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Correlation of low-frequency fluctuations measured by the gold neutral beam probe and end plates in GAMMA 10

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The electrostatic instability due to the density gradient was observed in many magnetic confinement devices. The electrostatic instability and radial particle flux due to the instability were also observed by using heavy ion beam probe (HIBP) in GAMMA 10. The potential fluctuation of the end plates settled at both side of GAMMA 10 was measured for the first time. The correlation between the potential fluctuation measured by HIBP and the potential fluctuation of end plates was assessed. We found that the measurement of end plates potential is useful measuring technique of radial fluctuation profile.

Keywords: heavy ion beam probe, electrostatic probe, mirror device, potential fluctuation, drift wave instability

1. Introduction

In magnetic confinement fusion plasmas, the particle and energy are important issues because the transports cause the decreasing of the density and the temperature. The formation of structures of inhomogeneous magnetized plasma has been one of issues in modern physics. The plasma particle and thermal energy run away across the confinement magnetic field as a result of the turbulence fluctuation due to the thermal force and instabilities in plasmas. The particle and thermal transports can't be explained in terms of neoclassical transport theory which handles the effect only the coulomb collision for the particle trajectory. The elucidation of the anomalous transport which leads to the improvement of the energy confinement time is one of the main issues. The fluctuations due to the instabilities cause the transports [1]. The ion temperature gradient mode is a branch of the drift wave called the universal instability caused by the density gradient [2-4]. The drift waves have been observed in many devices due to the plasma density gradient. Therefore, the study of the mechanisms of both the transport and the suppression leads to the reduction of the transports and the potential fluctuations [5].

Figure 1 shows schematic view of GAMMA 10. The x-axis and the y-axis are perpendicular to the magnetic field in the horizontal and vertical directions, respectively. The z-axis is parallel to the magnetic field. In the tandem mirror GAMMA 10, the lengths of central, anchor and plug/barrier cells are 6.0m, 4.8m and 2.5m, respectively. Magnetic field strength at the mid-plane of the central cell is 0.41T in the standard operation and mirror ratio is

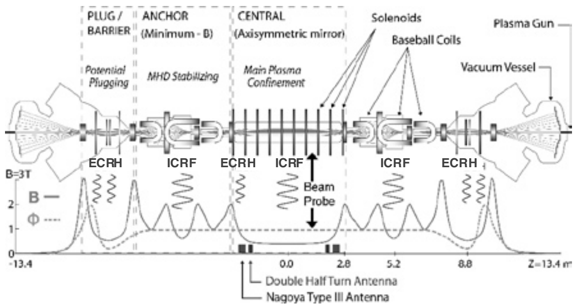

Fig.1 Schematic view of the GAMMA 10 tandem mirror. Magnetic coil set and magnetic flux tube with heating systems, as well as the axial profiles of magnetic field (solid curve) and potential (dashed curve) are illustrated.

5. The anchor cells are located at both sides of the central cell and consist of minimum-B mirror field which is produced by a base ball coil. The magnetic field strength is 0.61T at the mid-plane of the anchor cell and mirror ratio is 3. The plug/barrier cells are located at both ends of GAMMA 10, where the electron confinement potentials and ion confinement potentials are produced. The plasma is created by plasma guns, and heated and sustained using ion cyclotron range of frequency (ICRF) heating systems. There are three types of oscillators named RF1, RF2 and RF3. The waves excited with RF1 and RF2 systems take on the plasma production and ion heating in the central cell, respectively. The ion and electron axial confinement potentials are produced using electron cyclotron resonance heating (ECRH) at both sides of GAMMA 10. We use the heavy ion beam probe

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(HIBP) for potential measurement of core plasma at central cell in GAMMA 10. The electrostatic fluctuations are ever observed by HIBP during ICRF heating [6, 7].

The plasma touches the end plates along with the magnetic field. The end plates made of stainless steel are settled at both end sides of GAMMA 10. In this paper, the potential fluctuation of the end plates was measured for the first time. The correlation between the potential fluctuation measured by HIBP and that of end plates was assessed.

2. Gold neutral beam probe

We use a gold neutral beam probe (GNBP) system for measuring the plasma potential. Figure 2 shows schematic view of GNBP. The features of GNBP are using the neutral primary beam and the negative gold ion by Cs sputtering [8]. The energy and the incident angle of the primary beam passing the plasma center are about 12 keV and 40 degrees, respectively. Typical primary beam current is obtained 2 μA using the Faraday Cup. The GNBP system has two incident angle electrostatic deflectors of the vertical and the horizontal directions. A parallel plate type electrostatic energy analyzer with the incident angle of 45 degrees is installed on the x-y plane. In the analyzer, the micro-channel plate detector of 32 anodes which is mounted along y direction is utilized for the beam detector. The detected positive secondary beam is derived from the neutral primary beam ionized at the ionization position. The electron-impact ionization process is dominant in a case of the ionization of the primary beam. The secondary beam current depends on the electron distribution function at the ionization position. The density fluctuation is obtained from the perturbation of the detected beam intensity, and the potential fluctuation is obtained from the perturbation of the plasma potential. It is possible to measure the potential, density fluctuations and their phase difference at the arbitrary point simultaneously by GNBP.

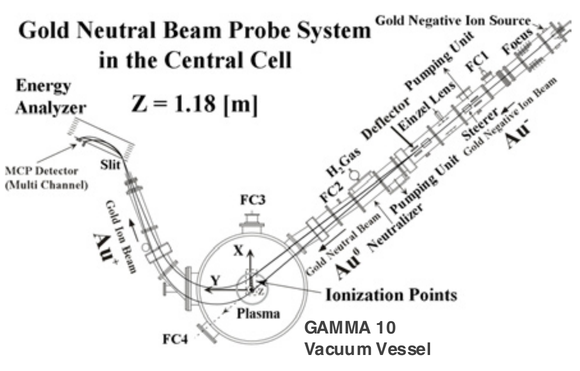

Fig.2 Gold neutral beam probe system in the central cell of the GAMMA 10 tandem mirror. In the case of a vertically directed beam sweep for radial potential profile observations in a single discharge, ionization points move in the vertical direction due to the incident angle changes. (Here, the *z*-axis is in the perpendicular direction to the plane).

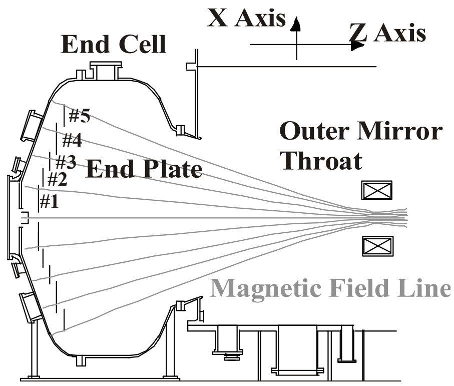

Fig.3 Schematic view of end plates settled at both side of GAMMA 10. The end plates consist of some divided plates. (Here, the Y-Axis is in the perpendicular direction to the plane).

3. End Plate measurement

The end plates consist of some divided plates. The end plates are divided into five sections in radial direction and are connected to ground though the cement resistor. The end plate #1, #2, #3 and #4 cover the region of radius compared at central cell ~5.5, 5.5~7.8, 7.8~11 and 11~16 cm, respectively. The #1, #2 and #3 end plates are divided into four. The #4 and #5 end plates are divided into eight sections in circumferential direction and normally connected. Figure 3 shows schematic view of end plate system. The 1 MΩ of cement resistor is connected to each plate. The end plate potential is affected by changing of this resistance value. Then it is possible to control the radial potential profile in GAMMA 10. The floating potential of each end plate by using the 50 Ω of pick-up resistor is measured. The electron mainly flows into the end plates because the electron is lighter than the ion. The floating potential is usually negative and significantly-decreased to negative during the formation of axial confinement potential by using the local electron heating.

The end plates are used for controlling the radial potential profile. The high-performance analog-digital convertor (ADC) was installed to the end plates. The established ADC has the resolution of 16 bits and it is possible to measure 16 channels simultaneously. The sampling frequency of waveforms is 333 kHz. It is easy to assess the correlation between the fluctuation measured by GNBP and end plates because both measurement equipment use the same ADC. It is possible to measure the radial fluctuation profile and assess the correlation by loading the end plates of radial position. The fluctuation of end plate potential was analyzed by using the sample of 512 points and haning window.

4. Results and Discussions

In GAMMA 10, after starting up the plasma with the both sides of plasma gun, ICRF heating systems are used in the central cell. The confinement potentials are formed at both end mirror region of GAMMA 10 by local electron heating. The plasma was heated from 50 ms by ICRF heating and increased the ion temperature. In this shot, RF1 and RF2 power were 180 and 150 kW, respectively. The plasma confinement was improved from 150 ms by electron cyclotron resonance heating. In this paper, we focused attention on ICRF heating time from 50 ms to 150 ms. Figure 4a shows the electron line density measured by microwave interferometer and the diamagnetism measured by diamagnetic loop in the central cell. The diamagnetism depends on the temperature and density. It shows the plasma stored energy. The electron line density and diamagnetism became the constant value from 100 ms. Figures 4b and 4c show the central potential measured by GNBP and end plate potential, respectively. Both central and end plate potential were kept in a steady state on the time when diamagnetism became the constant value.

The potential fluctuation was measured by GNBP at central cell. It is necessary that some plasma shots in which the heating sequence was fixed for discussing the characteristic of fluctuation on radial position. For measuring the radial profile we change the measurement point every shot by deflecting voltage in the ion source of GNBP. Figure 5 shows the spectrum of potential fluctuation near the central cell at 134.7 ms. The power spectrum was averaged by using root mean square (RMS) averaging. The analysis time interval is almost 1.5 ms. The RMS averaging points are 3. The potential

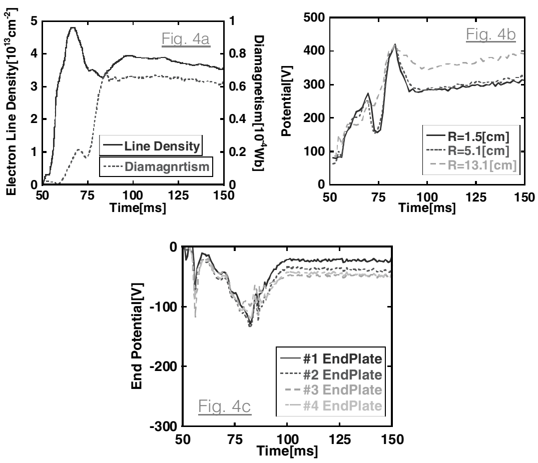

Fig.4 a) Time evolution of the electron line density measured by microwave interferometer and the diamagnetism measured by diamagnetic loop in the central cell. The solid and dotted curves are the electron line density and diamagnetism, respectively. b) Time evolution of the central potential measured by GNBP in radial position. c) Time evolution of the end plate potential from #1 to #4.

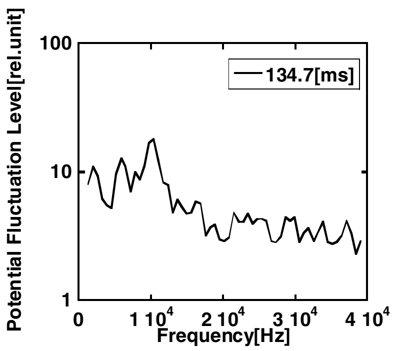

Fig.5 Spectrum of potential fluctuation measured by GNBP near the central cell at 134.7 ms.

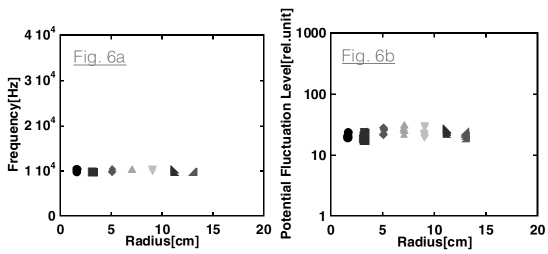

Fig.6 a) Frequency profile of this drift-type fluctuation measured by GNBP from 136.2 to 143.8 ms in radial position. b) Profile of radial potential fluctuation level measured by GNBP from 136.2 to 143.8 ms.

fluctuation had the peak near 10 kHz every time. The fluctuation near 10 kHz was identified by electrostatic probe (ESP) established in circumferential direction. The observed fluctuation was estimated as the drift-type fluctuation with the azimuthally mode number of 3. Because the fluctuation rotated right-handed to the magnetic field line. We calculated the mode number by the phase difference between two ESPs separated in circumferential direction. Previous research has suggested that the drift-type fluctuation occurs strongly in a high plasma pressure case at central cell [9]. Figure 6a shows the frequency profile of this drift-type fluctuation from 136.2 to 143.8 ms in radial position. These results show the drift-type fluctuation rotates in the same frequency in radial direction. Figure 6b shows the profile of radial potential fluctuation level measured by GNBP from 136.2 to 143.8 ms. The potential fluctuation had the same level in radial direction. These results show the drift-type fluctuation has global structure in radial direction.

The fluctuation of end plates potential was analyzed on the same plasma shot. Figure 7 shows the fluctuation spectrum of #1 end plate potential at 134.7 ms. The fluctuation of end plate potential had the peak near 10 kHz every time in the same way as the potential fluctuation measured by GNBP. Figure 8a shows the frequency profile of this potential fluctuation measured

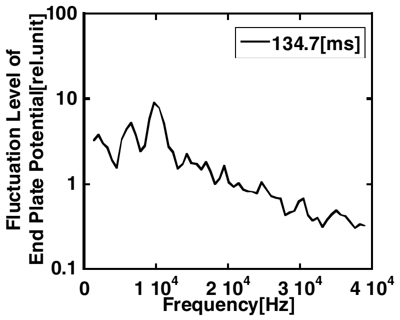

Fig.7 Fluctuation spectrum of #1 end plate potential at 134.7 ms.

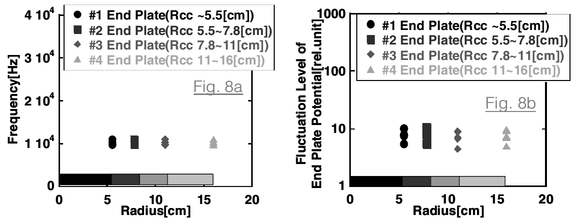

Fig.8 a) Frequency profile of this potential fluctuation measured by end plate #1 - #4 from 136.2 to 143.8 ms. The fluctuation near 10 kHz was observed in radial direction. b) Profile of potential fluctuation level measured by end plate #1 - #4 from 136.2 to 143.8 ms.

by end plate #1 - #4 from 136.2 to 143.8 ms. The fluctuation near 10 kHz was observed in radial direction. Figure 8b shows the profile of potential fluctuation level measured by end plate #1 - #4 from 136.2 to 143.8 ms. These results show that potential fluctuation of end plate is the same level in radial direction in the same way as the potential fluctuation measured by GNBP.

Figure 9 shows the cross spectrum between the potential fluctuation measured by GNBP and potential fluctuation of #1 end plate at 134.7 ms. A strong correlation was observed near 10 kHz. The drift-type fluctuation measured at central cell correlated strongly with the fluctuation measured at end cell. The coherence and cross-phase between end cell and central cell were 0.7 and 0.2 at 134.7 ms, respectively. Therefore this fluctuation at end cell appears identical to the drift-type fluctuation at central cell. It seems unlikely that the drift-type fluctuation occurs in a low plasma pressure case because the magnetic field line diverges at end cell. These results show that the drift-type fluctuation occurring at the central cell which has high plasma pressure propagates from the central cell to the end cell.

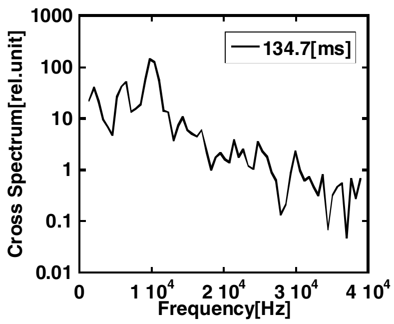

Fig.9 Cross spectrum between the potential fluctuation measured by GNBP and potential fluctuation of #1 end plate at 134.7 ms.

The measurement of end plate obtains the information of core plasma in radial direction simultaneously. It is also possible to analyze the fluctuation propagation in circumferential direction if the plates are disconnected each section. The measurement of end plate is useful fluctuation measuring technique using the feature of linear device which has the end.

5. Conclusion

We use GNBP for the measurement of potential fluctuation in core plasma region. The data analysis system of end plate settled at both side of GAMMA 10 was upgraded for fluctuation measurement. The drift-type fluctuation with the azimuthally mode number of 3 near 10 kHz was observed using GNBP at central cell and rotates in same frequency in radial direction. The fluctuation of end plate potential also has peak near 10 kHz in radial direction. It showed a strong correlation between the potential fluctuation measured by GNBP and the potential fluctuation of end plate. These results show that the drift-type fluctuation occurring at central cell which has high plasma pressure propagates from central cell to end cell. We found that the measurement of end plate is useful measuring technique of core plasma.

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7. References

[1] B. Fischer et al., Plasma Phys. Control. Fusion 31, 453 (1989).
[2] H. W. Hendel et al., Phys. Rev. Lett. 18, 439 (1967).
[3] H. W. Hendel et al., Phys. Fluids. 11, 2426 (1968).
[4] W. Horton, Rev. Mod. Phys. 71, 735 (1999).
[5] E. J. POWERS., Nucl. Fusion 14, 749 (1974).
[6] Y. Miyata et al., Trans. Fusion. Tech. 55, 168 (2009).
[7] Y. Miyata et al., J. Plasma Fusion Res. 2, S1101 (2007).
[8] Y. Miyata et al., Rev. Sci. Instrum. 79, 10F308 (2008).
[9] S. Tanaka et al., Rev. Sci. Instrum. 70, 979 (1999).