetic field configuration the $\bar{j} \times \bar{B}$ term is commonly considered as being mainly responsible for the acceleration of the plasma. It was remarkable, however, to observe that significant plasma acceleration also occurred without magnetic field. For this case the potential contours and the ablating area are shown in the lower part of Fig. 2. There is no significant difference between the upper and lower part (with the exception of the location of the anode attachment) indicating that the $\bar{j} \times \bar{B}$ term plays only a minor role in the accelerating process. The dominant accelerating mechanism which is called "electron pressure acceleration" is based on the existence of a rigid wall where the ablation takes place. Momentum to the ions is transferred by means of the electric potential field and the very same but opposite momentum is transferred to the electrons. The resulting acceleration comes about because the ions can leave the accelerator freely whereas the electrons are pushed by the electric field against the fuel surface. A self-consistent model of the electron pressure acceleration has been worked out and was found to be in good

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Index category: Electric and Advanced Space Propulsion.

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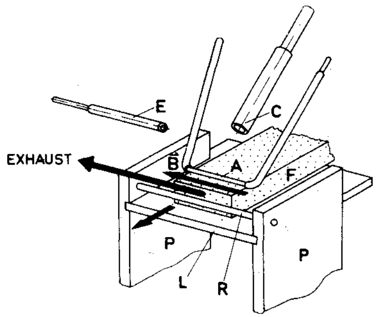

Fig. 3 Schematic of operational thruster.

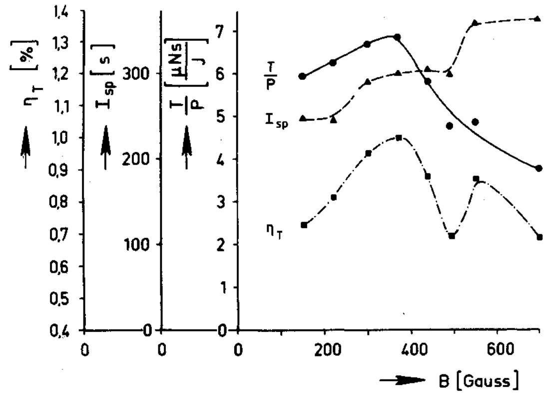

Fig. 4 Performance of thruster vs magnetic bias field.

agreement with the measurements of plasma potential and electron temperature.[2]

Some characteristics of the thruster and the discharge plasma are summarized in Table 1. An electrolytic capacitor (400 μF) was used as a power supply and CsI as a propellant. Because of the exponential type of decay of the discharge, the current and the voltage are time-dependent.

Table 1 Characteristics of the thruster and the discharge plasma

Duration: 2 msec	Impulse bit : 100 μN-sec
Current : 100–10 amp	Specific impulse : 300 sec
Voltage : 80–50 v	Exhaust velocity: 9 km/sec
Magnetic bias field : 400 gauss	
Mass consumption per discharge: 3×10^{-8} kg	
Electron temperature : 4.5 ev	

An operational device (which was endurance tested) is schematically shown in Fig. 3. The solid propellant *F* is fastened to a propellant carrier *L* which is pushed or pulled in the direction indicated by the arrow. (The pulling mechanism is not shown). The ceramic rod *R* acts as a retaining element to determine the fuel position with respect to the electrodes. The anode *A* (copper) and the brass cathode *C* are supported and insulated by ceramic tubes. The pole pieces *P* provide a magnetic bias field of 400 gauss parallel to *A*. This bias field serves to constrain the ablation at the propellant surface between the anode *A* and the retaining rod *R*. The propellant in this region (even the portion located underneath the retaining rod) is completely consumed. The propellant is supplied at a rate which is determined by its rate of ablation. The triggering element *E* is isolated electrically from the main discharge across *A* and *C*. The whole device is of small size (distance between the pole pieces: 1 cm) and weighs only 30 g (including the permanent magnet, excluding the fuel).

The thruster performance determined by the measurements of impulse bit, mass consumption, and input energy are summarized in Fig. 4 as a function of the magnetic bias field. The thrust efficiency (η_T) and the thrust to power ratio (T/P) display a maximum at about 400 gauss where the specific impulse (I_{sp}) curve shows a plateau. This point is considered as a practical optimum for this device.

Though a low thrust-efficiency is tolerable for certain attitude control functions some effort has been made to improve the efficiency. The main energy loss was identified as being due to electron heat conductivity. In spite of a number of thruster modifications, however, this energy loss could not be reduced.

References

[1] Guman, W. J. and Nathanson, D. M., "Pulsed Plasma Microthruster System for Synchronous Orbit Satellite," *Journal of Spacecraft and Rockets*, Vol. 7, No. 4, April 1970, pp. 409–415.

[2] Liebing, L. and Seidel, F., "A Low Current Pulsed Ablation Plasma Thruster," AIAA Paper 73-1068, Lake Tahoe, Nev., 1973.