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Effect of plasma Biasing on Suppression of Electrostatic Fluctuation in the Edge Region of STP-3(M) Reversed Field Pinch

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1. Introduction

The reversed field pinch (RFP) is one of the magnetic confinement systems for nuclear fusion research. The RFP configuration is obtained as a result of MHD relaxation and sustained by the RFP dynamo, where non-linear interactions of core-resonant tearing modes play a major role. Thus, the core confinement of standard RFP is dominated by magnetic fluctuations due to tearing modes, while electrostatic (ES) fluctuations dominate the particle and energy transport at the edge region [1]. Efforts have been devoted to improve the confinement characteristics in RFP since the beginning of the 90's, resulting in the realization of some improved confinement states. The recent significant achievement is the realization of the reduced diffusion coefficient, which is independent of the electron parallel velocity, indicating that the stochastic diffusion can be reduced in the core region of RFP plasmas.

In STP-3(M) RFP, formation of the velocity shear was observed spontaneously [1] and by plasma biasing [2], accompanied by the suppression of ES fluctuations. In this work, we will concentrate on the velocity shear resulted from plasma biasing. The effects of varying ES fluctuation on the radial distributions of electron density n_e, electron temperature T_e and plasma potential V_s were measured during the plasma biasing period using an electrostatic probe array, and the particle and energy fluxes due to the ES fluctuation were estimated. The velocity shear was observed when the particle and energy fluxes were suppressed with the biasing. The change in n_e and V_s distributions in the velocity shear region appeared to show the formation of the transport barrier by plasma biasing.

2. Experimental Set up

STP-3(M) is a small size RFP machine with a major radius $R = 500$ mm and a minor $a =$ 88 mm ($r/a = 1.00$). In STP-3(M), 26 semi-cylindrical molybdenum limiters of 12 mm thickness are attached onto the inner surface of the bellows liner at eight port sections from Port (1) to Port (8). The standard experiments were carried out in hydrogen discharges with maximum plasma current $I_{\mathrm{p}}^{\max} \approx 60$ kA and plasma lifetime $\tau \approx 1200$ μs . The plasma biasing experiments were carried out with the maximum plasma current $I_{\mathrm{p}}^{\max} \approx 50$ kA and plasma lifetime $\tau \approx 800$ μs . In typical plasma experiments, the electrode biasing was turned on at 650 μs . Typical global plasma parameters during the electrode biasing were as follows. Both the average toroidal field $< B_{\mathrm{t}} >$ and edge toroidal field B_{tw} decayed during that period so that the pinch parameter $\Theta\left(\equiv B_{\mathrm{pw}}(a)/< B_{\mathrm{t}} >\right)$ and field reversal parameter $F\left(\equiv B_{\mathrm{tw}}(a)/< B_{\mathrm{t}} >\right)$ remained almost constant. n_{e} decreased radially from $10^{19}\,\mathrm{m}^{-3}$ at $r/a \approx 0.85$ ($r = 75$ mm) to $10^{18}\,\mathrm{m}^{-3}$ at $r/a \approx 1.03$ ($r = 91$ mm), and T_{e} from 25 eV to 10 eV, both remaining roughly constant in time during the same period. The quiet period (QP) appeared after 400 μs .

The tip of the biasing electrode (molybdenum) consists of a cylinder 5 mm long and 6 mm in diameter. The rest of the electrode is covered with an alumina tube for electrical insulation. The inner and outer diameters of the alumina tube are 6 mm and 10 mm, respectively. The radial position of the top of the electrode r_{EL} was set at $r/a \approx 0.91$ ($r_{\mathrm{EL}} = 80\mathrm{mm}$) on the upper vertical port. Without biasing, we observed no significant influence on the plasma from inserting the electrode into this position. The initial bias voltage V_{EL} was set at -500 V, and V_{EL} actually supplied to the plasma was about -20 V. The maximum bias current I_{EL} through the electrode was limited to 500 A by a resistor in the bias circuit. Therefore, typical additional input power to the plasma by plasma biasing was 10 kW, which may be compared with the loss power of 6.87 kW through the ES fluctuation channel at $r/a \approx 0.91$.

The electrostatic probe array was set at the outer horizontal port, 90° toroidally away from the biasing electrode. It was movable on the mid plane from $r/a \approx 0.80$ to 1.59 through the outer horizontal port so that we could investigate the radial profiles of n_{e}, T_{e} and floating potential V_{f}, and their fluctuations near the edge. n_{e}, T_{e} and temperature fluctuation δT_{e} in the edge region were estimated by the triple probe method. It constitutes two closed circuits (i.e., two double-probes) from three probes and two of the probes were biased to -20 V and -40 V. The two toroidally separated probes provided floating potentials V_{f1} and V_{f2}.

The particle flux Γ_{es} and energy flux Q_{es} due to ES fluctuations were estimated from correlation analysis of the fluctuations of electron density δn_{e}, electron temperature δT_{e}, plasma potential δV_{s} and phase difference between floating potentials, δV_{f1} and δV_{f2}, at toroidally separated two locations.

3. Experimental Results

Figure 1 compares I_p, Θ, F and the average toroidal field fluctuation $\delta < B_t >$ in typical discharges with and without plasma biasing (only I_p adding $I_p^{max} \approx 60$ kA). V_{EL} and I_{EL} are shown in Fig. 1(b) in dashed lines. V_{EL} was applied to the electrode at $t = 660 - 670$ μs ; the earlier start of biasing resulted in less effective suppression of the fluctuations. The time evolution of Θ, F and $\delta < B_t >$ values were not influenced by the electrode biasing, as are evident in Figs. 1(c), 1(d) and 1(e).

Figure 2 shows the radial electric field E_r profiles obtained by the relation $E_r = -\nabla V_s$ (where $V_s = V_f + 2.5T_e$) for with plasma biasing, without plasma biasing and $I_p^{max} \approx 60$ kA. In the case of $I_p^{max} \approx 60$kA, E_r was estimated as $E_r = 5.44 \pm 0.7\,\mathrm{kV/m}$ when averaged over 0.93< r/a <0.99, and the varying of E_r was widely radial region. In plasma biasing, the large but very localized E_r, as high as $13.1 \pm 1.2\,\mathrm{kV/m}$, was generated by biasing at $r/a \approx 0.91$. Note that E_r far from the biased region was about $1.90 \pm 0.15\,\mathrm{kV/m}$, comparable to the value of E_r in the case of without biasing. Thus, the E_r shear was generated locally with biasing.

Figure 3 shows the radial profiles of Γ_{es} for with and without plasma biasing and $I_p^{max} \approx 60$ kA. The range 0.90< r/a <0.96 where Γ_{es} decrease at $I_p^{max} \approx 60$kA agrees with the region($r/a \approx 0.93 \pm 0.03$) of the

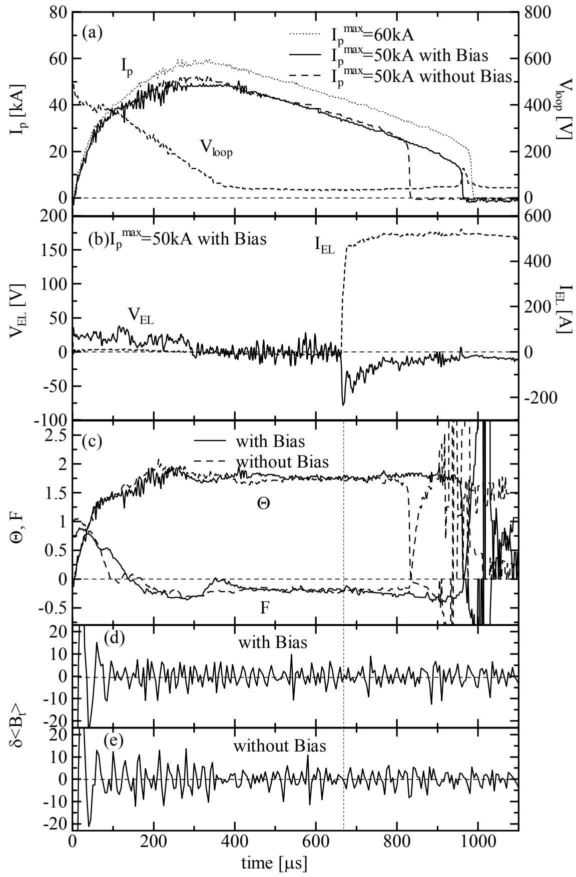

Fig. 1. Waveforms of (a) the plasma current I_p (with bias: solid line, without bias: dashed line, $I_p^{max} \approx 60$ kA: dotted line) and loop voltage V_{loop} (dashed line), (b) bias voltage V_{EL} (solid line) and bias current I_{EL} (dashed line), (c) the pinch parameter Θ and the field reversal parameter F (with bias: solid line, without bias: dashed line), (d) the average toroidal field fluctuation $\delta < B_t >$ with plasma biasing and (e) $\delta < B_t >$ without plasma biasing in typical discharge with plasma biasing at $I_p^{max} \approx 50$ kA.

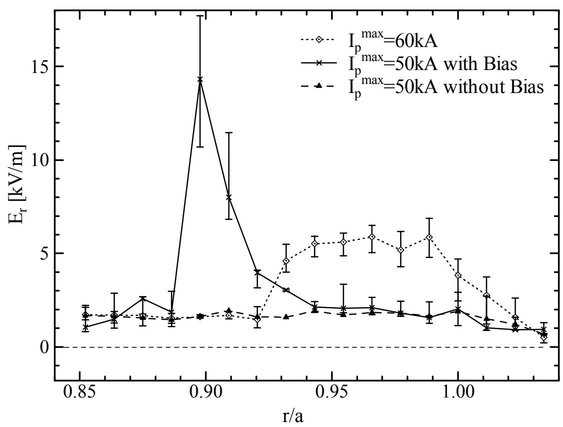

Fig. 2. The radial electric field E_r profiles with plasma biasing (solid line), without plasma biasing (dashed line) and $I_p^{max} \approx 60$ kA (dotted line).

enhanced velocity shear, indicating that the shear suppresses particle flux. By applying plasma biasing, the Γ_{es} was suppressed by approximately an order of magnitude in the vicinity of the electrode region ($r/a \approx 0.91$). And the Γ_{es} was suppressed over 0.90 < r/a < 0.98. The reduction of Γ_{es} was directly caused by plasma biasing, since no significant changes were observed in F , Θ and $\delta < B_{\text{t}} >$ values during the biasing.

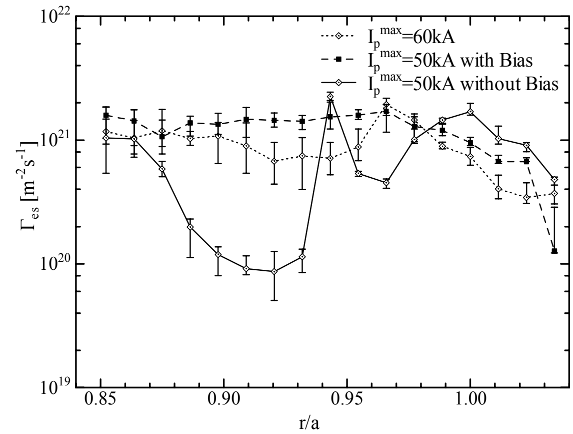

Fig. 3. Radial profiles of the particle flux Γ_{es} due to the electrostatic fluctuation with plasma biasing (solid line), without plasma biasing (dashed line) and $I_{\text{p}}^{\text{max}} \approx 60$ kA (dotted line).

4. Discussion

In the case of plasma biasing, the large but very localized E_{r} was generated in the vicinity of the electrode region. The radial electric field shear frequency ω_{s} on the radial profile of E_{r} was estimated by the following formula [3],

$$|\omega_{\text{s}}| = \left| k_{\perp} \Delta_{\text{r}} \frac{dv_{\text{E}\times\text{B}}}{dr} \right| \approx \left| k_{\perp} \Delta_{\text{r}} \frac{dE_{\text{r}}}{Bdr} \right|, \qquad (1)$$

where $k_{\perp}$ is the perpendicular wave number of the cross field, $\Delta_{\text{r}} (\approx 0.020\text{m})$ is the radial correlation length, and $v_{\text{E}\times\text{B}}$ is the $E \times B$ shear velocity dominated by the E_{r} shear. We have estimated the ω_{s} values at $r/a \approx 0.90$, close to the bias electrode surface, as $\omega_{\text{s}} \approx (1.57 \pm 0.50) \times 10^{8}$ rad/s with plasma biasing. While the diffusion rate $2\pi\tau_{\text{D}}^{-1}$ ($= 2\pi D/\Delta_{\text{r}}^{2}$, where D is the particle diffusion coefficient) [3] is estimated as $(1.37 \pm 0.34) \times 10^{5}$ rad/s in the case of without plasma biasing. Therefore, the ω_{s} resulted from plasma biasing was much higher than the $2\pi\tau_{\text{D}}^{-1}$ without biasing. Moreover, both the electrostatic particle flux broadly decreased with plasma biasing, and the velocity shear frequency was high enough to decorrelate turbulence. It was suggested that the formation of velocity shear by plasma biasing has resulted in the reduction of particle flux due to the ES fluctuation.

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