DIAGNOSTIC EXPERIMENT AND NUMERICAL ANALYSIS OF ONE-DIMENSIONAL MPD FLOWFIELDS

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Abstract

A quasisteady magnetoplasmadynamic (MPD) arcjet with 30-cm-class long electrodes, i.e., with a long acceleration zone almost realizing a one-dimensional channel flow, was developed to examine current distributions in the discharge chamber. It was found that the current patterns depended strongly on gas species and discharge current levels regardless of electrode length and that the feature on current conduction below the theoretical critical current was divided into two cases, depending on monatomic and molecular gases. These experimental results agreed with analytical ones. Furthermore, in the transition to a quasisteady current pattern at discharge start the travel of a current sheet was observed. The velocity for each gas increased linearly with the discharge current although it was much smaller than the quasisteady exhaust velocity evaluated by a pendulum method. At a constant discharge current, the motion of the current sheet depended only on molecular weight.

I. Introduction

The quasisteady magnetoplasmadynamic (MPD) arcjet is a promising propulsion device which utilizes principally electromagnetic acceleration of the interaction between discharge current of kiloamperes and azimuthal magnetic field induced by the discharge current. Various propellants, such as light gases of H_2 and He, heavy gases of Ar, Xe and SF_6, and waste ones in space stations etc, can be used because the thrust depends only on the discharge current and does not basically on propellant species for electromagnetic acceleration. However, in the accelerator channel of the discharge chamber, complicated chemical reactions including dissociation and ionization are expected to occur together with acceleration process. Therefore, it has been recognized that the performance characteristics on the discharge voltage, thrust, thrust efficiency and electrode erosion depend on propellant species.[1-4]

One or two dimensional analyses of MPD arcjet flowfields have been made by many researchers[5-7], in which the electric field is determined by the point of the sonic or the magnetosonic singularity. These calculated results are significant for optimum design of MPD arcjet chambers and for understanding of the discharge feature and the acceleration mechanism. Particularly, the streamwise discharge current distribution is important because the processes of heating and acceleration are determined positively by the current pattern.[2,4,6-9]

In the present paper, discharge current distributions are examined using an MPD arcjet chamber with long electrodes, i.e., with a long acceleration zone almost realizing an one-dimensional channel flow. The experimental results are compared with analytical ones.

II. Experimental Apparatus

The coaxial MPD arcjet newly designed, as shown in Fig.1, is provided with a straight anode 50 mm in diameter × 280 mm deep. The long electrode with the long acceleration zone almost realizes an one-dimensional channel flow. The anode made of copper is divided axially into 14 anode parts, each of which is electrically insulated to one another. The current entering each anode segment is measured with a Rogowski coil, as shown in Fig.2, to examine current fractions on the anode, i.e., to infer the current pattern in the interelectrode region. Also, the cylindrical cathode 9.5 mm in diameter × 250 mm long, respectively, are made of thoriated tungsten.

The MPD arcjets are provided with two auxiliary electrodes at floating potential. The floating electrodes are useful in relaxing current concentration near the anode and cathode bases at the initial state of the discharge. Gases are injected with a cathode slit / anode slit ratio of 50/50 into the discharge chamber through a fast acting valve (FAV) fed from a high pressure reservoir. The rise time and width of the gas pulse, measured with a fast ionization gauge, are 0.5 and 6 msec, respectively. The mass flow rates are controlled by adjustment of the reservoir pressure and the orifice diameter of the FAV.

The main power-supplying pulse forming network (PFN), which is capable of storing 62 kJ at 8 kV, delivers a single nonreversing quasisteady current of maximum 27 kA with a pulse width of 0.6 msec. A vacuum tank 0.6

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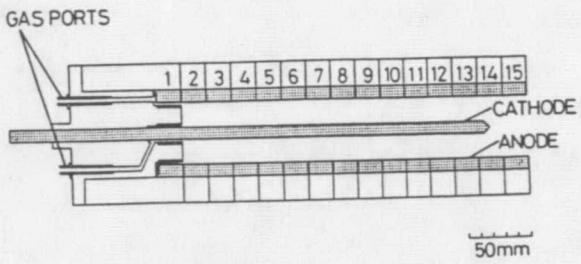


Fig.1 Cross section of MPD arcjet chamber with long electrodes.

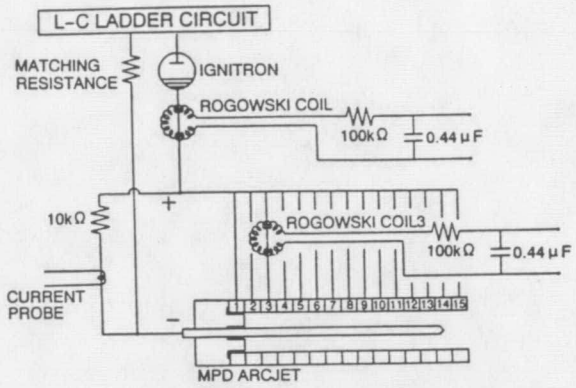


Fig.2 Electrical circuit for measurement of current fractions on anode.

m in diameter × 5.75 m in length, where the arcjet is fired, is evacuated to some 10^{-3} Pa prior to each discharge.

Discharge current is measured with a Rogowski coil calibrated with a known shunt resistance. Voltage measurement is performed with a current prove (Iwatsu CP-502), which detects the small current bled through a known resistor (10 kΩ) between the electrodes.

Ⅲ. Experimental Results and Discussion

Quasisteady Current Distributions

The present experiments are conducted with five gases of helium, argon, hydrogen, nitrogen and mixture of nitrogen and hydrogen simulating fully decomposed hydrazine at discharge currents of 5, 10 and 15 kA. The mass flow rate for each gas is set up at a corresponding critical current of about 10 kA, which is derived theoretically from the rule of minimum input power or Alfvén's critical ionization velocity.

Figures 3–7 show the current fractions distributed on the segmented anode. The current fractions on the anode segment No.15 are highest for all gases; i.e., the current concentrates near the downstream end. Furthermore, the current fractions of No.15 for molecular gases are much larger than those for monatomic gases regardless of particle weight, and in other words for monatomic gases the current is distributed in the intermediate region of the anode although for molecular gases the current hardly exit in the region. These are explained from MPD flowfield analyses as follows.[6,7] The ionization process of molecular gases is slower than that of monatomic ones owing to a time lag due to dissociation process at low current levels. Therefore, the ionization process of molecular gases starts near the arcjet exit. Also, the current fractions of No.15 decrease with increasing discharge current, and the current is distributed in more upstream segments. Hence, these features on current conduction are found to depend strongly on gas species and discharge current levels.

In previous papers[6,9], we reported current distributions in a short-electrode MPD discharge chamber. The MPD arcjet had a anode 50 mm in diameter × 70 mm long and a cathode 45 mm long. The anode diameter is equal to that of the long-electrodes MPD chamber used for the present study. The current patterns were measured with

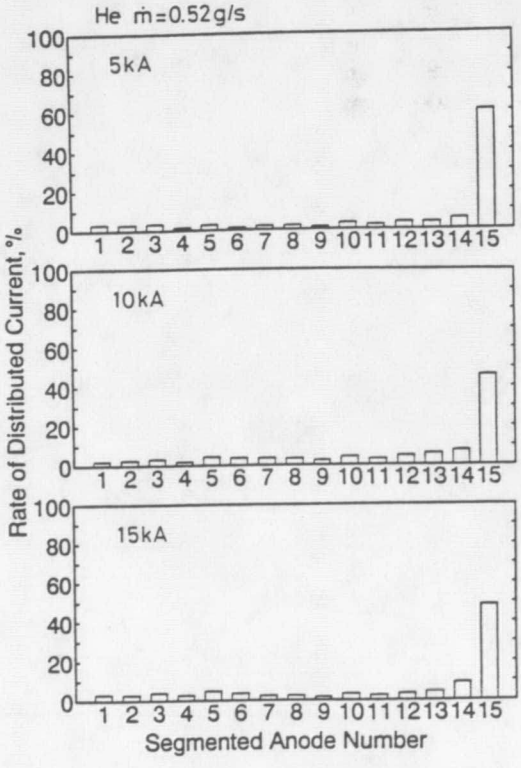


Fig.3 Current fractions on anode for helium.

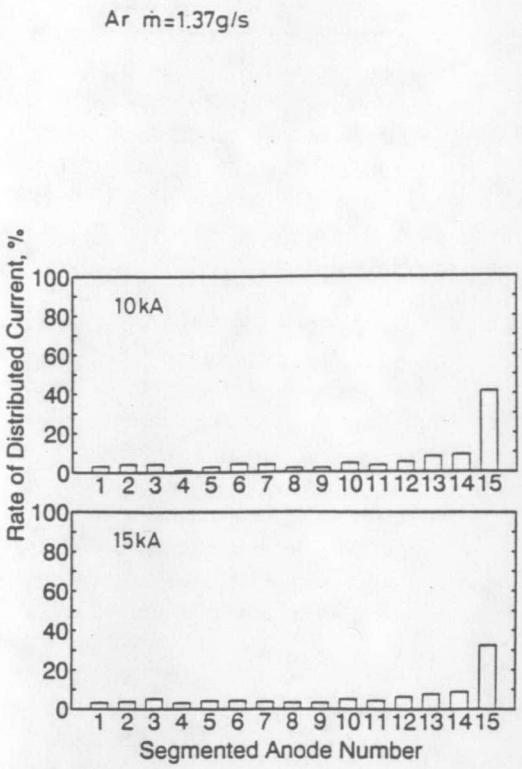


Fig.4 Current fractions on anode for argon.

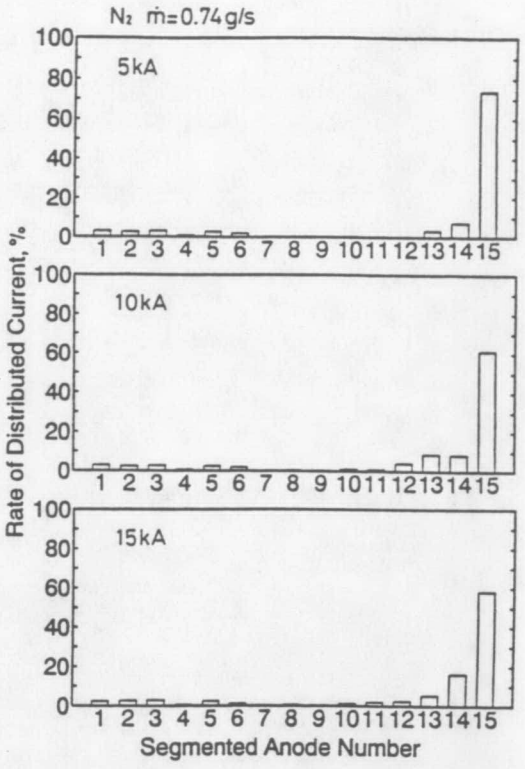


Fig.6 Current fractions on anode for nitrogen.

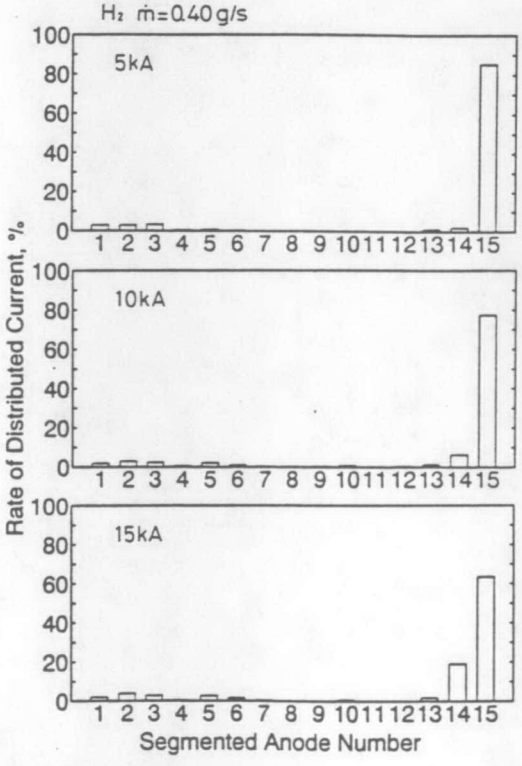


Fig.5 Current fractions on anode for hydrogen.

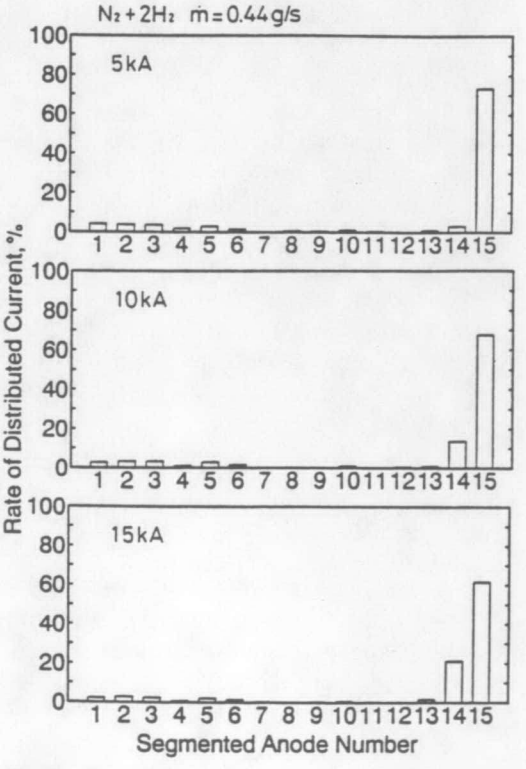
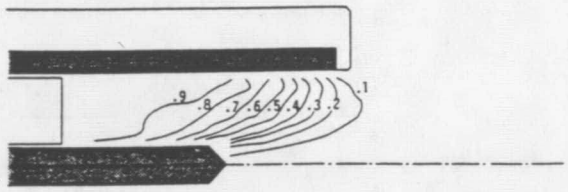
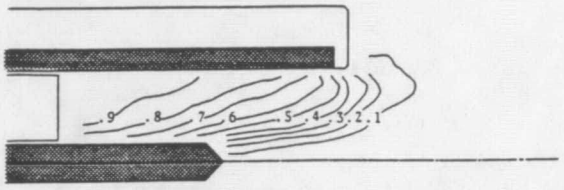


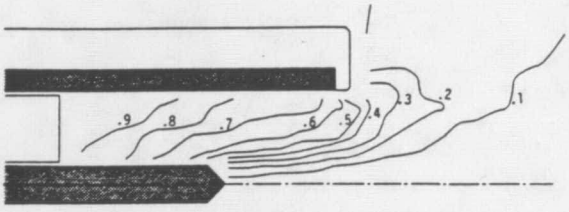
Fig.7 Current fractions on anode for mixture of nitrogen and hydrogen.



(a) 5 kA.

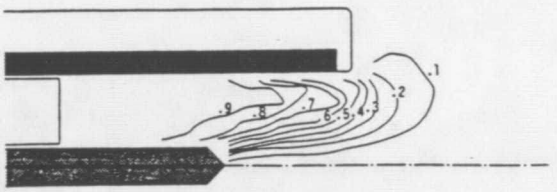


(b) 10 kA.

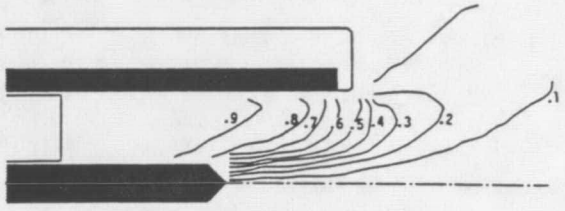


(c) 15 kA.

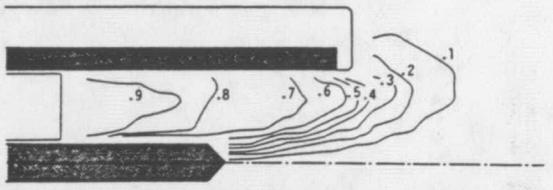
Fig.8 Spacial current patterns in MPD discharge chamber with short electrodes for helium. These patterns were measured with a Bθ probe.



(a) 5 kA.



(b) 10 kA.



(c) 15 kA.

Fig.9 Spatial current patterns in MPD discharge chamber with short electrodes for hydrogen. These patterns were measured with a Bθ probe.

a Bθ probe. The typical enclosed current contours for the short-electrode arcjet chamber are drawn in Figs.8 and 9, where the number of the given line to the discharge current. It is shown that the current patterns are divided into two classes, particularly, at the low current level. For the monatomic gases such as He and Ar, the discharge occurs mainly inside the discharge chamber, and the current flows almost uniformly over the side surface of the cathode. For the molecular gases such as H_2 and N_2, the given contours are withdrawn downstream, and most of the discharge current enters the regions of the cathode tip and the end surface of the anode. As the discharge current increases, the current patterns for the molecular gases are similar to those for the monatomic gases; that is, the zones of current conduction spread widely from the inside of the arcjet chamber to the downstream region. Accordingly, these features on current conduction for the short-electrode MPD chamber agree with those for the long-electrode arcjet chamber; i.e., the electrode length does not influence them, as expected from several MPD flowfield analyses.

Transition to Quasisteady Current Pattern at Discharge Start

Electrical breakdown is expected to occur near the upstream end in the discharge chamber just after applying a high PFN-charging voltage between the electrodes. The rise time of the discharge current is about 40-50 μsec. In the transition to a quasisteady current pattern in discharge start, the current waveforms are observed on anode segments as shown in Figs.10-12. It is inferred that a current sheet, which we call the current spike observed, is generated on the upstream segments and travels downstream on the electrodes. After the travel of the current sheet, a quasisteady current distribution is created. Generally, a practical MPD propulsion system is provided with an auxiliary electrode supplied an ignition pulse at the upstream end of the discharge chamber.[3] In these systems the travel of current sheets is expected to occur as well as the present experimental system.

The velocity of the current sheet can be evaluated from the delay time of the current spike observed on

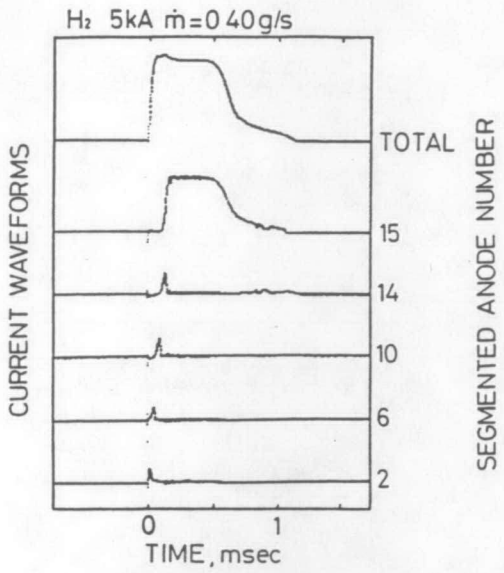


Fig.10 Current waveforms on anode segments for hydrogen at 5 kA.

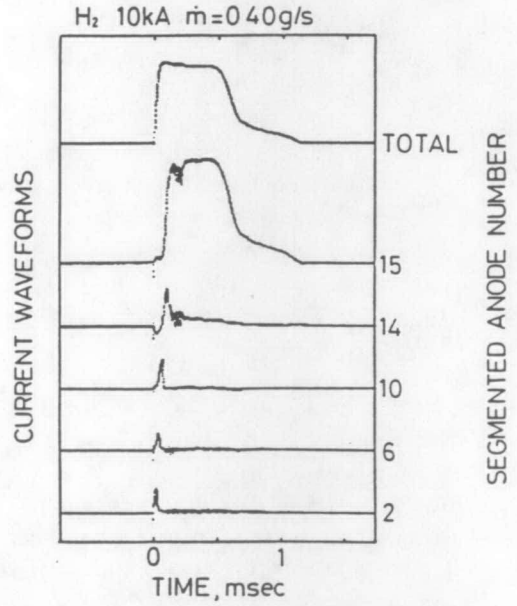


Fig.11 Current waveforms on anode segments for hydrogen at 10 kA.

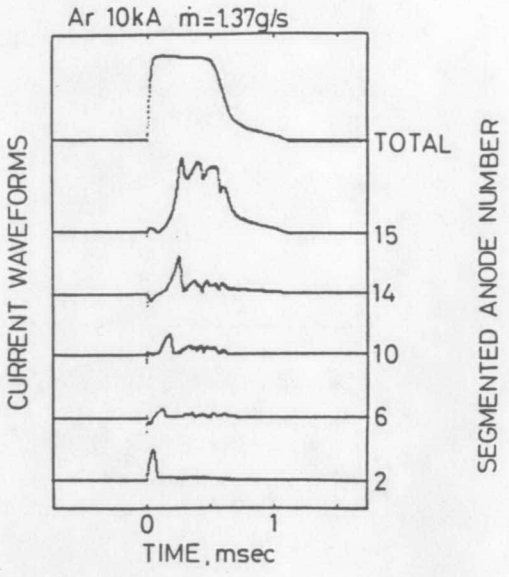


Fig.12 Current waveforms on anode segments for argon at 10 kA.

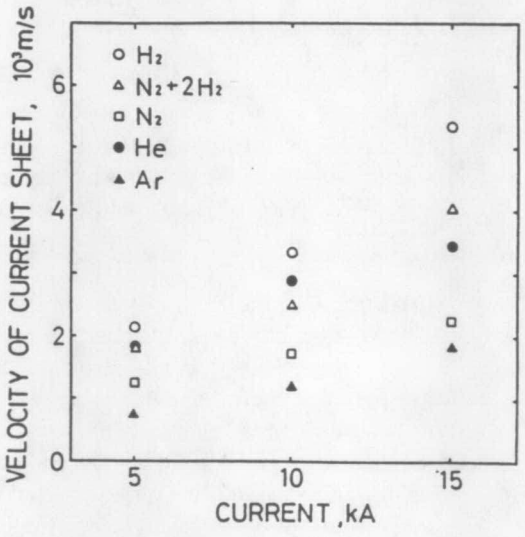


Fig.13 Current sheet velocities vs discharge current characteristics.

anode segments. Figure 13 shows the velocity of current sheets vs discharge current characteristics. The velocity for each gas increases linearly with the discharge current although it is much smaller than the quasisteady exhaust velocity estimated by a pendulum method. At a constant discharge current, higher the velocity is as smaller the molecular weight is. This is reasonable with a constant electromagnetic body force; that is, the motion of the current sheet depend only on molecular weight.

Ⅳ. Conclusions

A quasisteady magnetoplasmadynamic (MPD) arcjet with 30-cm-class long electrodes, i.e., with a long acceleration zone almost realizing a one-dimensional channel flow, was developed to examine current distributions in the discharge chamber. It was found that the current patterns depended strongly on gas species and

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