Exhaust Flow and Propulsion Characteristics of a Pulsed MPD-Arc Thruster

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Theme

THE influence of an auxiliary magnetic field on the exhaust characteristics and performance of a pulsed, nitrogen, MPD thruster is examined. The impact pressure is measured in the exhaust at a station located 30 cm downstream from the thruster source. The temporal history at selected radial positions is described and is used to determine thrust vs time for various thruster parameters, with and without an auxiliary magnetic field. Measured thrust is compared to theory for the self-field case. Incorporating number density data of earlier work with the impact pressure data, exhaust velocity profiles and mass flow rates are determined.

Contents

Measurements of exhaust impact pressure were undertaken to more directly determine thruster-related performance and to provide basic data on arc-powered exhaust flow, important in other applications such as high-density plasma injectors. Earlier impact pressure measurements[1] identified starting transients in the exhaust of a single-shot, pulsed discharge. Transient wave structures were found to dominate for at least 100 μsec. In the present work, a newly designed piezoelectric pressure probe[2] was used to measure not only the starting transient but also the impact pressure in the following exhaust flow.

Megawatt-level MPD thrusters have been operated single-shot, being powered for a fraction of a millisecond. Such a discharge cannot be expected to simulate steady-state operation because of much longer thermal time constants for the electrodes and because of the long time constant of the mass flow settling time that is required in the arc chamber. However, when a square wave current drive is applied for short periods (≈ 1 msec) and some exhaust characteristics appear relatively constant, such behavior has been termed "quasi-steady." In the present experiment the thruster is powered by a crowbarred capacitor bank, producing an almost linear-ramp decay in driving current for about 0.5 msec after reaching peak current in 20 μsec. As in the square wave current drive case, the ramp current drive of this experiment produces an exhaust flowfield after a starting transient, followed by a flow period, called the plasma flow region, during which flow properties decay similarly to the current and mass flow decays.

Figure 1 presents the temporal variation of the exhaust impact

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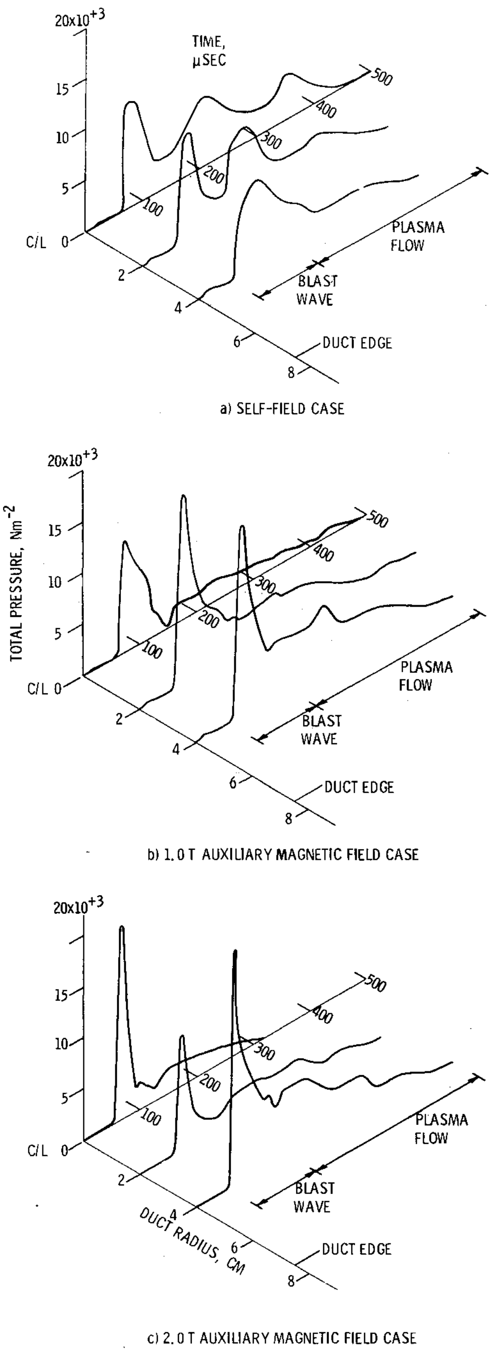

Fig. 1 Impact pressure profiles (20.0 ka peak current case).

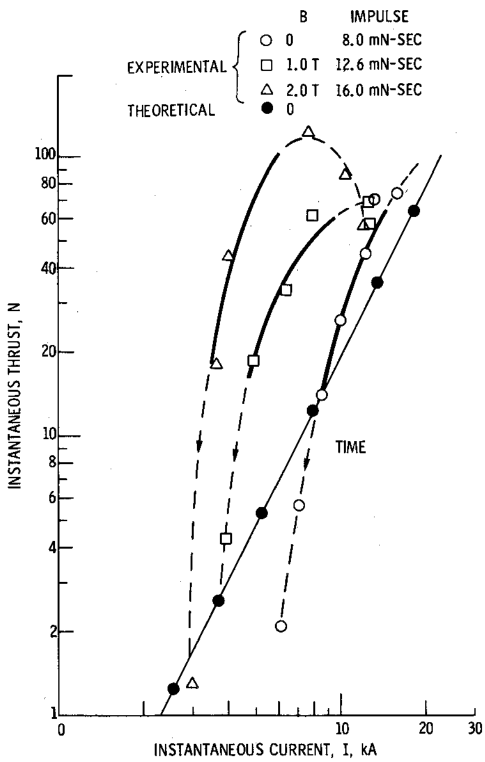

Fig. 2 **Instantaneous thrust vs instantaneous current (20.0 ka peak current case).**

pressure at 30 cm downstream from the thruster anode, for the 20 ka peak ramp current case, for various auxiliary magnetic fields, 0, 1.0, and 2.0 *T*, and for three different exhaust duct radial positions (0, 2, and 4 cm). The magnetic field is generated by a 11.5 cm i.d. superconducting torus, with axis along the exhaust vessel axis and situated at the source plane. The pressure pulses demonstrate a common profile: the initial pressure pulse[1] (8–10,000 N/m^2, 20 to 70 μsec wide) with lower and varying pressure (2–7000 N/m^2) thereafter for 200 μsec. The present effort is concerned primarily with the plasma flow occurring after the initial blastlike pulse. For the $B = 0$ case (a), the plasma flow impact pressure profile decays with radius, the maximum being at centerline. By contrast, for the $B = 1.0$ T case (b), the plasma flow pressure increases with radius at a given time. This behavior is further exaggerated in the $B = 2.0$ T case (c). For both magnetic nozzle cases, the pressure on centerline is less than for the self-field case. The reduced density portion (or "hole") in the exhaust on centerline was first described in terms of number density in earlier work[3] and now also appears as reduction in impact pressure. For the 20 ka case, the time to reach peak impact pressure in the plasma flow is about 200 μsec at 30 cm downstream from the thruster anode. Data were also taken for the 11.2 ka peak ramp current case and are generally a factor of two lower, with the same trends being evident.

One benefit of pressure probing the plasma flow portion of the exhaust is that the impact pressure measurements vs radius and time can be integrated over the exhaust area to determine thrust vs time and impulse bit. These were calculated for various thruster parameters, with and without auxiliary magnetic field. Small gas dynamic corrections to convert measured pressure to axial momentum were neglected. These instantaneous thrust magnitudes were also correlated with the instantaneous value of discharge current (Fig. 2) for the 20 ka peak ramp current case, with auxiliary magnetic field as the parameter. Time during the discharge event (decreasing current) progresses downward in the figure. The darkened curves are for the data of interest. The lighter portions of these curves are starting transients and nonmatched lower current conditions.

Because a puff propellant valve is used, the mass flow rate through the thruster decays with time during the powering cycle. This valve introduces a 90-μsec duration puff of propellant into the arc chamber. After a 650-μsec settling time, the arc is powered. At the 30-cm station the pressure measurements combined with number density data indicated that the plasma mass flow rate decayed from 1.6 to 0.3 g/sec of nitrogen during the period from 150 to 400 μsec. If the thruster is not powered, the measured cold flow mass flow rate during the time corresponding to the darkened curves of Fig. 2 would have decayed from 2.2 to 1.8 g/sec.

Also presented in Fig. 2 is the variation of theoretical self-field electromagnetic thrust[4] vs current. The period of higher current flow with $B = 0$ is seen to agree reasonably well with the steady-state theory. The data show clearly the role that an auxiliary magnetic field can play in increasing the thrust for a given discharge current. Thrust monotonically increases with field. Impulse bit ranged from 0.003 to 0.018 nsec depending on auxiliary magnetic field.

The time-varying pressure data of the present report were combined with the number density data of Ref. 3 to provide a calculated instantaneous velocity for the plasma flow portion of the exhaust. The velocities ranged from 2×10^4 to 7×10^4 m/sec and were found to be functions of radial position as well as auxiliary magnetic field. For the self-field case, the experimentally determined velocities agree with the theory of Ref. 4 where acceleration is produced entirely by electromagnetic force.

References

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