FLUTE LIKE FLUCTUATION SUPPRESSION BY THE POTENTIAL FORMATION IN GAMMA 10/PDX

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Abstract

In the hot ion mode experiments of the tandem mirror GAMMA 10/PDX plasma, suppression of the flute like fluctuation of which rotation direction was ion diamagnetic rotation direction was observed during the axially confined potential formation with applying the electron cyclotron heating (ECH) at the barrier (B) and plug (P) cells for the first time. In the previous experiments, the electron diamagnetic rotation type fluctuations were clearly suppressed with application of both B /P-ECH. The flute like fluctuation of ion diamagnetic rotation is also suppressed by the ExB drift and/or ExB drift shear with confinement potential formed by the application of B/P-ECH.

1. INTRODUCTION

Fluctuation study in fusion plasmas is one of the most important issues in magnetically confined fusion plasmas. The fluctuations due to the instabilities cause the anomalous transports. The drift-wave mode arises due to the existence of density and temperature gradients. The radial electric field E causes an $E\times B$ plasma rotation in the direction of the ion diamagnetic drift, which may enhance instabilities such as rotational flute modes, and degrade radial confinement. In the tandem mirror GAMMA 10/PDX, an electrostatic potential for improving an axial confinement is created by applying electron cyclotron resonance heating (ECH) in the end mirrors (plug/barrier cells) [1-8]. Present studies show that the suppression of low frequency drift type fluctuations on the density and the potential during the formation of axial confinement potential by applying plug-ECH (P-ECH) [1-6]. The former works discussed the stability of drift waves as the effects of ambipolar potential [9,10] and the ion Landau damping caused from the velocity shear effect of the $E\times B$ rotation [11-14]. The density fluctuation is observed using microwaves, such as the interferometer, reflectometry and Fraunhofer diffraction method, and electrostatic probes [1-3,5,6]. The potential fluctuation is observed by the gold neutral beam probe (GNBP) and the end plates [4,15-19]. In the former experiments, we studied the drift-type fluctuation suppression by applying the P-ECH [5,6,15-19]. The axial confinement potential formation formed the radial electric field and suppressed the drift-type density and potential fluctuations. In this study, we observed the flute like fluctuation suppression during the confinement potential formed by P/B-ECH for the first time. This flute like fluctuation means that the rotation direction is the same as the ion diamagnetic rotation and the axial direction phase difference is zero. We optimized the iris limiter, fueling gas pressure and ion cyclotron range of frequency (ICRF) powers to produce the flute-like fluctuation before P-ECH in GAMMA 10/PDX. In the hot ion mode plasmas, the drift waves are sometimes excited by the pressure gradient and the plasma rotation along the electron diamagnetic rotation direction is observed. After the optimization of the plasma, the flute like fluctuation is observed by the microwave interferometer and electrostatic probes and all other diagnostics that determined by the azimuthal direction settled electrostatic probes as the rotation along the ion diamagnetic rotation direction. We measured the edge floating potential by using the fast reciprocating probe (FRP) to obtain the radial potentials in the edge region. The radial potential profiles observed by using GNBP for the plasma core region and FRP for the edge region. The flute like fluctuation of low frequency was suppressed by the formation of axially confined potential produced by P-ECH. In this paper, we show the flute like fluctuation suppression by the formation of the radial electric field simultaneously produced with axial confinement potential for the first time.

2. EXPERIMENTAL APPARATUS

2.1 Tandem mirror GAMMA 10/PDX

GAMMA 10/PDX is an effectively axisymmetrized minimum-B anchored tandem mirror with thermal barrier at both end-mirrors (FIG. 1) [1-6]. 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/PDX, the lengths of central, anchor and plug/barrier cells are 6.0 m, 4.8 m and 2.5 m, respectively. Magnetic field strength at the mid-plane of the central cell is 0.41 T in the standard operation and mirror ratio is 5. The anchor cells are located at both sides of the central cell and consist of minimum-B mirror field that is produced by a baseball coil. The magnetic field strength is 0.61 T 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/PDX, where the electron confinement potentials and ion confinement potentials are produced by the application of B/P-ECH. The plasma is created by plasma guns, and heated and sustained using ICRF heating systems. There are three types of oscillators named RF1 and RF2. The waves excited with RF1 and RF2 systems take on the plasma production and ion heating in the central cell, respectively. The typical electron density, electron and ion temperatures are about 2×10^{12} cm^{-3}, 0.04 keV and 5 keV, before applying P/B-ECH, respectively.

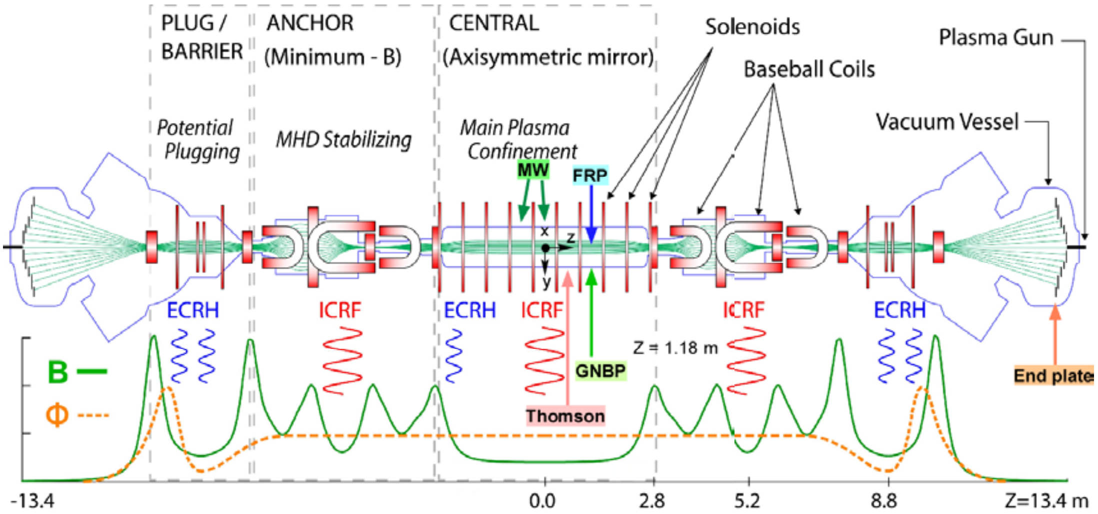

FIG. 1. Schematic view of GAMMA 10/PDX.

2.2 Microwave interferometer systems

Microwave diagnostics have been developed to measure the density and their fluctuation components in magnetically confined plasmas. A single channel frequency-multiplied interferometer system with movable horns has been installed at Z = −0.6 m and is operational in the central cell of GAMMA 10/PDX. We have developed a multichannel microwave interferometer (Z = 0 m) and applied it to measure the electron density radial profile and its fluctuation, simultaneously, in a single plasma shot [5,6]. It was designed using a Gaussian-beam propagation theory and a ray tracing code. The multichannel microwave interferometer can measure radial profiles of line integrated density at Y = 8.2 cm (channel 1), 4.8 cm (channel 2), 0.9 cm (channel 3), −3.0 cm (channel 4), −7.4 cm (channel 5), and −14.0 cm (channel 6). The spatial resolution of the system is approximately 3 cm. The signals are recorded in 50 kSa/s by CAMAC system. The line-integrated electron density of each position is calculated numerically by considering the phase change between the probing and reference beam is directly related to the electron line density. The Abel inversion technique is used for obtaining the electron density radial profile. The FFT analysis is used for studying the electron line density fluctuations.

2. 3 Gold Neutral Beam Probe

We use the heavy ion beam probe for potential measurement of core plasma at the central cell of GAMMA 10/PDX. We measured the potential and its fluctuation by using GNBP in the central cell (Z = 1.18 m) [4,15-19]. 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. GNBP can measure the radial potential profile from R~0 cm to R~14 cm in the error of ±10 V. The path integral effect is low in the density and potential fluctuations measured in the density range and low fluctuation levels of GAMMA10/PDX experiment. 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. Unfortunately, we could not carry out two-point measuring for local electric field, because of the detector problem. The radial profile of the potential is measured by changing the measuring position shot-by-shot.

2. 4 Fast reciprocating probe

We measured the edge floating potential by using the fast reciprocating probe (FRP) to obtain the radial potential profile in the edge region. The probe head of diameter of 11 mm contains five tungsten probes of length of 2 mm and diameter of 1 mm set at the positions of No. 1 (center, x = 0 mm, y = 0 mm, z = 0 mm), No. 2 (North, x = 0 mm, y = +4 mm, z = 0 mm), No. 3 (South, x = 0 mm, y = -4 mm, z = 0 mm), No. 4 (East, x = +5 mm, y = 0 mm, z = -4 mm), and No. 5 (West, x = +5 mm, y = 0 mm, z = +4 mm), respectively. The FRP can be moved by high pressure gas from X = 30 cm to 14 cm in 150 ms. We set the FRP probe head position at fixed position of X = 15.35 cm and 17.35 cm to measure floating potentials.

3. FLUTE-LIKE FLUCTUATION MEASUREMENTS

The plasma is heated and maintained with applying ICRF waves from t = 51 to 240 ms and the confinement potential is produced by applying B-ECH with power of 100 kW from t = 150 to 200 ms and P-ECH with power of 100 kW from t = 150 to 170 ms. The iris limiter diameters set in z = -114 and 90 cm are 34.5 and 40.0 cm, respectively. Figure 2 shows the diamagnetism (a), electron line density(b), FFT analyzed spectrogram of line density (c), potential measured by GNBP at X = 0 cm (d), and floating potential measured by FRP at X = 15.35 cm (e). In FIG. 2, the hatched light blue region shows the duration of B/P-ECH application. The radial potential profiles were measured by GNBP and FRP with changing the measuring position shot-by-shot. The central potential quickly increased during the P/B-ECH period. In FIG. 3, we show the cross-power density (a) between the north (No. 2) and south (No. 3) probes of FRP and phase difference (b) at X = 17.35 cm. The phase difference is +4.6 degree at frequency of 10.2 kHz. We can find that the rotation direction of the fluctuation is the same as the ion diamagnetic rotation whichever means it as a flute like fluctuation. The radial profiles of potential and electric fields in the central cell by using GNBP are shown in FIG. 4 (a) and FIG. 5 (b), respectively. The circles and the squares show the electric field without and with P/B- ECH, respectively. Observed electric field includes error of less than 10 V/cm. In FIG. 5 and FIG. 6, we show the fluctuation spectra of the potential and electron line density at the plasma center before and during ECH, respectively. The potential and line density fluctuations with the frequency of about 10 kHz and mode number of 2 which correspond to the flute like fluctuation identified by the rotation direction of fluctuation from the segmented central limiter analysis. From the phase analysis between the two probes of FRP, the rotation direction is the same as the direction of ion diamagnetic drift (FIG. 3). The observed coherent fluctuations are suppressed during the P/B-ECH period. Figure 7 shows the radial profiles of potential fluctuations at frequency from about 9 kHz to 11 kHz, respectively. The closed circles and the closed squares show the potential fluctuations without and with P/B-ECH, respectively. Potential and density fluctuation suppression with the application of P/B-

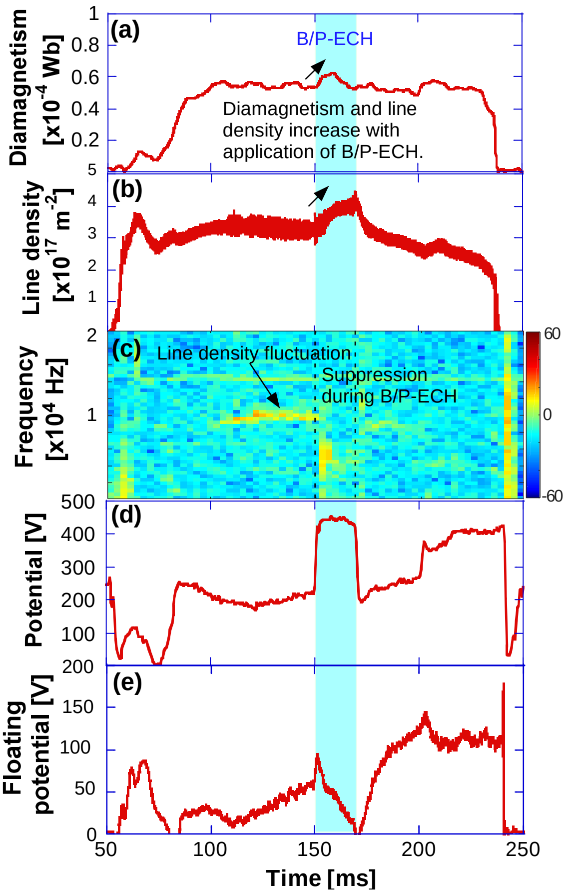

FIG. 2. Time evolution of diamagnetism (a), electron line density (b), its spectrogram (c), potential measured by GNBP (d), and floating potential measured by FRP (e). The low frequency fluctuation was clearly suppressed by the application of P/B-ECH.

ECH was clearly observed at radial positions r < 12 cm. The potential and density low frequency fluctuations which are the flute like fluctuations are suppressed with applying the P/B-ECH. In FIG. 8, we show the electric field shear related value, $d^2\phi/dr^2$, before and during ECH. Before application of P/B-ECH, the $d^2\phi/dr^2$ has smaller value compared with that during ECH. With application of P/B-ECH, the $E\times B$ drift shear is produced around at r ~ 8 cm. However, it was not continued during ECH application periods. Then, the $E\times B$ drift shear was not the main reason for fluctuation suppression. During application of P/B-ECH, the rotation direction in the core plasma region is kept to the ion diamagnetic rotation by $E\times B$ drift. The stronger rotation velocity of the ion diamagnetic rotation direction by $E\times B$ drift was produced by application of P/B-ECH. Then, it is thought that the flute like fluctuation is suppressed by the $E\times B$ drift

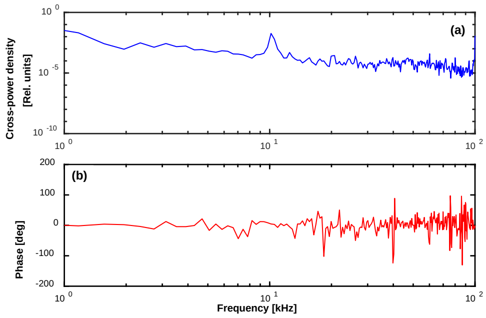

FIG. 3. Cross-power density (a) between the north (No. 2) and south (No. 3) probes of FRP and the phase difference (b) between them.

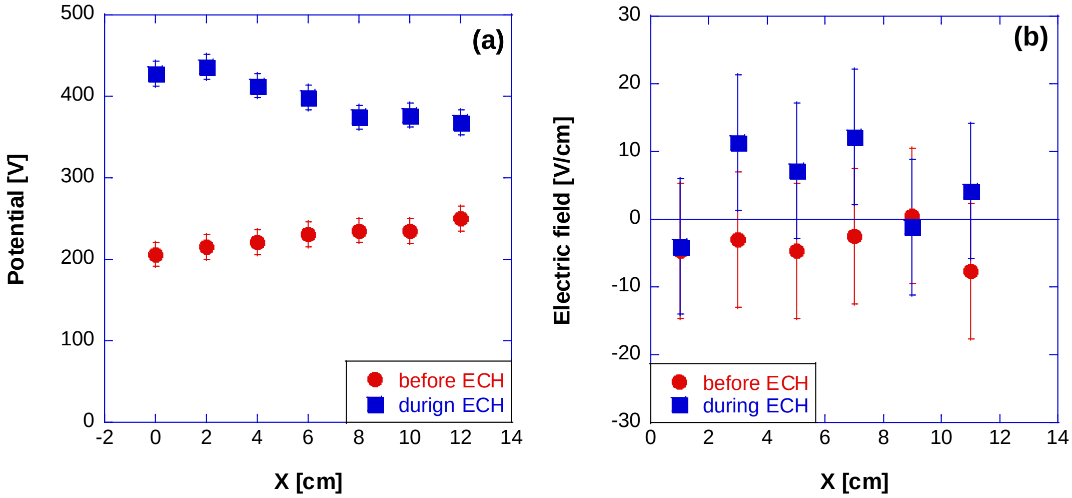

FIG. 4. Potential (a) and electric field (b) radial profiles without (circles) and with ECH (closed squares), respectively.

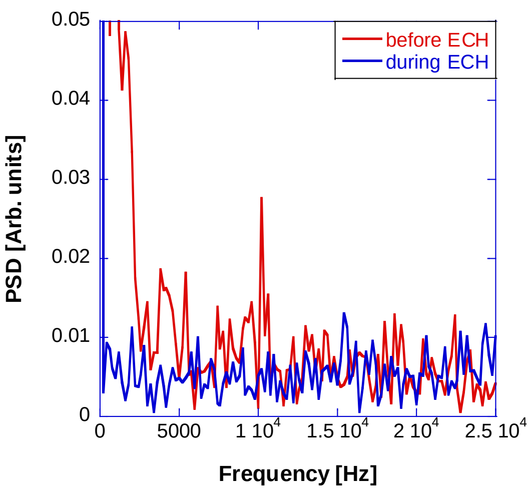

FIG. 5. Potential fluctuation spectra before ECH (bold line) and during ECH (thin line) on R = 0 cm, respectively.

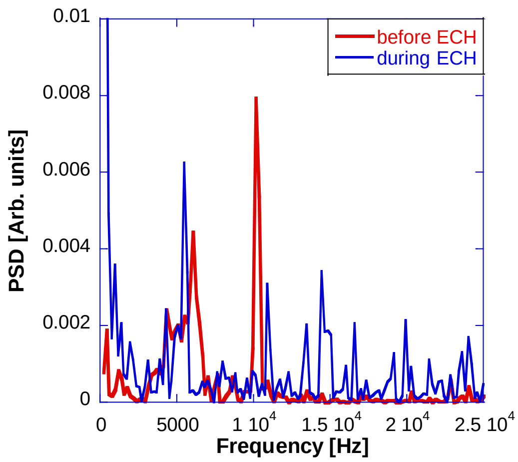

FIG. 6. Electron line density fluctuation spectra before (bold line) and during ECH (thin line) at Y = 0.9 cm, respectively.

velocity and/or $E \times B$ drift produced by P/B-ECH application.

The flute instability simulation under the shear flow in the GAMMA 10 magnetic field was shown in ref. 20 and 21 for investigation of the effects of stabilization of flute instability by the $E \times B$ drift velocity shear. It was found that the flute mode could be unstable to the step functional $E \times B$ flow shear profile. The shear flow can excite the

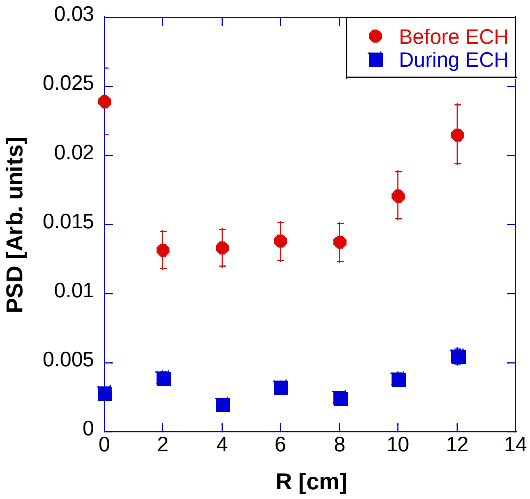

FIG. 8. Radial profiles of the potential fluctuations before (closed circles) and during ECH (closed squares), respectively.

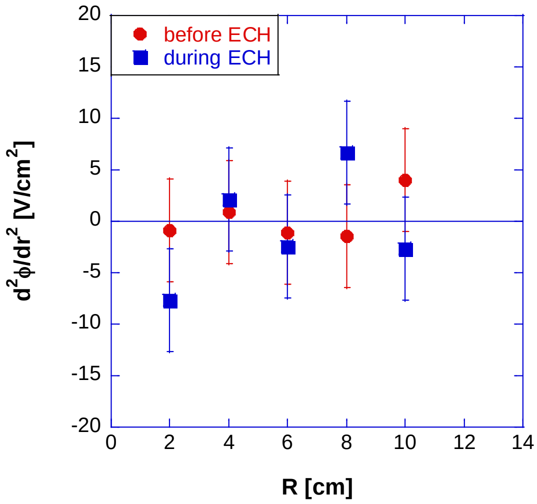

FIG. 9. Radial profiles of electric field shear related value, before (closed circles) and during ECH (closed squares), respectively.

Kelvin-Helmholtz (K-H) instability which is stable in the uniform shear flow. A flute instability was transformed into a K-H instability after linearly growing phase in the uniform shear flow. The reduced MHD simulation shows that the flute instability was stabilized by the $E \times B$ shear flow in the linear phase. In this experiment, the initial condition of electrostatic potential was almost flat in radial and have large positive electric field at around r ~ 14 cm, which was different from the simulation. However, the flute type fluctuation was stabilized with the confinement potential and $E \times B$ drift by the application of ECH. It seems that the confinement potential forms the $E \times B$ shear flow and/or $E \times B$ drift to stabilize the flute like fluctuation.

4. SUMMARY

In the hot ion mode experiments of the tandem mirror GAMMA 10/PDX plasma, the low frequency flute like fluctuations of 10 kHz on the density and potential were suppressed with applying P/B-ECH for the first time. It is thought that the flute-type fluctuation is suppressed by the $E \times B$ drift and/or $E \times B$ drift velocity shear formed by the confinement potential with application of P/B-ECH.

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