DIRECT MEASUREMENT OF A PLASMA FLOW VELOCITY USING A MACH PROBE IN HANBIT MAGNETIC MIRROR DEVICE

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ABSTRACT

A plasma flow velocity was measured by using a Mach probe in the central cell of Hanbit magnetic mirror device. The Mach probe was attached on the fast injection probe system, which can scan the central cell chamber of Hanbit device in the radial direction. The fast injection probe system also has an emissive probe so that the radial profile of the plasma potential is measured simultaneously. Therefore, the flow velocity measured from the Mach probe can be directly compared with the drift calculated from the measured plasma potential profile. The experimental results are analyzed by using existing theories of the Mach probe. The measured flow velocity shows about 3 km/s, and the flow direction and magnitude is approximately the same as the drift velocity.

I. INTRODUCTION

A poloidal plasma flow velocity induced from the radial electric field in the central cell of Hanbit magnetic mirror device is important to understand the transport property and plasma dynamic. To measure the plasma flow velocity and radial electric field, a fast injection probe system was installed in the central cell of Hanbit. The fast injection probe system has various probe tips, including triple/Mach/ emissive (TME) probes so that the TME probe can measure the electron density, temperature, plasma potential and poloidal plasma flow velocity simultaneously.

A Mach probe is a common method to measure plasma flow velocity, which is composed of two Langmuir probes, shielded from each other, collecting the ion saturation current from the upstream and downstream directions. Although there have been many analysis of Mach probe theory in magnetized plasma, there is no consistent theory for unmagnetized plasma. The Mach probe data measured in Hanbit device needs to be analyzed by the theory of unmagnetized plasma because the ion Larmor radius is larger than the probe radius and the flow direction is perpendicular to the B field.

To calculate the Mach number, two unmagnetized Mach probe models such as Hajis and Lidsky, and Mott-Smith and Langmuir were used. To measure the plasma potential in Hanbit, the strong emission method was used and the drift velocity was deduced from the potential variation. Hence, the poloidal plasma flow velocity measured from the Mach probe can be directly compared with the drift velocity induced from the emissive probe. Here E_r is the radial electric field and B is the magnetic field.

In Sec. II, the TME probe is described and plasma discharge condition in the central cell of Hanbit device is presented. In Sec. III, the measured data from the TME probe is analyzed by two existing Mach probe models. Summary is presented in Sec. IV.

II. EXPERIMENTAL SETUP

The main purpose of the design of the TME probe was to find an arrangement of Langmuir probes that could measure various plasma parameters simultaneously, and be mounted on an injection probe system. The TME probe head consists of insulator tube and three different probe tips as shown in Fig. 1. First, the Mach probe is used to provide information about plasma flow velocities and consists of two identical collectors separated by an insulator. The two collectors of the Mach probe are made of tungsten wire of 1 mm diameter. Probe tips are 3 mm long and they are 8 mm apart along the poloidal direction and are separated by a ceramic insulator. Both collectors are negatively biased enough to draw the ion saturation currents. Two ion saturation current I_{up} and I_{down} were
Central Cell Chamber and Coils

Slot Antenna

Double Half Turn Antenna

Emissive probe

Mach probe

Poloidal direction

TME probe head

Fast Injection Probe

Position transducer

9mm

Fig. 1. A schematic drawing of the central cell of the Hanbit device with the FIP assembly and TME probe head configuration is also shown.

time-averaged to reduce the fluctuation, where \( I_{up} \) and \( I_{dn} \) refer to upstream current and downstream current, respectively.

The TME probe head also has one emissive probe for measuring of the plasma potential. The emissive probe was operated with strong emissive method which is much less sensitive to probe geometry and magnetic field direction and provides the plasma potential information with accuracy of the emitting tungsten temperature \( T_w/e \), such as \( -0.2 \) eV.

As a regular operation mode in this paper, an input RF power has a simple RF input waveform, which is ramped up to 100 kW from 0 to 20 ms and remains at this level to 300 ms, then is ramped down to zero at 350 ms, and the RF frequency is 3.5 MHz. The central cell magnetic field is fixed at 0.24 T and the configuration of magnetic field was simple mirror. Hydrogen is used as discharge gas in the regular operation mode.

III. EXPERIMENTAL RESULTS

Figure 2 shows the ratio of upstream and downstream currents, which were measured from the TME probe, and the ratio is slightly deceased from 8 cm to the center of the central cell. The ratio of the two ion saturation currents, \( R = I_{up}/I_{dn} \) was measured when Hanbit was operated as simple mirror configuration in the central cell.

The ion saturation current at 100 ms during the discharge was used to calculate the ratio because the plasma properties of Hanbit showed good stability at that time. Line density and net RF input power showed good reproducibility at 100 ms discharge time also.

From the measured current ratio, poloidal velocity

![Graph showing Mach number profile](image)

Fig. 2. The radial profile of Mach number.
was calculated by using two existing unmagnetized Mach probe theories.

R (Hudis and Lidsky model)
\[ R = \frac{J}{n} = \exp[4\sqrt{\tau M}] \]

and

R (Mott-Smith and Langmuir model)
\[ R = \frac{\exp[-\tau M^2] + \sqrt{\pi} M [1 + \text{erf}(\sqrt{\tau M})]}{\exp[-\tau M^2] - \sqrt{\pi} M [1 - \text{erf}(\sqrt{\tau M})]} \]
where \( \tau = T_i / T_e, M = V_{\text{drift}} / \sqrt{T_e / m_i} \).

The results were compared with the \( E \times B \) drift, which were deduced from the potential profile of the emissive probe. In calculating Mach number, ion temperature was assumed as 3 Te and 6 Te and the results are shown in Fig. 3.

As shown in Fig. 3, results from 6 Te case shows relatively good agreement.

Fig. 4. Experimental results of plasma potential obtained from the emissive probe.

IV. SUMMARY AND FUTURE WORKS

The radial plasma potential and poloidal plasma flow velocity were successfully measured. The poloidal Mach number has been analyzed with existing unmagnetized Mach probe theories. The poloidal velocity shows about 3 km/s at the 58 mm from the center and the result is compatible with the deduced \( E \times B \) drift velocity.

In the future, a new Mach probe theory needs to be developed for the analysis of flowing unmagnetized plasma and the Mach probe result are recommended to be confirmed by another diagnostics such as laser-induced fluorescence or optical emission spectroscopy.

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REFERENCES