Feasibility Studies on an Auxiliary Propulsion System Using MPD Thrusters

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Theme

A NUMBER of systems integration problems must be examined before a low-power MPD thruster system can be built for satellite station keeping and attitude control. Three such problems have been studied experimentally and are reported in this paper. They are: 1) varying the direction of the thrust vector, 2) reducing system power complexity to one power-supply bus, and 3) powering the thruster from rechargeable batteries. Lightweight tank storage of the xenon propellant is examined analytically.

Content

Figure 1 shows the MPD thruster described by Burkhart[1] but with the exhaust end coil removed and replaced by two 100-turn skewed coils for thrust vectoring. The normals to the planes of the coils are each 15° from the thruster center line. The thruster was operated such that the two normals to the coil planes and the thruster center line were in the same geometrical plane. This geometrical plane was placed horizontal for all testing. Vectoring was achieved by unbalancing the currents in the two coils.

When thrust is desired, an electric circuit is energized which a) energizes the thruster magnets, b) opens solenoid valves in the propellant feed system supplying xenon to the anode and hollow cathode of the thruster, and c) impresses a high starting voltage across the anode and cathode initiating the discharge. A steady electrical discharge is maintained until the end of the thrusting period. Thrust results from the acceleration of ionized xenon by the axial plasma electric field that is produced in the thruster's magnetic nozzle.

An ion collecting (molybdenum button) probe was used to determine ion exhaust beam flux profiles and to establish the presence of thrust vectoring. Figure 2 shows a typical profile, obtained for a 3.5° shift in thrust vector. This shift resulted from a corresponding shift of 3.5° in the axis of the magnetic field. A one-to-one correspondence in thrust vector shift to magnetic field shift was found up to $\pm 5°$. It was established that the mild steel pole pieces of the present design (Fig. 1) limit the magnetic field shift (hence also the thrust vector) to $\pm 5°$. For thrust vectoring in two directions, a minimum of one additional skewed coil must be added.

Gimbaling the cathode tip position through an arc of $\pm 20°$ does not disturb the shape or position of the ion flux distribution. Hence, gimbaling the downstream cathode does not produce thrust vectoring.

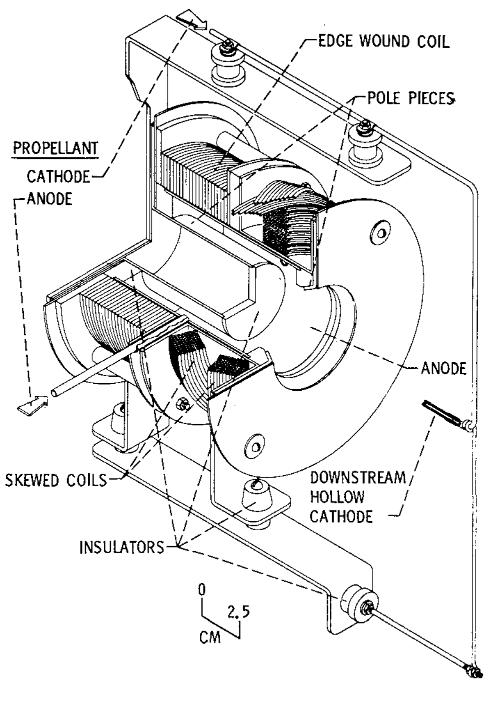

Fig. 1 Low-power MPD thruster with skewed magnet coils.

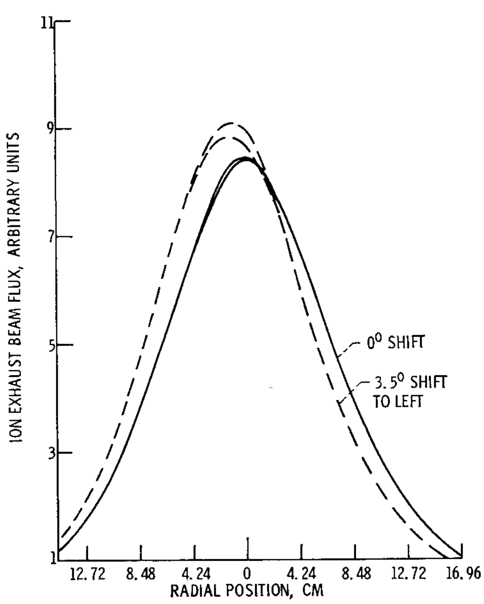

Fig. 2 Plot of ion exhaust beam flux vs radial position, left and right of thruster axis.

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Figure 3 shows the circuit used to achieve one power-supply operation of the MPD thruster. The thruster magnets and solenoid valves are placed in series with the power leads. A 0.05 μf capacitor is placed around the magnets to limit the peak start-up voltage. The circuit branch in parallel with the thruster is for start-up. A plenum of approximately 1.0 cc is formed in each propellant line between the calibrated leak and solenoid valve. At time zero these plenums are filled to upstream pressure (taking 30 sec). Next the transistor switch is closed, thus opening the two solenoid valves and storing energy in the thruster magnetic field. When the gas pulse peaks in the cathode region, 22 millisec later, the transistor switch is reopened generating an 800 v peak pulse (for a supply bus of 200 volts d.c.) and ignition occurs.

In the steady state, thrust performance was evaluated for this configuration. The thrust stand, vacuum facility, type of measurements, and equations for data reduction are identical to Burkhart.[1] Thrust efficiency was much like that of Burkhart[1] but a bit lower, probably due to the weaker magnetic field existing when coils pass discharge current. This condition can easily be corrected by a slight resizing of coils. The series magnet arrangement was found to make the steady state discharge very stable and eliminated the need for the ballast resistor used in Burkhart.[1]

Interfacing an MPD thruster with a power supply consisting of rechargeable nickel-cadmium battery cells may be desirable on many satellites where batteries are already available but are not in continuous use. Station-keeping functions could then be carried out by low-duty cycle MPD thrusters powered from these batteries at times when other spacecraft power drains are minimal. For some missions, batteries may intentionally be added to the thrusting system, e.g. if station-keeping functions are to be done when the spacecraft is in the Earth's shadow. Possible power conditioning advantages also arise when a set of batteries are used. For example, if the batteries are charged in parallel at spacecraft voltage and then series connected for thruster operation, the batteries plus switching and charging circuits replace a power conditioning system. Since a battery system could be electrically disconnected from the spacecraft solar array during thruster operation, such a system also minimizes any potential electrical coupling between a thruster and other spacecraft loads.

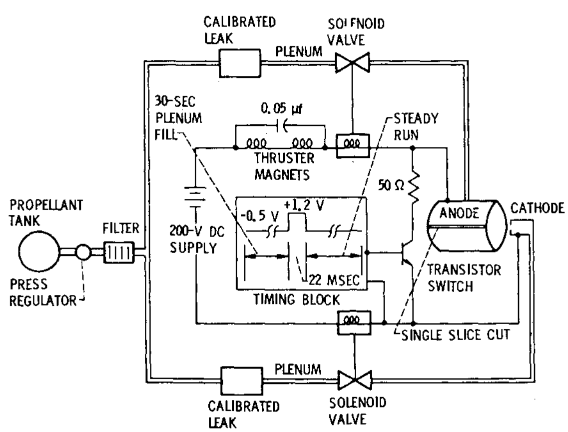

Fig. 3. MPD thruster operation from a single power supply.

A 168 volt (nominal value) rechargeable nickel-cadmium battery system was constructed by placing 140 sub-C cells (45 g mass per cell) in a single series string. Battery charging was carried out by switching the large series string into seven 20-cell (24 volt, nominal) strings and then charging the seven strings in parallel. Thruster performance with the battery was found to be very stable and quite close to the data of Burkhart.[1] No battery damage or degradation resulted from thruster start-up transients.

Using a stress analysis procedure almost identical to that for studies of cold gas jet propellant tanks,[2] it was concluded that a spherical xenon propellant tank can be constructed of titanium alloy type 6 Al-4V and will weigh about 13% of the propellant weight. Tank diameters for typical auxiliary propulsion missions are of the order of 20 cm with wall thicknesses (assuming a safety factor of 2.2) of approximately 0.115 cm. Initial propellant pressure would be at 100 atm for storage temperatures up to 50° C.

For the same titanium alloy but using the technique of fracture mechanics,[3] a weight 9% of propellant weight can be realized. Using the more conservative stress analysis technique but by going to a more advanced technology material such as a filament-wound epoxy composite,[2] a reduction in tank weight to 9% of propellant weight might also be realized. The lack of data on filament-wound epoxy composites using fracture mechanic techniques makes it impossible to evaluate such a technique for design of a filament-wound epoxy composite tank.

It is quite evident that many of the MPD thruster systems integration problems have very feasible solutions. However. the overall problem of thruster life must still be solved.

References

[1] Burkhart, J. A., "Exploratory Tests on a Downstream-Cathode MPD Thruster," *Journal of Spacecraft and Rockets*, Vol. 8, No. 3, March 1971, pp. 240–244.

[2] Anon., "Spacecraft Attitude Control Gas Systems Analysis," SSD-70172R, NASA CR-86661, April 1967, Hughes Aircraft Co., El Segundo, Calif.

[3] Holcomb, L. B., private communication of June 23, 1971, Liquid Propulsion Section, Jet Propulsion Lab. of the California Institute of Technology, Pasedena, Calif.