Development of Mach probe for the ion flow measurement in VEST

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1. Introduction

Plasma flow is an interesting issue in the tokamak plasma, and it is measured from various devices to unveil the characteristics of the flow. While the main source of the plasma flow in core region is NBI (neutral beam injection), in the scrape off layer (SOL), flow velocity to the local sound speed is measured in many devices driven by the plasma itself due to such as a radial electric field, turbulence generated from the scrape off layer [1-3]. Considering the importance of the SOL flow not only at the edge but also to the core plasma, properties of SOL flow is studied in several tokamak devices [4, 5].

In this research, the SOL flow in a spherical torus is measured using Mach probe. Since plasma properties in the spherical torus such as Versatile Experiment Spherical Torus (VEST) can be quite different from typical tokamak in terms of high pitch, strong gradient of magnetic field from low aspect ratio, properties of SOL in the spherical torus are expected to have different characteristics than a large aspect ratio tokamak. By measuring the flow and plasma properties in the scrape off layer region, SOL flow patterns in spherical torus can be analyzed.

There are several flow measurement techniques in tokamak plasmas, but they generally require high density or temperature plasma to get sufficient intensity of radiation for the measurement. Since Mach probe can be used to the low density and temperature plasma, Mach probe is widely used method in scrape off layer for measurement of flow velocity. This Mach probe is accepted to measure the flow velocity in this study.

2. Experimental method

In this section, design of Mach probe and its measurement techniques are introduced.

2.1. Probe design

There are two electrodes in this probe system. A ceramic insulator is located between two tips, to allow the analysis of the ion flow. For the design of the tips, typical plasma parameters are used for the calculation. Also the cylindrical tungsten tip is used since geometry effect of Mach probe is considered to be negligible in magnetized plasma [6]. Using the value of electron density of 10^{18} m^{-3} and temperature of 30 eV in SOL, values expected in VEST, the design of probe is determined as in Figure 1.

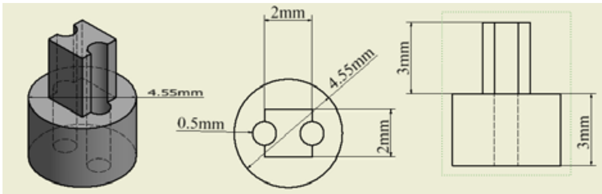

Fig. 1. The geometry of the probe. Two exposed 1mm diameter tungsten wires project into the plasma on 4.5mm diameter alumina.

By using the parameters, mean free path and sheath thickness are considered to not give a perturbation for the each tip measurement. The size of the tip allows the measurement of the plasma in relatively high temperature. [7] The expected ion saturation current achieved from the Bohm flux is about 30mA.

2.2 Theoretical model

Mach probe is a probe system to deduce the plasma flow from the ratio of ion saturation currents. An insulator to separate each tip is located between two tips. This allows directional measurement of upstream and downstream side of the plasma. The relation between upstream current and downstream current gives flow velocity by

$$R = J_{up} / J_{down} \approx \exp(KM_{\infty}) \tag{1}$$

$$M_{\infty} = v_d / \sqrt{T_e / m_i} \tag{2}$$

Using the Chung's theoretical model [7], flow velocity can estimated.

2.3 Bias voltage

When estimating flow velocity using Mach probe, electrodes should be biased sufficiently to accept positive ion current. Even when the edge temperature is low enough, variation of floating potential is also important to determine the bias voltage of the probe. Considering the variation of floating potential in Figure 2, each electrode in Mach probe is biased negatively to 100 V to accept positive ion current

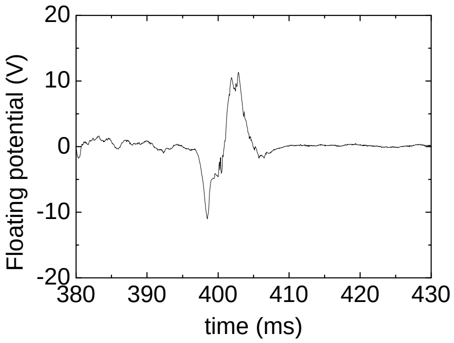

Fig. 2. Time evolution of floating potential in ohmic start-up

3. Calibration and result

3.1. Area calibration

When estimating the flow velocity in Mach probe, the area of two tips has to be identical ideally. To confirm the area in two tips, measurement was conducted in the glow discharge plasma which is considered to have no flow velocity. Calibrating the area ratio of each tip allows the appropriate measurement of the flow velocity

3.2. Velocity calibration

For calibrating the velocity from the Mach probe, experiment is conducted in a plasma gun device where the flow velocity is known before applying to VEST. In this experiment, the plasma flow is generated from the *JxB* force induced from the rail gun. In the measurement at plasma jet, a photo diode, rather than a probe is used for the estimation of the plasma velocity using time of flight method. With the similar velocity estimated from the both experiments with Mach probe and time of flight method, this shows the capability of using Mach probe in the flow measurement in VEST device.

3.3. Measurement in VEST

The flow velocity is measured from VEST. While the plasma current is about 10 kA in the discharge, the flow velocity to the local sound speed is measured. The velocity is converted to the absolute velocity with assumption in the ion temperature. The measurement result is shown in Figure 3.

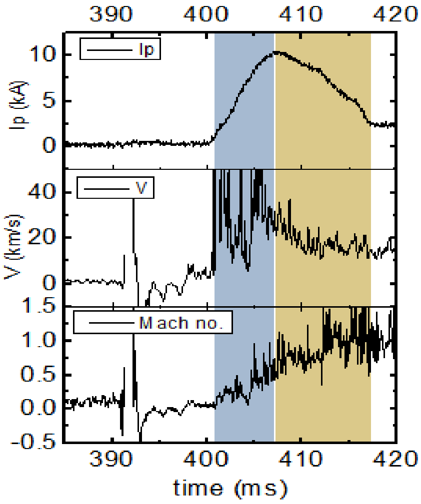

Fig. 3. Flow velocity measured from the Mach probe and plasma current in VEST

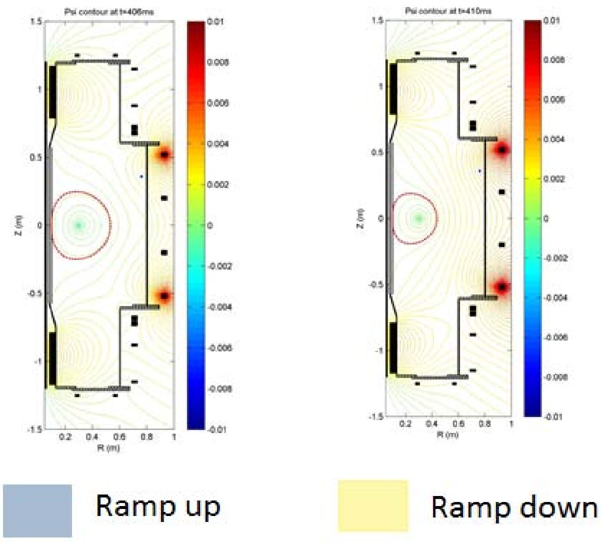

Fig. 4. Equilibrium reconstruction result with single filament method

The location of probe in the magnetic coordinate is estimated from the single filament method in figure 4. For the analysis of the measured flow, electron temperature, density and radial electric field information is used.

4. Conclusions

Mach probe is design to measure the flow velocity in VEST. Using the Mach probe, flow velocity at the scrape off layer is estimated. For the calibration, area ratio between two tips and comparison to the time of flight method is conducted. Through the experiments, capability of Mach probe with supersonic velocity is shown. Using the results, SOL flow patterns in spherical torus can be analyzed.

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