First Results of Simultaneous Multipoint Plasma Potential Measurements Using a Gold Neutral Beam Probe

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The physical mechanisms of the improvement of plasma confinement due to the formation of electrostatic potential and electric field were studied. A 12-keV gold neutral beam probe (GNBP) with the same capabilities as a heavy ion beam probe was operated on the GAMMA 10 tandem mirror. The simultaneous multipoint system was developed to measure the local electric field. The structure of the novel analyzer and the technique for measuring the local electric field were studied by using the calculation code of three-dimensional beam trajectory. It was possible for the first time to measure the local electric field in a single plasma shot by the simultaneous multipoint plasma potential measurement system using the GNBP in the GAMMA 10 tandem mirror.

Keywords: gold neutral beam probe, simultaneous multipoint measurement, plasma potential measurement, electric field measurement

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Fluctuations caused by instabilities in plasmas are observed in some magnetic confinement devices [1–3]. It is quite important to study plasma particle transport across the confinement magnetic field caused by fluctuation. In the GAMMA 10 tandem mirror, the electrostatic and magneto-hydrodynamic fluctuations were measured and were found to be related to radial transport [4, 5]. In addition, a decrease in the plasma stored energy due to the radial transport was also observed.

The physical mechanisms of the plasma confinement improvement due to the formation of electrostatic potential and electric field were studied [6,7]. A beam probe is a useful tool in terms of the energy conservation of a heavy ion beam for potential and fluctuation measurements. A gold neutral beam probe (GNBP) with same capabilities as heavy ion beam probes is operated on the GAMMA 10 tandem mirror [8–10]. Figure 1 shows a schematic view of the GNBP system. The energy and incident angle of the neutral beam that pass the plasma center are about 12 keV and 40 degrees to the horizontal direction, respectively. The typical negative ion beam diameter and current intensity are 5 mm and 2 μA, respectively, as measured by a Faraday Cup detector. The gold positive ion beam produced in collisions with plasma electrons is analyzed by parallel-plate type electrostatic energy analyzer with the incident angle of 45 degree to the ground plate. The width and length of the current slit are 0.7 and 12 mm, respectively. The positive ion beam is detected by a micro-channel plate (MCP) with 32 anodes. The width and length of each anode are 2.4 and 31 mm, respectively.

It is difficult to measure the local electric field with high precision. Previously, two measuring techniques were used to measure the radial potential profile and electric field in the core plasma. In the first measuring technique, the measuring position is changed by the deflecting beam trajectory for each shot. This measuring technique has high time resolution; however, the calculation of radial electric field has a large error induced by the poor reproducibility of the plasma shot. Another measuring technique involves changing the measuring position by sweeping the applied choppy voltage to the deflecting plate in a single plasma shot. In this measuring technique, there is no difference between the shots, but the time resolution is low because the measuring position varies with time. Since it is not impossible for both measuring techniques to measure the local electric field in detail, a simultaneous multipoint measurement system that can measure the local electric field is required.

The development of a simultaneous multipoint measurement system involves the passing of positive ion beams by the injection port and not over each other on the MCP detector of the energy analyzer. The experimental results reveal that the positive ion beam, which passes the current slit with a width of 0.7 mm, has the width of almost 12 ch on the detector. The full width at half maximum of the beam profile is wider than the slit width induced by the character of poorly- converged parallel-plate-type electrostatic energy analyzer with the incident angle of 45 degrees. The structure of a novel analyzer with two point measuring intervals of $\Delta R = 10$ mm and the measuring technique of local electric field was studied by using the calculation code of three dimension beam trajectory [11].

The beam energy analyzer was calibrated with the

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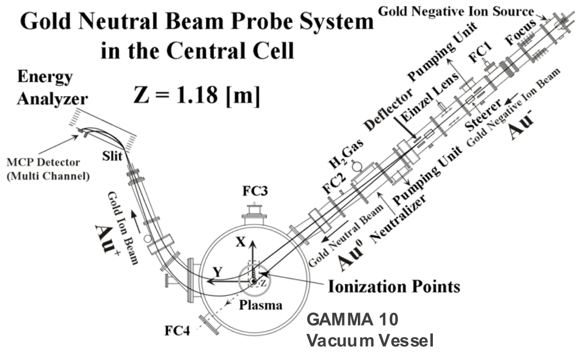

Fig. 1 Schematic view of the GNBP system.

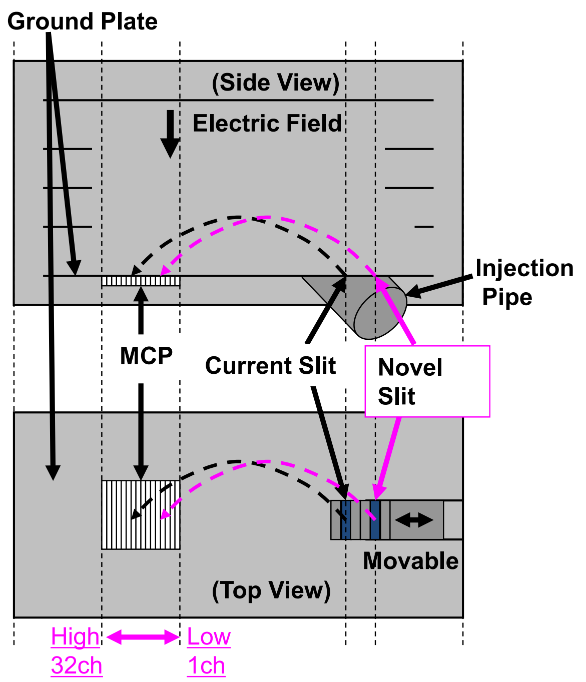

Fig. 2 Schematic view of the parallel-plate-type electrostatic energy analyzer.

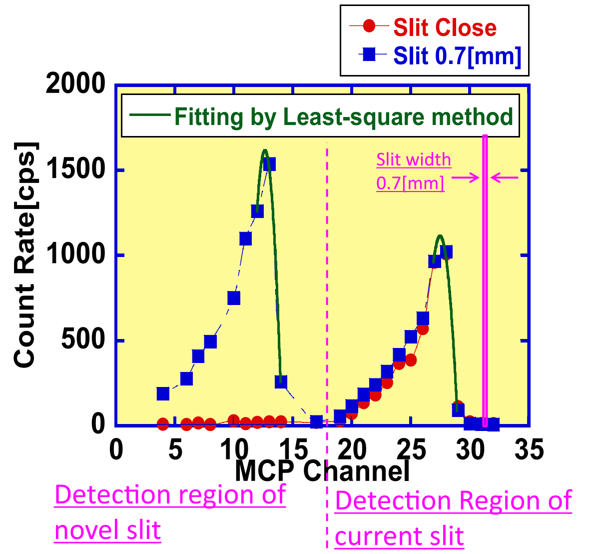

Fig. 3 Result of performance assessment of the multipoint measurement system by the calibration experiments.

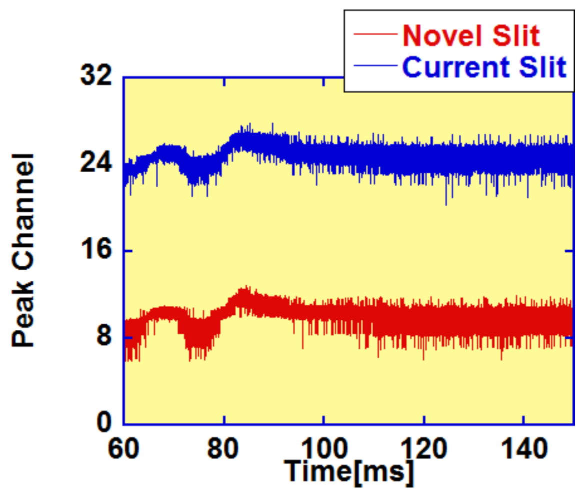

Fig. 4 Temporal evolution of peak channels detected passing through the novel and current slits.

entrance structure designed by the calculation of a three-dimensional beam trajectory. Figure 2 shows a schematic view of the parallel-plate-type electrostatic energy analyzer. The 32-ch MCP detector is on the high energy side. Figure 3 shows the result of the performance assessment of the multipoint measurement system as performed with the calibration experiments. The horizontal and vertical axes indicate the channel number of MCP and count rate, respectively. The closed circles show the beam profile for the case of a novel slit closed by using a terminal connected to an external vacuum. This shows that only one beam profile was confirmed on the detection region with the novel slit. The closed squares show the beam profile for the case that the novel slit has a width of 0.7 mm. In this case the two beam profiles were confirmed at both detection regions from the novel and current slits. The Gaussian beam profile spreads on the high-energy side induced by the character of poorly- converged analyzer. The solid line shows the best-fit curve of the three points of near-peak channels of beam profile are fitted with a Gaussian profile by the least-square method. The peak channels of each beam profile were derived by this fitted curve. The simultaneous multipoint measurement was using the novel entrance structure.

The simultaneous multipoint measurement was performed a part of the GAMMA 10 plasma experiments. Figure 4 shows the temporal evolution of MCP peak channels of detected beam passing through the novel and current slits. The horizontal and vertical axes indicate the time and peak channel, respectively. A conversion factor from channel to potential is about 64 V/ch. The red and blue lines indicate the peak channels of novel and current slits, respectively. The temporal evolution of potential from 60 to 80 ms fluctuated because of the evolution of density and temperature in the initial plasma. The temporal evolution of the peak channels interval shows the time evolution of the potential difference. It is possible to calculate the local electric field from the difference in the peak channels, because the peak channels indicate the potential at the positions of two-point measuring intervals, $\Delta R = 10$ mm. From the calibration experiment, the peak channels interval is about 14.7 ch if the potential at two points is equivalent. If the peak channels interval is larger than 14.7 ch, a positive electric field is formed. The observed electric field strength is almost +20 V/cm at $R \sim 6$ cm. The time resolution of the electric field measurement is 3 μs because of the performance of the analog to digital converter. The spatial resolution of each measurement point is almost 10 mm. The potential measurements have an error of about ±25 V for the case of an electron density of about 2×10^{18} m^{-3}. The electric field strength observed in GAMMA 10 is smaller than this uncertainty. This demonstrates the need for this work's development of an analyzer and a potential calculation method for high-precision electric field measurements.

In conclusion, the simultaneous multipoint potential measurement system has been developed. It can measure the local electric field in a plasma shot with high precision. The structure of the novel analyzer and the measuring technique of a local electric field were studied by using the unique development calculation code of a three-dimensional beam trajectory. The performance assessment of the novel analyzer was confirmed with the entrance structure designed by the calculation of a three-dimensional beam trajectory. It is possible to obtain the local electric field from the difference in peak channels, as measured by the simultaneous multipoint potential measurement system.

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