21PB-093

Experimental Study on Effect of Magnetic-Field Geometry on Arc Jet Plasma Flow

アークジェットプラズマ流に様々な磁場形状が与える効果に関する実験的研究

Jun Takeda, Keisuke Tajima, Atsushi Nezu and Hiroshi Akatsuka

武田遵[1]，田島圭祐[1]，根津篤[2]，　赤塚洋[1, 2]

1) Department of Energy Sciences, 2) Research Laboratory for Nuclear Reactors,
Tokyo Institute of Technology, 2-12-1-N1-10, O-Okayama Meguro-ku, Tokyo 152-8550, Japan

東京工業大学　〒152-8550　東京都目黒区大岡山2-12-1-N1-10

We report effects of mirror and cusp magnetic fields on arc-jet plasma flow. For the weaker magnetic field, we experimentally found that ions move in more random directions and some of them even across the magnetic field. On the other hand, the direction of the ion flow in the downstream comes close to that of the magnetic lines of force due to Coulomb attractive force by electrons, which are fully magnetized under the present experimental conditions. Along the mirror type magnetic field, the plasma forms a high potential region around the radial boundary of the plasma and a low potential region around the axis of the plasma. For the cusp type, we observed a dark region near separatrix, which is considered as a shock wave.

1. Introduction

Recently, interactions between plasma flow and applied-field have been used for various purposes. For example, plasma expansion along open field lines has applications and related researches, such as material processing, space propulsion and nuclear fusion. For material processing, an arc jet plasma is used for a spray coatings [1] and an ion implantation [2]. Open field lines are expected to control arc jet plasma characteristics precisely. In open field magnetic field, supersonic flow of plasma ions is accelerated, and flow along magnetic lines of force with electrons [3]. Plasma acceleration along open field lines has potential to improve efficiency of electric propulsion for spacecrafts.

A lot of studies about plasma flow with non-uniform magnetic field are reported up to now, but the interactions between plasma flow and non-uniform magnetic field are not examined yet very much. On the basis of this background, this study intends to understand the effect of the magnetic field configurations on plasma flow experimentally. We discuss mirror type and cusp type magnetic field, as fundamental configurations.

2. Experimental Setup

Figure 1 shows a schematic diagram of the experimental setup. Our experimental equipment consists of a rarefied gas wind tunnel, a pumping system, a plasma generator, six electromagnets, a traversing mechanism and a Mach probe.

The rarefied gas wind tunnel has an internal diameter of 1.2 meter and is 2.0 meter long. It is evacuated by the pumping system. Ultimate pressure is the order of 10^{-4} Torr. During the stationary arc jet expansion, the background pressure is kept at least in the order of 10^{-3} Torr constantly.

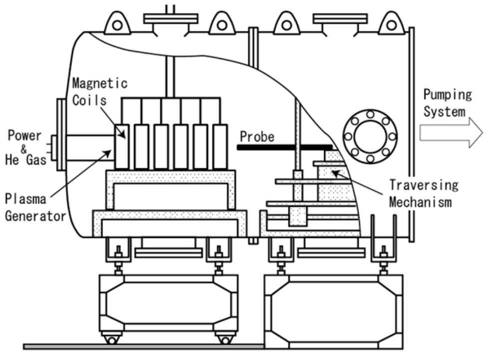

Fig.1. Schematic diagram of the experimental setup

An arc discharge is generated between the cathode and the anode in the discharge chamber at near atmospheric pressure. The typical discharge conditions are: a DC arc current of 120 A and a DC arc voltage of about 25 V; the feeding gas is helium (99.5 % pure), and the helium flow rate is about 1.4 l/s. Electrodes are assembled like a general DC arc torch in the plasma generator [4].

We use a four-tip Mach probe to measure plasma parameters. According to [5], the angle of plasma flow with respect to the probe axis and the ion Mach number M_i are determined from the ratio of ion saturation currents of each electrode. In addition to that, this probe can measure plasma space potential, electron temperature, and electron density as a Langmuir probe.

3. Results and conclusion

Figure 2 shows the direction of the ion flow and the magnetic field at the mirror type magnetic field. For weaker magnetic field, ions move to inertial directions. However, as the plasma flows to the

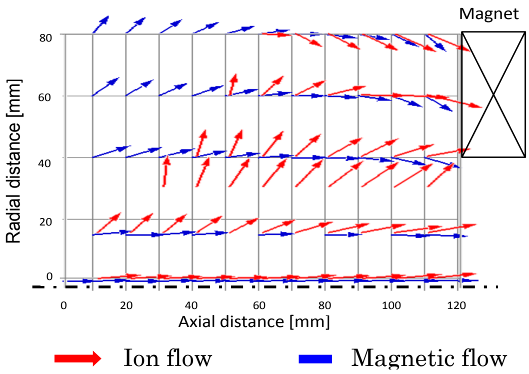

Fig.2. Vector diagram of the ion and mirror type magnetic field

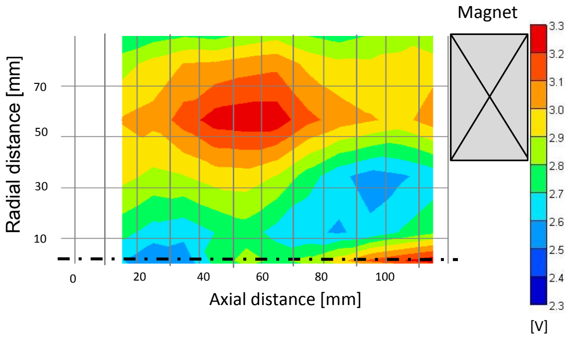

Fig.3. Diagram of the plasma potential contour in mirror type magnetic field

downstream direction, the direction of ion flow comes close to the magnetic lines of force. Figure 3 is the diagram of the plasma potential contour. It appears that high potential region are formed at r = 50 mm and r =70 mm. On the axis, higher potential is found around downstream than upstream. Here, the hall parameter is calculated as $h = \omega_c / 2\pi\nu$ using the cyclotron frequency $\omega_c/2\pi$ and collision frequency ν. Electron hall parameter is much larger than unity over the plasma flow. In contrast, ion hall parameter is much smaller than unity. It indicates that ions diffuse to marginal region and electrons move along magnetic field lines since they are fully magnetized. Hence, such plasma potential is formed.

Next, we discuss the cusp type magnetic configuration. Figure 4 shows the direction of ion flow and magnetic field in cusp type magnetic field. The cusp type magnetic field has null point, which means the point of zero magnetic flux density. Upstream positions of the null point, ions tend to move inertial direction. On the other hand, electrons move to boundary region along the expanding magnetic field. Therefore, the plasma potential rises around the null point. At the downstream of the null point, plasma potential falls by ~1 V since electrons are fully magnetized and gather to axially central position. These experimental results show that

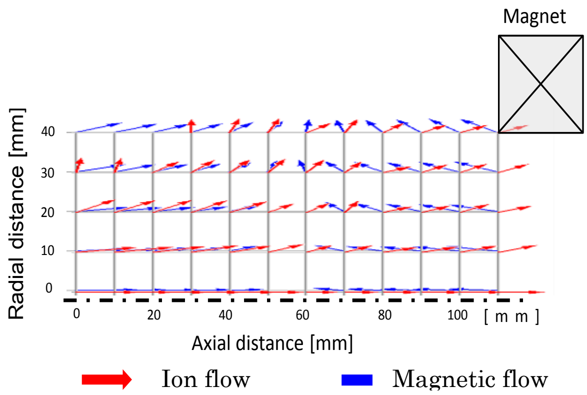

Fig.4. Vector diagram of the ion and cusp type magnetic field

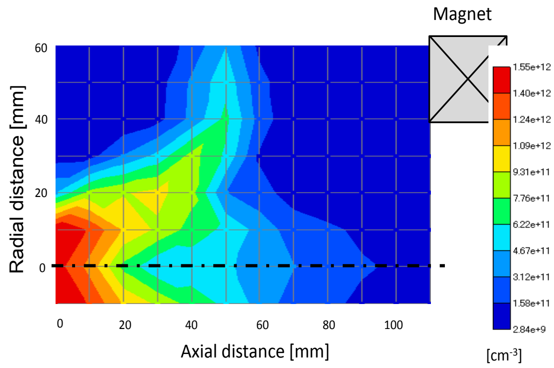

Fig.5. Diagram of the ion density contour in cusp type magnetic field

plasma potential is formed by the difference between ions and electrons moving due to magnetization characteristics.

Figure 5 is a diagram of the ion density contour in cusp type magnetic field. This figure shows that ion density decreases drastically around the axial position of z =30 mm. Around this position, we also observed dark corn. Generally, ion temperature and density change discontinuously in the vicinity of shock wave [6]. Therefore, we assumed that the dark region corresponds to a shock wave.

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