Establishment of Quasi-Steady Operation in a Pulsed MPD Arcjet

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Theme

EXPERIMENTAL studies were made on the properties of the plasma stream emanating from a pulsed MPD arcjet, expecially with respect to the quasi-steady operation.[1-4] From diagnostic measurements, a large fraction of the discharge current was found to extend in the plasma downstream of the electrodes. It has been questioned whether this extending current is desirable in the operation of an MPD arcjet. The purpose of the present work is to answer this question with respect to the establishment of the quasi-steady operation. The quasi-steadiness of the operation should be inferred from the properties of the plasma stream as well as the current and voltage of the arc discharge.

Contents

The pulsed MPD arcjet used in the present experiment is similar to that described in Ref. 1. The maximum discharge current is 12.5 ka and the maximum power is about 2 Mw. The discharge current and voltage are steady and last for more than 800 μsec. An annular coil is mounted concentric to the arcjet system with its center plane at the front surface of the anode. The maximum strength of the magnetic field is 20 kgauss at the center of the coil. The working gases are hydrogen, helium and argon. The mass-flow rate $\dot{m}$ is variable—for instance, from 50 mg/sec to 300 mg/sec for hydrogen. The MPD arcjet is installed on an end flange of a vacuum tank which is 1.5 m in diameter and 2.8 m in length. The metal surface inside the tank is completely covered with Mylar sheet in order to prevent the discharge current from flowing in the tank wall. The tank pressure before each run is about 10^{-5} torr.

The working gas injection phenomena was studied to determine the trigger time of the arc discharge so that the amount of the neutral gas injected before triggering the arc discharge could be minimized, and also to find how a quasi-steady injection of the working gas is established in the discharge region. To this end, the pressure was measured in the jet of neutral gas by a newly developed fast ionization gauge.[5] From the gauge signal, the gas pressure was found to rise in about 600 μsec after opening the gas ports and reach a constant value. A steady state lasts for 3 $\sim$ 5 msec. Figure 1 demonstrates the time variation of the pressure distribution along the center line in the jet of neutral argon. The origin of time in this figure is taken arbitrarily and the normal trigger time is 1 msec in this case. As the time increases, the experimental curve tends to follow a Z^{-2} law. The coordinate Z is taken along the center line and measured from the anode surface. The pressure dependence on Z^{-2} law is predicted from the spherically expanding steady flow at frozen molecular speed. At the normal trigger time—i.e. 1 msec—the steady flow is found to be established as far downstream as $Z = 30$ cm. In the case of hydrogen and helium, the steady flow is achieved several times faster than in the case of argon because of their greater molecular speeds.

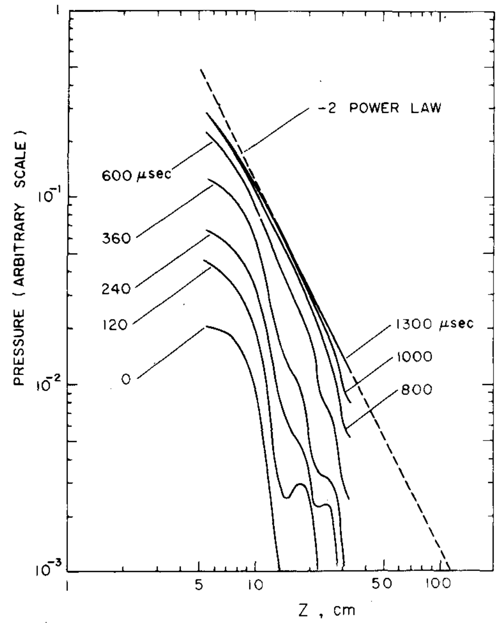

Fig. 1 Time variation of pressure distribution along center line, argon.

The ion number density was measured by the Langmuir probe. The probe surface is plane and parallel to the flow. The probe is biased strongly negative. The electron temperature is found to be 4 ev typically and rather insensitive to the operation conditions. Figure 2 is a matrix representation of the ion density trace: the column refers to the probe location and the row refers

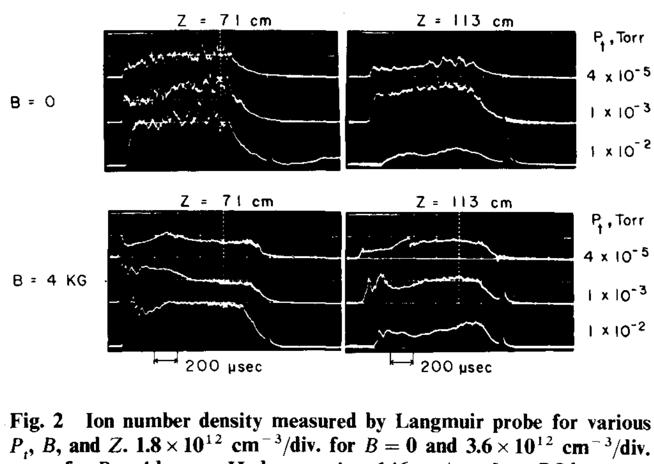

Fig. 2 Ion number density measured by Langmuir probe for various P_t, B, and Z. 1.8×10^{12} cm^{-3}/div. for $B = 0$ and 3.6×10^{12} cm^{-3}/div. for $B = 4$ kgauss. Hydrogen: $\dot{m} = 146$ mg/sec, $I_A = 7.5$ ka.

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Index categories: Electric and Advanced Space Propulsion; Plasma Dynamics and MHD.

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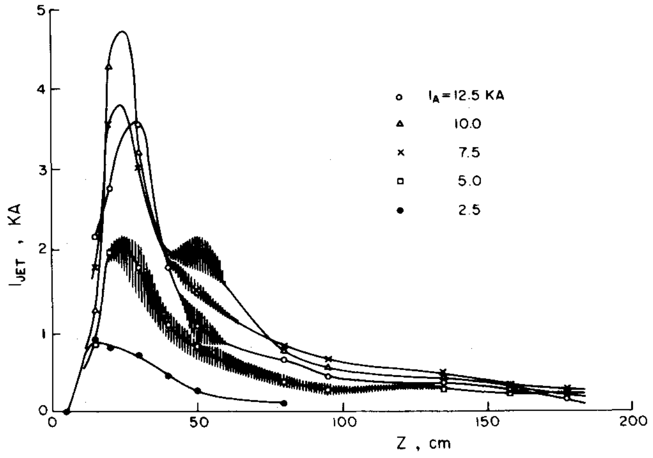

Fig. 3 **Current extending in plasma plume. Hydrogen: $\dot{m}$ = 146 mg/sec, B = 6 kgauss.**

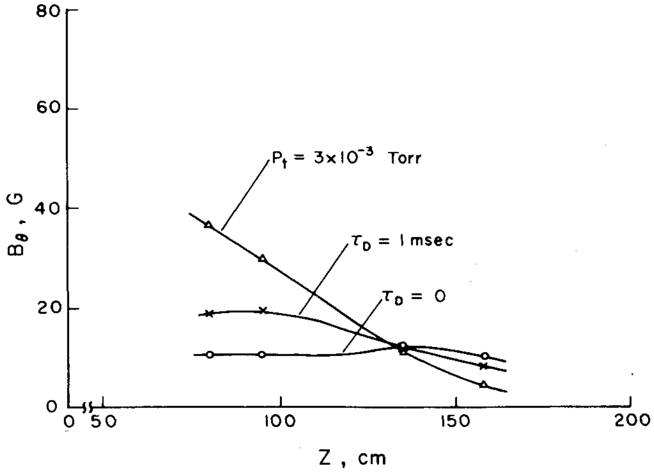

Fig. 4 Effects of initial tank pressure and trigger delay on azimuthal magnetic field. $P_t = 2\times10^{-5}$ Torr for $\tau_D = 0$ and $\tau_D = 1$ msec. Hydrogen: $\dot{m}$ = 146 mg/sec, I_A = 7.5 ka, B = 4 kgauss.

to the magnetic field B. The initial tank pressure P_t is taken as parameter. The horizontal sweep of the traces is triggered by the pulse that triggers the arc discharge. The time of the plasma front arrival at the probe τ_F is defined as the moment when the ion density reaches steady value. The smaller τ_F simply means a faster speed of the plasma front. Apparently the front speed is slowed when the tank pressure is raised. In addition, as the tank pressure is increased to 10^{-2} torr, the rising of the ion density at the plasma front becomes gradual when the magnetic field is absent. When the magnetic field is applied, not only is the plasma front accelerated but also the ion density rises more steeply. As for the final part of the trace, the density for $B = 0$ begins to fall off the steady value earlier and decays more slowly than that for $B = 4$ kgauss. With an applied magnetic field, the ion density has a longer steady state and falls off more rapidly. From all these results, the magnetic field is concluded to contribute significantly to increasing the duration of steady state, even when the tank pressure is increased.

When the trigger delay τ_D from the normal trigger time is 1 msec, significant increase of τ_F is observed downstream of $Z \simeq 1$ m. From the results of the working gas injection, the steady flow of the neutral gas is considered to be established as far downstream as $Z \simeq 1$ m for hydrogen at the normal trigger time. Therefore, it is reasonable that the effect of the trigger delay becomes significant downstream of $Z \simeq 1$ m.

From the magnetic probe and Rogowski coil measurements, a large fraction of the discharge current was found to flow in the plasma plume. It may well be expected that the plasma front could be accelerated by the extruding current,[6] and also that the operation parameters like B, P_t, and τ_D influencing the plasma front speed might influence the current extrusion. The results of the magnetic probe and Rogowski coil measurements are summarized in Fig. 3. The current I_{JET} is defined as the total current through a circle of 10 cm diam perpendicular to and concentric with the center axis. As shown in this figure, almost 50% of the discharge current flows out of the arcjet when the magnetic field of 6 kgauss is applied. When the magnetic field is absent, the extending current is vanishingly small, and the measured I_{JET} falls far below the lowermost curve in this figure. The vertical spines on the experimental curve represent the oscillations of the azimuthal magnetic field, and their heights denote the amplitudes of the oscillation. The observed frequency of the oscillation ranges from 20 to 100 kHz. The ion cyclotron frequency referred to the conditions at $Z = 50$ cm falls within this range.

Figure 4 demonstrates how the azimuthal magnetic field B_θ measured at 5 cm from the center line is affected by the initial tank pressure P_t and the trigger delay τ_D. This magnetic field B_θ is equivalent to I_{JET}. When the tank pressure is increased from 2×10^{-5} torr to 3×10^{-3} torr, B_θ is increased upstream of $Z = 130$ cm, but rapidly decays downstream. The trigger delay is found to cause similar effects to the increased tank pressure. From the radial distribution of B_θ, the extending current is found to be enhanced at $Z \simeq 1$ m by increasing the tank pressure. These results suggest that the extending current is increased to drive an extra amount of the working gas.

From all the results, the following situation can be expected. Even when the working gas is injected before triggering the arc discharge, the diffusing front of the neutral gas, which moves much slower than the plasma front, is caught by the ionizing front accompanied with the extending current. The preinjected gas is thus effectively ionized and accelerated. Therefore, it is concluded that the extending current is advantageous as far as the establishment of quasi-steady operation is concerned.

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