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# Fluctuation measurements during the formation of potential confinement in GAMMA 10

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**1. INTRODUCTION.** Considerable interests have been focused on the study of turbulent fluctuations in magnetic confinement system, since various theories predict such turbulent fluctuations lead to anomalous transport and energy loss in the transverse direction. In fact, low frequency plasma turbulence and the resultant anomalous transport observed in various devices exhibit rather common features. We observed the suppressions of density fluctuations by the potential formation during the application of electron cyclotron heating (ECH). Potential fluctuations were measured by a gold neutral beam probe (GNBP) in the GAMMA 10 tandem mirror. We observed the suppression of the potential fluctuation during the confining potential formation by ECH. The particle flux due to the phase difference between the potential and density fluctuations measured by using GNBP was evaluated. It is confirmed that the observed fluctuations are the source of the radial anomalous transport that decreases the plasma stored energy.

**2. GAMMA 10 TANDEM MIRROR.** In the GAMMA 10 tandem mirror, the plasma confinement is improved by not only a magnetic mirror configuration but also high potentials at both end regions. The main plasma is produced and heated by ion cyclotron range of frequency power. The potentials are produced by the electron cyclotron heating (ECH) at the plug/barrier region. The typical electron density, electron and ion temperatures are about $2 \times 10^{18}$ m$^{-3}$, 0.1 keV and 5 keV, respectively. In order to study the plasma confinement improvement by the confinement potential formation, we have constructed the multi-channel microwave interferometer [1]. This system can measure electron density and its fluctuation radial profiles in a single plasma shot. The measuring position of y = 0.05 m (ch. 1), 0.01 m (ch. 2), −0.02 m (ch. 3), −0.07 m (ch. 4), −0.10 m (ch. 5), and −0.12 m (ch. 6) at the central horizontal axis of GAMMA 10. The spatial resolution of the system is approximately 3 cm. We measured the potential and its fluctuations by using a gold neutral beam probe system (GNBP) in the central cell [2]. The beam probe system consists of a beam source and a beam detector by use of an electrostatic energy analyzer. Analyzed beam position and beam current in the energy analyzer correspond to the potential and the relative density, respectively. By sweeping the beam trajectory, the system can measure radial profiles of the potential and relative density, and their fluctuations, simultaneously.

**3. DENSITY FLUCTUATION.** We observed time dependent radial density profiles using the multi-channel interferometer system. Fast-Fourier-Transformed (FFT) fluctuation spectra of the electron densities measured at each position before ECH (hair line, t = 120–122.56 ms) and during ECH (solid line, t = 170–172.56 ms) are shown in Fig. 1 (a) at horizontal position of 0 m, (b) at 0.03 m, (c) at 0.06 m, and (d) at 0.09 m, respectively. It is noticed that the FFT power on each position of plasma densities is suppressed during the application of ECH. The frequency peaks of about 9 kHz which correspond to the diamagnetic drift are observed before the application of ECH and during application of ECH those frequency peaks are suppressed. The frequency peaks of about 9 kHz are observed at the region from r = 0 to r = 0.09 m. The mode number of this fluctuation is m = 1.

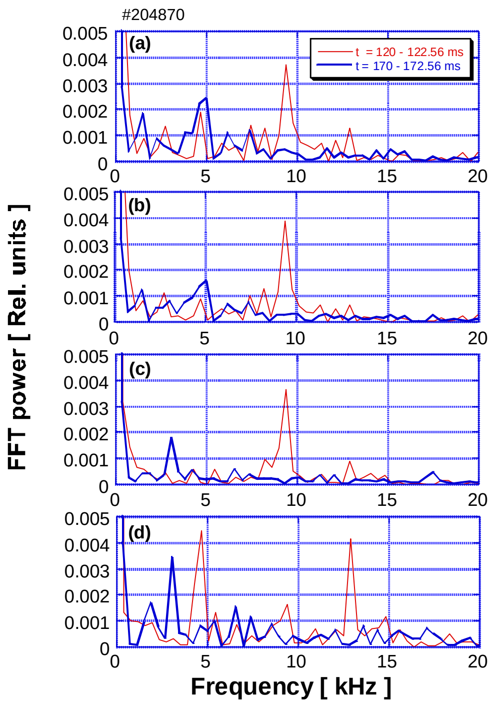


*FIG. 1. FFT spectra of each channel before ECH (hair line, t = 120–122.56 ms) and during ECH (solid line, t = 170–172.56 ms) are shown in FIG. 1 (a) at horizontal position of 0 m, (b) at 0.03 m, (c) at 0.06 m, and (d) at 0.09 m, respectively.*

**4. POTENTIAL FLUCTUATION.** The central-cell potential is raised due to plug potential formation because of improved electron confinement between the central cell and the plug regions in GAMMA 10. Without plug ECH, the potential is relatively low (around 200 – 300 V). Figure 2 shows the temporal evolution of the potential measured by GNBP at the central cell. This potential is measured at the fixed position of r ~ 0 cm. With plug ECH, the sudden increase of the potential is observed. In Fig. 3, we show the fast-Fourier-transformed (FFT) fluctuation of potential which is averaged in the radial position from r = 0 to r =12 cm. When the plug ECH applied, the significant decrease of the fluctuation is clearly observed. The decrease of potential fluctuation starts before application of plug ECH, because the time resolution of the potential fluctuation is about 1 ms which depends on the FFT analysis. During the application of plug ECH, the potential fluctuations are found to be significantly reduced. The ion confining potential formation with plug ECH made a potential fluctuation suppression which suggests particle confinement improvement.

**5. PARTICLE FLUX ANALYSIS.** The origin of the anomalous transport is said to be particle flux loss induced by drift wave type instabilities. The phase difference between the potential and the density fluctuations is a key whether these fluctuations induce the anomalous particle transport or not. The particle flux was evaluated from the fluctuations of the potential and the density and their phase difference measured by GNBP. In GAMMA 10, the azimuthally propagating electrostatic fluctuations are observed. Radial particle flux for experimental investigation is derived as $\Gamma_p \approx \frac{2}{B}\int_0^\infty k_\theta |\gamma_{n\phi}| \tilde{n}\tilde{\phi} \sin\alpha_{n\phi} d\omega$ , where $k_\theta$, $\gamma_{n\phi}$, $\tilde{n}$ , $\tilde{\phi}$ , $\alpha_{n\phi}$ show the wave number, the coherence between the density and the potential fluctuations, the density and the potential fluctuations, and the phase difference between the density and the potential fluctuations, respectively. We observed the potential and the relative density fluctuation frequencies of about 10 to 12 kHz which correspond to the drift type fluctuation. Figure 4 shows the temporal evolution of the low-frequency potential (solid line) and density (dotted line) oscillations at r ~ 2 cm. A good correlation between both oscillations is recognized in this plasma. Figure 5 shows the time evolution of the diamagnetism (dotted line) and radial flux estimated from these fluctuations (solid line). The frequency of the diamagnetism and the particle flux oscillation is about 100 Hz. The diamagnetism began to decrease at 120 ms and particle flux was on the increasing phase. When the particle flux was on the decreasing phase at 125 ms, the diamagnetism goes into an increasing phase. The particle flux of about 0.035 is the threshold of increasing and decreasing phase of diamagnetism. In detailed particle flux analysis, the edge particle flux

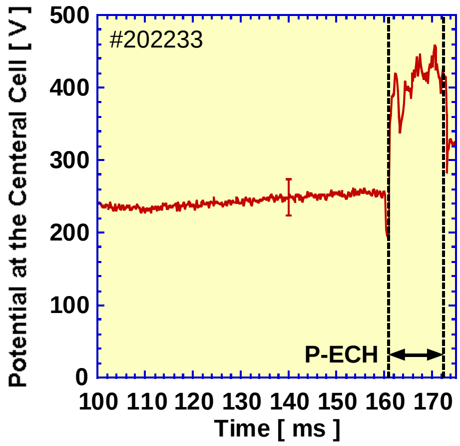


*FIG. 2. Temporal evolution of the potential measured by GNBP. This data was obtained at the fixed position of r = 0 cm.*

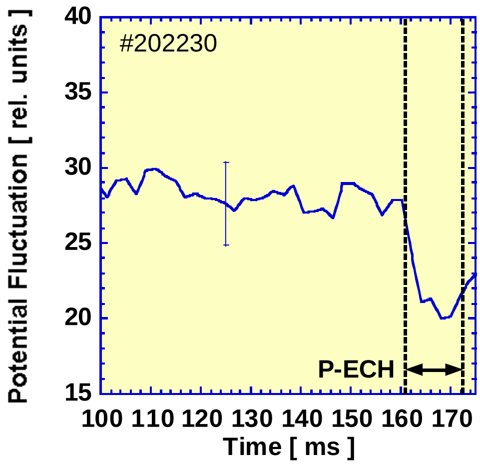


*FIG. 3. Temporal evolution of FFT fluctuation of potential.*

must be considered. However, the qualitative analysis of particle flux can be done. This correlation tells us that the source of the anomalous radial transport is the potential and density fluctuations observed in Fig. 4 and the fluctuations decrease the plasma stored energy as seen in Fig. 5.

**6. SUMMARY.** We studied the density and potential fluctuations during the formation of the confinement potential with application of ECH in GAMMA 10 and the correlation between the radial particle flux and stored energy by using GNBP. It is found that the radial anomalous transport induced from the observed fluctuations causes the reduction of the plasma stored energy. The results suggest the possibility of the suppression of the anomalous transport by the potential with plug ECH by GNBP, which will be studied further. We will make a further analysis of the observe the global particle flux in future.

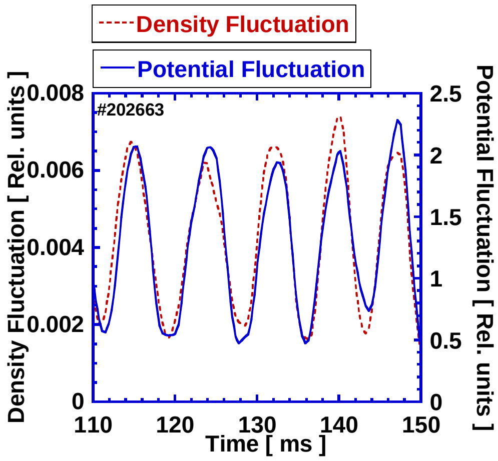


*FIG. 4. Temporal evolution of the low-frequency potential oscillation and the density oscillation near the central of GAMMA*

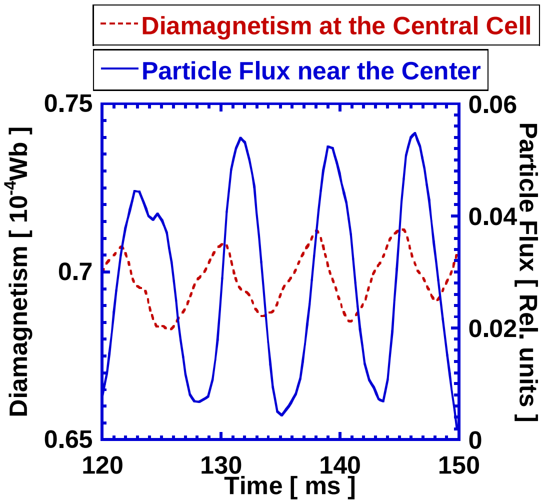


*FIG. 5. Temporal evolution of diamagnetism and radial flux due to the phase difference between potential and density fluctuations.*

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**References.** [1] M. Yoshikawa, *et al.*, Plasma Fusion Res., Vol. **2**, 048 (2007).[2] Y. Miyata, *et al.*, Plasma Fusion Res., Vol. **2**, S1101 (2007).