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Experimental Investigation of the Characteristics of a Hollow Cathode MPD Arc Thruster

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SEVERAL investigations have been made related to the physical processes involved near the cathode of an MPD arc thruster,[1,2] and some recent experimental results show that the thruster with hollow cathode is superior to that with conventional one in several respects as follows: thrust characteristics, thermal efficiencies, stability of operation, etc.[3,4] In the present experiments, operating characteristics under applied magnetic fields, such as the total reaction force (thrust), the reaction force which acts on electrode assembly or on magnetic coil, and the pressure at cathode tip, were evaluated for MPD arc thrusters with hollow and conventional cathode. And using these results, we investigated the difference between the physical processes involved in such thrusters.

Apparatus and Experimental Procedure

Figure 1 shows the MPD arc thruster used. The nozzle-shaped anode (copper) has a throat diam of 10 mm. Two types of cathode are used, which are a hollow cathode (tungsten tube of 6 mm o.d. and 3 mm i.d.) and a conventional cathode (6 mm diam tungsten rod with conical tip). In the case of conventional cathode, propellant is supplied through the port at the wall of arc chamber and in the case of hollow cathode, through the port at the cathode tip.

The electrode assembly was mounted on a parallelogram-pendulum thrust stand, and the electrical power for the arc was brought onto the stand through mercury pots. Deflection of the stand was sensed by a linear differential transformer. The total reaction force (thrust), T_t, was measured, mounting the magnetic coil on the electrode assembly. The reaction force which acts on the electrode assembly, T_{ea}, was measured, attaching the magnetic coil to the coil holder connected rigidly with a vacuum tank. In this case, the interaction force between current passing through the electrode assembly and applied magnetic field was excluded, evaluating it by reversing the direction of magnetic field. To check this technique, the interaction force was also measured at some operating points, using an electrode assembly in which the cathode is shorted to the anode. Using T_t and T_{ea}, the reaction force which acts on the magnetic coil, T_{mc}, can be obtained from $T_{mc} = T_t - T_{ea}$.

Two taps are provided for the measurement of pressure in the thruster. Tap 1, drilled through the insulator, senses the arc chamber pressure. In the case of conventional cathode, Tap 2 (2 mm i.d.) is located at the cathode tip, sensing a pressure which is approximately equal to the pressure at the center of cathode spot. In the case of hollow cathode, Tap 2, which is made of porcelain tube of 0.8 mm o.d. and 0.5 mm i.d., is located at 15 mm upstream from the tip in the passage of hollow cathode, because of experimental difficulty (see the magnified figure in Fig. 1). In the present experimental conditions, at the position of Tap 2, the dynamic pressure of flowing gas is less than one-tenth of the static pressure, and so it can be assumed that the pressure sensed by Tap 2 is approximately equal to the pressure of flowing gas.

All experiments used argon as the propellant and were conducted in a 0.5-m-diam by 1.2-m-long vacuum chamber. In these experiments the background pressure was maintained at about 5×10^{-2} torr. The experimental results shown in Ref. 5 suggest that the background pressure in the present experiments is not sufficiently low to obtain accurate data of performance; however, the results of the present experiments will be useful for the understanding of the physical processes involved. In the present experiments, arc current (I) was varied from 150 to 700 amp and propellant mass flow rate ($\dot{m}$), from 15 to 60 mg/sec, at applied magnetic field (B), measured at cathode tip, up to about 2000 gauss.

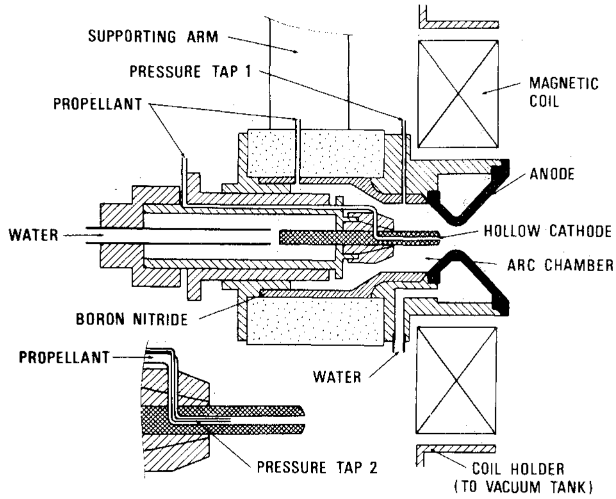

Fig. 1 MPD arc thruster used (hollow cathode is installed).

Results and Discussion

Figure 2 shows a typical example of the behavior of the total reaction force (T_t) and the reaction force on the electrode assembly (T_{ea}) vs the applied magnetic field, for the case of hollow and conventional cathode. In this experiment ($\dot{m}$: 30 mg/sec), the arc current was fixed at 700 amp, while the arc voltage increased, with increasing magnetic field, from 20 to 25 v

Received July 25, 1974.
Index categories: Electric and Advanced Space Propulsion; Plasma Dynamics and MHD.
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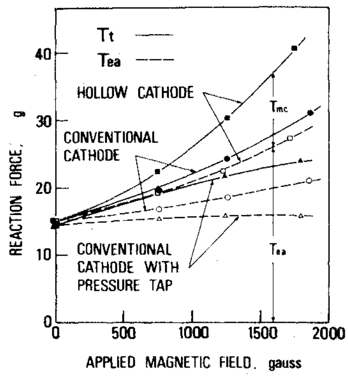

Fig. 2 T_t **and** T_{ea} **vs applied magnetic field (**$I = 700$ **amp and** $\dot{m} = 30$ **mg/sec),** $T_t = (T_{ea} + T_{mc})$**: total reaction force,** T_{ea}**: reaction force on electrode assembly,** T_{mc}**: reaction force on magnetic coil.**

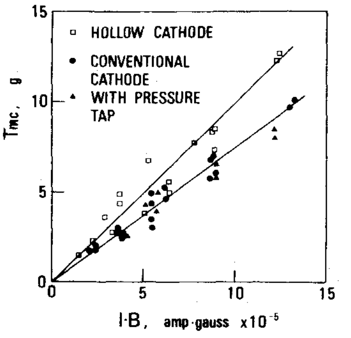

Fig. 4 T_{mc} **vs** IB **(I: 150–700 amp,** B**: 0–2000 gauss, and** $\dot{m}$**: 15–60 mg/sec).**

(hollow cathode) or from 20 to 22 v (conventional cathode). In the present experiments, it was seen generally that the thrust efficiency of the thruster with hollow cathode is superior to that with conventional one. It must be noticed here, that the increase of T_t, with increasing magnetic field, results from the increase of both T_{mc} and T_{ea}.

It is seen in Fig. 2 that, in the case of conventional cathode, T_{ea} decreases with the furnishing of cathode pressure tap under a relatively strong magnetic field, although some decrease of thrust caused by the furnishing of it is already reported in the case of large arc current under a weak magnetic field.[6] We confirmed experimentally that the difference in T_{ea} in the cases with and without pressure tap decreases in proportion to the square of arc current, approximately, and this matter suggests the role of the blowing contribution which is expressed as $(\mu I^2/4\pi) \ln (r_a/r_c)$.

Under the operating condition in the case of Fig. 2, when no magnetic field is applied, the values of T_{ea} are nearly same for the cases of hollow and conventional cathode. It must be noticed, however, that the increase of T_{ea}, with increasing magnetic field, in the case of hollow cathode is much larger than that in the case of conventional one. We confirmed experimentally that the difference in increase of T_{ea} between these cases does not decrease markedly with decreasing arc current. This fact may support the suggestion that the difference is related to that in the behavior of cathode-tip pressure for magnetic field strength, as described below.

Figure 3 shows the behavior of the pressures measured through the pressure taps vs the applied magnetic field in the case of the experiment shown in Fig. 2. It is seen that the pressure at the tip of conventional cathode, P_{ct}, decreases with increasing magnetic field, and such a tendency was noticed by Malliaris and a possible explanation was suggested.[1] In the case of hollow cathode, the pressure measured through Tap 2, P_c, increases with increasing magnetic field. This behavior of the pressure suggests that the cathode-tip pressure also increases with increasing magnetic field, provided that the effect of friction and the heating of flowing gas in the passage of hollow cathode are not varied so much with the change of magnetic field.[7] The increase of cathode-tip pressure, under the condition of subsonic flow, corresponds with that of impulse function, and hence, that of the reaction force on the cathode tip. For the increase of cathode-tip pressure in the case of hollow cathode, with increasing magnetic field, a tentative explanation is suggested here as follows: in the region of cathode tip, the flow of conducting gas has an outward radial velocity component, and, combined with the B_z field, it induces an azimuthal current j_θ. This current flows in such a direction that, when combined with B_z field, it provides a $j_\theta \times B_z$ force with inward radial direction.

It has been suggested by Cann that the reaction force on the magnetic coil, T_{mc}, increases linearly with magnetic field,[8] and, in the present experiments, it was found that T_{mc} can be expressed as a function of IB (see Fig. 4). In some thrusters, it is also shown that the increase of thrust with magnetic field, $T_t - T_t(B=0)$, can be expressed as a function of IB.[9] It is seen in Fig. 4 that the value of T_{mc} is not affected by the furnishing of cathode-tip pressure-tap in the case of conventional cathode, while, at a fixed value of IB, the value of T_{mc} for the case of hollow cathode is a little larger than that for the case of conventional one.

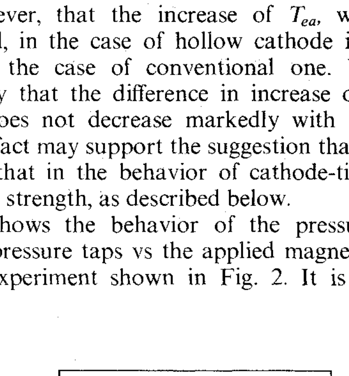

Fig. 3 P_{ac}, P_{ct}, **and** P_c **vs applied magnetic field (**$I = 700$ **amp and** $\dot{m} = 30$ **mg/sec),** P_{ac}**: arc chamber pressure,** P_{ct}**: cathode tip pressure (conventional cathode),** P_c**: the pressure in the passage of hollow cathode, 15 mm upstream from the cathode tip.**

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