Effects of the Hollow Cathode Discharge on Throttled Ion Thruster Performance

PAUL J. WILBUR*
Colorado State University, Fort Collins, Colo.

Theme

THE effect of cathode discharge region dimensions, baffle aperture area and flow distribution on throttled thruster performance are examined. A thruster operating mode wherein arc current does not vary significantly with arc voltage is identified, characterized and found to enhance performance.

Contents

A 20-cm-diam hollow cathode thruster[1,2] was modified so the diameter (D) and length (L) of the cathode discharge region could be varied by inserting sleeves within the cathode pole piece and moving the cathode axially in the sleeve in the manner suggested by the sketch at the top of Fig. 1. As the cathode region diameter was varied, the baffle diameter was also varied in such a way that the ratio of baffle aperture area to baffle area was fixed. The details of the thruster, instrumentation and the test facility are presented in Ref. 3. The effect of reductions in cathode discharge region dimensions on arc discharge losses at a fixed propellant utilization (η_u) and a fixed arc voltage (V_{arc}) are presented in Fig. 1. The data were obtained at 0.825a eq. and 0.465a eq. total flow conditions ($\dot{m}_t$) with the discharge losses being evaluated at 85% and 80% utilization, respectively. They show reductions in cathode discharge dimensions 1) do not affect arc discharge losses significantly at the higher flow condition except at small discharge region lengths where losses increase, and 2) do effect significant reductions in these losses at the lower total flow. The cathode flow rate ($\dot{m}_c$) required to achieve 37v arc voltage at the desired utilization was reduced significantly when the diameter of the cathode discharge (and correspondingly the baffle aperture) was reduced but was not affected as much by reductions in discharge region length. The performance gains achieved by these reductions in cathode discharge diameter and cathode flow rate are due to a reduction in arc current with no significant reduction in beam current at 37v arc voltage.

The use of a 3.5-cm-diam sleeve within the 6.35-cm-diam cathode pole piece resulted in a more peaked ion beam profile than that achieved with the pole piece alone confining the discharge apparently because of the introduction of primary electrons into the main discharge away from the critical field line. Substitution of a 3.5-cm-diam pole piece for the pole piece-sleeve assembly restored the flattness of the ion beam profile and gave essentially the same performance data as that presented in Fig. 1.

It has been recognized that reducing the cathode flow rate results in a reduction in discharge losses[4] and this may represent the mechanism by which the performance gains shown in Fig. 1 were achieved at the throttled flow condition. Attempts to reduce cathode flow with a large cathode discharge region were thwarted however by the onset of arc current oscillations which became more violent as cathode flow was reduced. When cathode discharge region dimensions were reduced, cathode flows could be reduced through that flow where the oscillations were now minor into an operating region which was again free from oscillations.

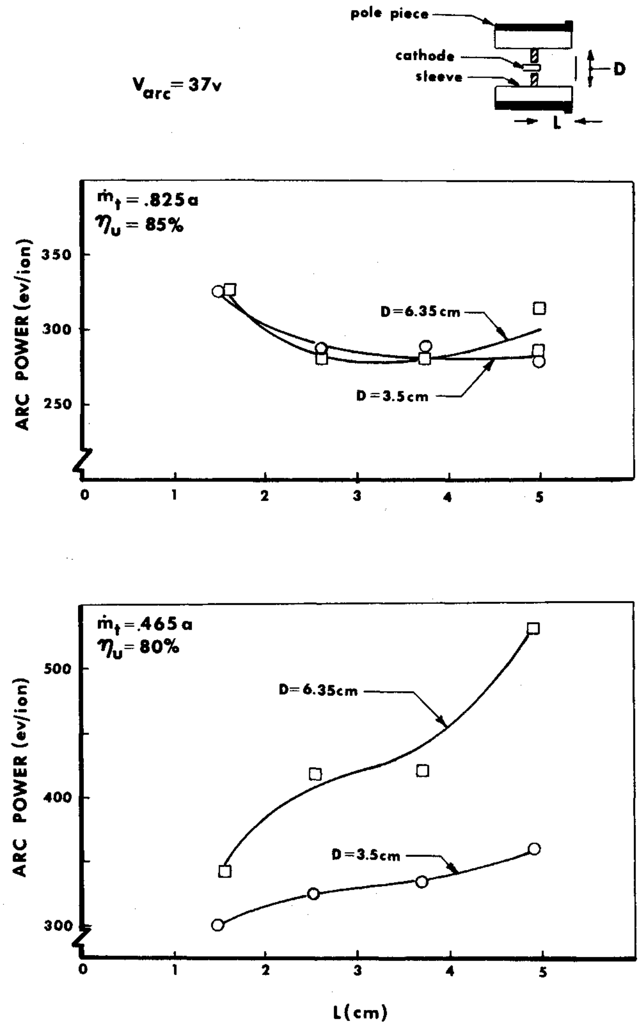

Fig. 1 Effect of cathode discharge dimensions on arc discharge losses.

Figure 2, which shows the arc voltage-current characteristics obtained with a small cathode discharge region (3.5 cm diam × 2.7 cm long) at the indicated cathode flow rates, provides some insight into the observed performance improvements. It shows a change in the character of these curves as cathode flow is reduced from 0.100 amp to 0.080 amp from one in which current varies with voltage (variable arc current mode) to one in which current does not vary with arc voltage (limited arc current mode). With further reductions in cathode flow the same limited variation in arc current is observed but the magnitude of the arc current is increased. Bechtel et al.[4] have identified arc current-voltage operating regions in which arc current varies with arc voltage (variable arc current mode) and arc current varies with essentially no change in arc voltage, and they point out the first of these exhibits lower discharge losses. Examination of

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* Associate Professor. Member AIAA.

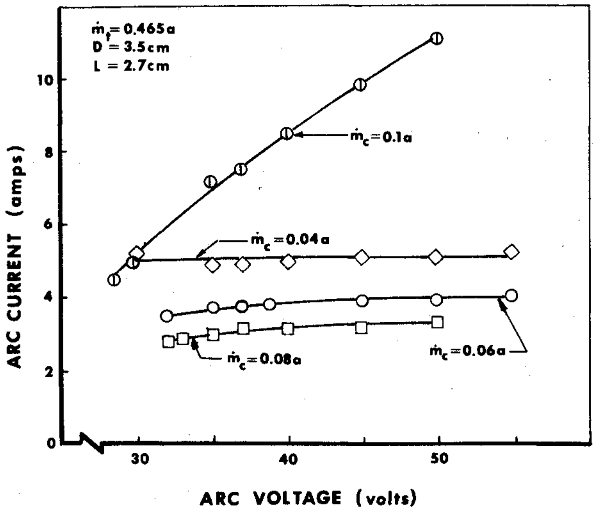

Fig. 2 Arc voltage—current characteristics.

performance curves corresponding to the data of Fig. 2 show the limited arc current mode not observed by Bechtel is characterized by still lower losses than the variable arc current mode.

Figure 3 shows the effect of cathode flow rate on arc current at 0.465 amp total flow with the small cathode discharge region. The transition between operating modes is seen to occur at about 80 mamp. It is characterized by a sudden rise in impingement current and in keeper voltage in addition to the drop in arc current shown in Fig. 3 as cathode flow is reduced. Performance curves show discharge losses at a given utilization are at a minimum at the onset of the limited arc current mode (i.e., when the cathode flow is just below the transition value). The cathode tip temperature is also a minimum at this condition, and this suggests it would also correspond to the longest cathode lifetime. Langmuir probe data obtained in the two modes facilitate characterization of the limited arc current mode as one of higher main discharge electron densities and lower cathode region electron densities than the variable arc current mode.

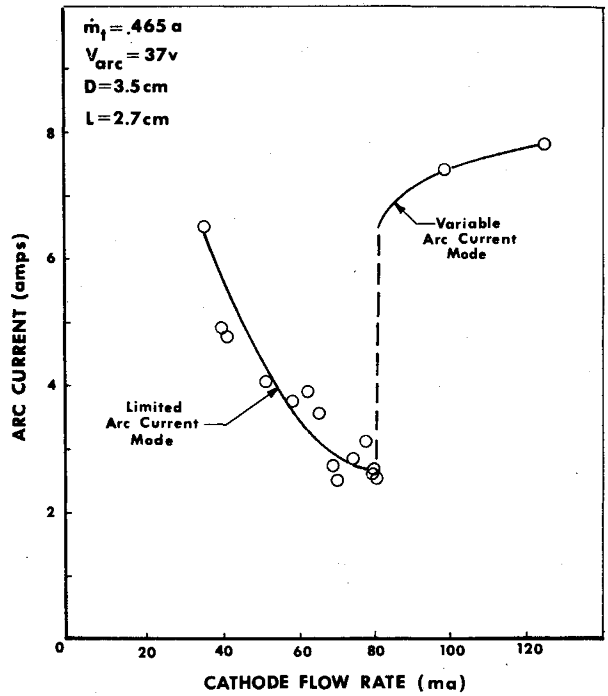

Fig. 3 Effect of cathode flow rate on arc current.

References

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[4] Bechtel, R. T., Csiky, G. A., and Byers, D. C., "Performance of a 15-Centimeter Diameter Hollow-Cathode Kaufman Thruster," TMX-52376, Jan. 1968, NASA.