N91-28107

ELECTRODE EROSION IN LOW POWER ARCJET THRUSTERS*

S44-20
26625
P-6

A. Ghosh and P. Ray
School of Engineering and Architecture
Tuskegee University, AL

ABSTRACT

Low power arcjet thrusters (0.5 to 3kW) are currently being considered for North-South station keeping of geosynchronous communications satellites. The erosion mechanisms of cathodes in these thrusters are not well understood. The experimental set-up to produce a steady state electric arc in a gas flow is described and some preliminary theoretical results on cathode erosion are presented.

---

*Work supported by NASA Grant NAG3-726

ELECTRODE EROSION IN LOW POWER ARCJET THRUSTERS

Introduction

The power available for auxiliary propulsion on communications satellites currently ranges from 0.5 to 3kW. Low-power arcjet thrusters are being developed for North-South station keeping of these satellites. These devices convert electrical energy to thermal energy by heat transfer from an arc discharge to a propellant gas and subsequently from thermal energy to directed kinetic energy by expanding the gas through a nozzle. Arcjet thrusters offer more than 50 percent increase in specific impulse over state-of-the-art auxiliary propulsion [1]. Significant mass savings can thus be achieved for these spacecrafts using auxiliary propulsion.

Extensive work has been done in the last few years in understanding the interaction between various parameters of the low-power constricted arcjet thrusters [2-4]. This has resulted in significant advances in the performance of these devices. A 1000-hr life test (500 cycles of 2-hr duration) at a specific impulse of about 450 sec and about 1.2kW power level was recently successfully completed [5].

It was observed from this test that a burn-in period spanning over several cycles existed before a stable and consistent thruster operation was obtained. The burn-in period was characterized by voltage excursions, some of which were rapid while others were step changes. A rapid increase in steady state arc voltage was observed during the burn-in period, indicating rapid cathode tip recession.

To maintain the arc, the cathode emits electrons through an extremely complex process which makes it one of the key components in the arcjet thruster. One result of an arc discharge is the loss of cathode material ejected in the form of vapor jets at high velocities. The arc termination at the cathode is characterized by the formation of molten areas called spots, which can be highly mobile. It is presumed that the voltage fluctuations observed during the burn-in period are caused by the motion of the arc spot at the cathode tip. The objective of this research is to understand the mechanisms of cathode erosion in the low-power constricted arcjet thrusters by using both experimental techniques and theoretical analysis.

Experimental Setup

An experimental assembly to generate an open dc arc has been fabricated. The arc is established in an argon environment at or below one atmosphere pressure. Initial studies have been made to gain an understanding of the arc ignition and maintenance processes and to get preliminary information on electrode erosion. A schematic drawing of the experimental system is shown in Fig. 1.

The cathodes used are 3.2 mm diameter, 2 percent thoriated tungsten rods ground to a 30° half angle tip. For preliminary arc characteristic studies and mass loss information, the anode inserts used are finely polished bolt heads made of various materials such as low carbon steel, aluminum, brass and titanium. Cathode and anode holders are designed in a way so that the electrode inserts can be replaced quickly.

The cathode is put inside a brass electrode holder and held in place by a brass screw clamp. The brass electrode holder is made to thread into the copper cooling jacket. The cathode tip would typically extend about 2 cm from the brass holder.

The anodes are threaded directly into the copper cooling jacket. The inlet and outlet connections to the cooling water jackets are fitted with thermocouples to monitor temperatures of water circulated through the electrode assemblies.

The distance between the cathode and the anode can be set precisely by the use of a micrometer head. The rotation of the micrometer spindle is translated into a linear motion of the cathode assembly, thereby adjusting the gap width to the desired value. The gap width generally ranges from 1 to 5 mm.

A current-controlled, voltage-regulated dc power source (Sorenson Power Supply) with a maximum capacity of 18 A at 600 V is used to provide the power. Initial testing has been done in the range of 5 to 15 A arc current.

The test chamber which contains the arc is a pyrex cross. To start the arc ignition process, vacuum is first obtained by the use of a roughing pump. Argon is then forced into the pyrex test chamber to increase the pressure to the desired level.

The arc is started at about 200 V by separating the electrode contacts. After the arc is initiated, the voltage across the arc drops to approximately 40 V. For the ballast resistance, a set of 1 kW, 1 ohm resistors are used. The resistors could easily be added to or removed from the system. It was found that a combination producing 2 ohm of resistance provided adequate stability to the arc.

The measured voltage-current characteristics confirm the observed trend that the arc voltage decreases as the current increases. The arc voltage also tends to increase as the distance between the electrodes increases. The mass loss is observed to range from 1 to 40 μ g/C depending on the material and the arc power level.

Theoretical Analysis

A preliminary theoretical parametric study of the cathode processes of a low-current electric arc was done. The independent parameters were the cathode fall potential, work function of the electrode material, atomic mass of the electrode material and thermal conductivity. The dependent variables were the electron current density, the ion current density at cathode spot, the ratio of ion current to total current, the electric field in the cathode fall region and the temperature of the cathode spot.

The cathode temperature was found to be related to the cathode spot radius, a, the heat flux, Q, and the thermal conductivity, K. It is given by the relationship:

$$T_c = a.Q/K. \qquad (1)$$

The heat flux was related to ion current density, J_i; cathode fall potential, U_c, and work function, φ, by

$$Q = J_i . (U_c - \varphi) . \qquad (2)$$

The cathode spot radius can be written as a function of arc current, I, and arc density, J.

$$a = (I/\pi J)^{1/2}. \qquad (3)$$

Defining $\nu = J_i/J$, one gets

$$a = (I\nu/\pi J_i)^{1/2}. \qquad (4)$$

Hence,

$$T_c = (I\nu J_i)^{1/2}.(U_c - \varphi)/(\pi^{1/2} K). \qquad (5)$$

The erosion of the cathode can be calculated by assuming that the ion bombardment raises the temperature of the cathode spot beyond the melting point of the cathode material. The cathode mass removal rate, m, is given by

$$m = \nu(U_c - \varphi)/[(L + C_s(T_s - T_r) + C_l(T_c - T_s)] \qquad (6)$$

where L is the latent heat of fusion of the cahtode material, C_s and C_l are the specific heats of cathode in solid and liquid state respectively, T_r is the room temperature and T_s is the melting point of the cathode material.

Discussion

An experimental assembly to generate an open arc in an argon environment has been fabricated and is operating satisfactorily. In the next phase of this research, we plan to incorporate an arcjet thruster into this assembly and study the cathode spots through the use of optical spectroscopy, high speed photographic techniques and scanning electron microscopy.

From the theoretical analysis it was found that the ion current density plays a crucial role in determining the cathode spot temperature and cathode spot size. For an ion current density ranging from 1×10^9 A/m^2 to 1×10^{10} A/m^2, the cathode spot temperature varies between 2000°K to 6000°K. The cathode spot size varies between 4μm to 150μm for the given range of ion current density. The rate of cathode erosion is dependent on the cathode spot temperature as well as on the melting point of the cathode material. The erosion rates are in the range of tens of micrograms per coulomb and these values correspond well to the erosion rates that have been observed with electric arcs.

References

1. Stone, J.R., "Recent Advances in Low Thrust Propulsion Technology", Paper No. AIAA-88-3283. (1988).
2. Hardy, T.L.; Curran, F.M., "Low Power dc Arcjet Operation with Hydrogen/Nitrogen/Ammonia Mixtures", Paper No. AIAA-87-1948. (1987).

3. Haag, T.W.; Curran, F.M., "Arcjet Starting Reliability: A Multistart Test on Hydrogen/Nitrogen Mixtures", Paper No. AIAA-87-1061, (1987).

4. Curran, F.M.; Haag, T.W., "Arcjet Component Conditions Through a Multistart Test", Paper No. AIAA-87-1060, (1987).

5. Curran, F.M.; Haag, T.W., "An Extended Life and Performance Test of a Low Power Arcjet", Paper No. AIAA-88-3106, (1988).

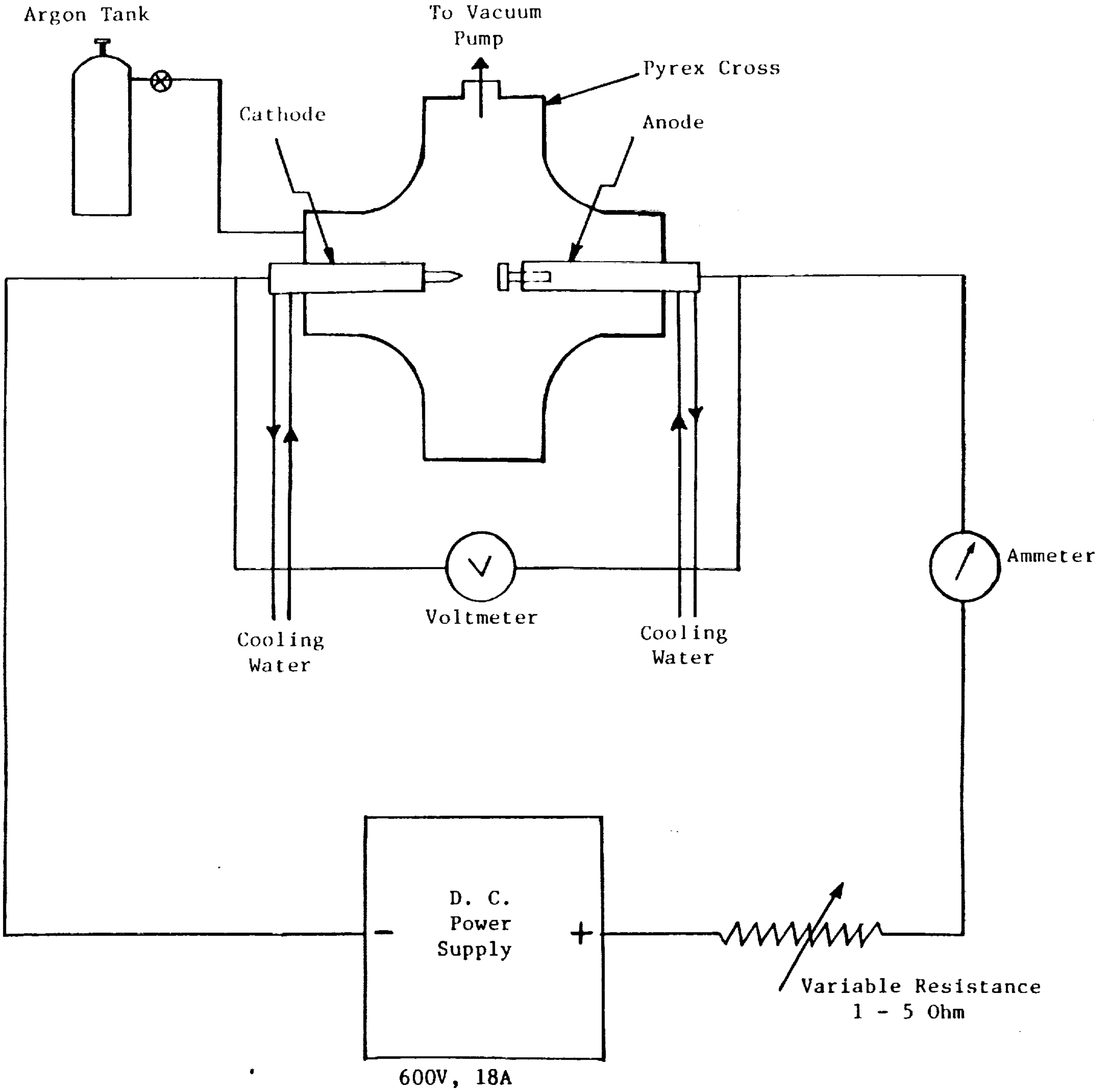

Figure 1. Schematic drawing of the arc discharge experimental system.