Effects of Externally Applied Magnetic Perturbation in a Spherical Tokamak Plasma Produced by ECH on the LATE Device

F. Watanabe, M. Uchida, H. Tanaka and T. Maekawa

Graduate School of Energy Science, Kyoto University, Kyoto, Japan

In toroidally confined fusion plasmas, transport of particle and energy caused by externally applied magnetic perturbation (MP) fields and/or therefore stochastic fields is very important for controlling the plasma performance and MHD instabilities. For example, modifications of edge localized modes (ELMs) have been observed by controlling the edge pressure gradient by application of resonant magnetic perturbations (RMPs) in various tokamak plasmas such as DIII-D [1] and JET [2]. On the other hand, losses of runaway electrons (can reach high energies of several tens of megaelectronvolts) in ergodized plasmas with RMPs are investigated in JFT-2M [3] and TEXTOR [4]. Loss of high energy electrons is smaller than that of thermal electrons, because the large shift of the drift surface of high energy electrons from the magnetic surface causes a significant reduction in transport with RMPs. Among these studies on RMPs in various tokamaks, the major difference is the MP spectra, which includes not only the mode number but also the ratio of the resonant to the non-resonant components. Therefore, it is important to clarify the effects among these qualitatively different RMPs, especially possible effects by non-resonant components on both bulk plasmas and high-energy particles.

In this article, we describe effects of an externally applied MP field on high-energy electrons in the low aspect ratio torus experiment (LATE) device. Non-inductive plasma current start-up and ramp-up solely by electron cyclotron heating and current drive (ECH/ECCD) have been developed in recent experiments on the LATE device [5, 6]. The formation of closed magnetic surface is produced by a current carrying high-energy electron tail. Therefore, passing/trapped high-energy electrons (fast electrons) play an important role in the ECH/ECCD plasma performance. In addition, effects on an externally applied MP field in the plasma may provide new information about transport physics on fast electrons.

The MP coil system in the LATE device is shown in Fig. 1(a). This is composed of four coils installed to surround horizontal port sections outside the vacuum vessel, where each coil winding number has 25 turns, and each maximum coil current (I_{MP}) is 2.5kAT. As shown in Fig 1(b), the applicable normalized MP filed strength ($|\delta b_{\mathrm{r}}^{\mathrm{n}=1,\,2}|/B_0 < 1.7\times10^{-2}$ at R = 0.25m; n is toroidal mode number) is fairly large compared with that for control of ELM and runaway electrons in large tokamaks, where B_0 is the vacuum toroidal field at the torus center. In LATE plasmas, the safety factor at the last closed flux surface (q_{LCFS}) is very high. The achieved q_{LCFS} is at least approximately 30, which is evaluated on a 20 kA current ramp-up discharge under a magnetic configuration of B_t = 690G and B_v ~ 190G [6], where the B_t and B_v are toroidal and vertical magnetic field strengths at R = 0.25m, respectively. Therefore, the MP spectra of n = 1 and 2 have mainly non-resonant components in LATE plasmas compared with resonant one.

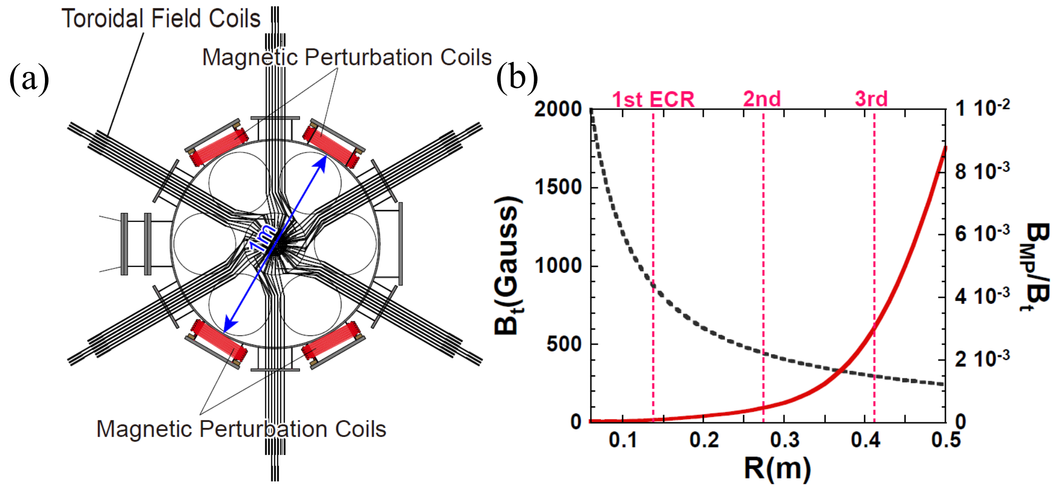

Figure 1 (a)MP coils in LATE device. (b)Horizontal radial profiles of toroidal magnetic field strength B_t and MP field strength with the magnetic perturbation coil current I_{MP} = 50AT normalized by the B_t, when the applied n = 1.

Figure 2 shows a discharge waveform with the n = 1 MP field under a magnetic configuration of B_t = 480G and B_v = 40G. The applied MP field has a flat-top with I_{MP} = 50AT for t = 1.94-2.36s. Slight decrease in plasma current (Ip) is observed in the phase of the applied n = 1 MP (Fig. 2(b)), but the line averaged electron density (n_eL) does not change (Fig. 2(c)). In addition, as shown in Fig. 2(d), a hard X-ray (HX) emission measured by a NaI scintillator which results from fast electrons hitting the center post component cannot be observed in the range of B_v = 40G, because

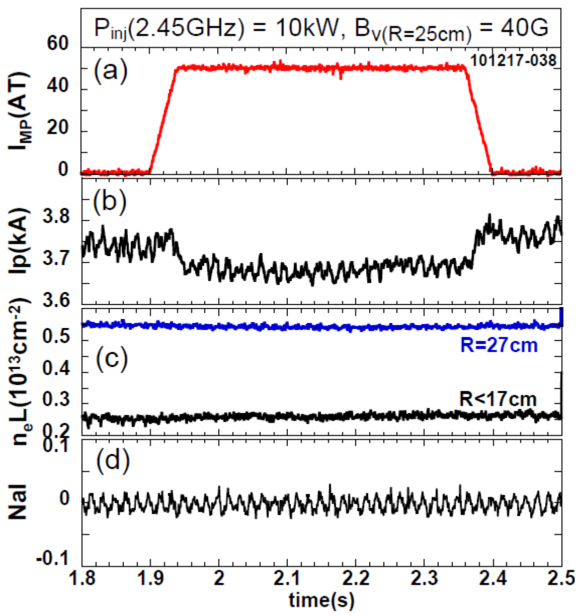

Figure 2 Time traces of ECH/ECCD plasma with the n = 1 MP field (I_{MP} = 50AT), where B_t = 480G, $B_{v(R=25cm)}$ = 40G and P_{inj} = 10kW.

an energy range of the fast electrons is still low. It should be noted that in even lower B_v ($\leq$ 25G) configurations the plasma performance hardly changes even though the n = 1 MP field strength increases. On the other hand, in the discharge of high B_v (= 80G) configuration shown in Fig. 3, an significant modification is observed with increases in Ip and n_eL as follows: Ip = 6.97kA → 7.73kA and $n_eL(R = 0.27\text{m})$ = $0.74\times10^{17}\text{m}^{-2} \rightarrow 1.15\times10^{17}\text{m}^{-2}$ (Figs. 3(b) and 3(c)). Moreover, according to a visible spectroscopy measurement, the bulk electron temperature also increases, because the impurity line radiation of OV (excitation energy = 72eV) and CV (304eV) having high excitation energies is significantly enhanced compared with that without the MP phase.

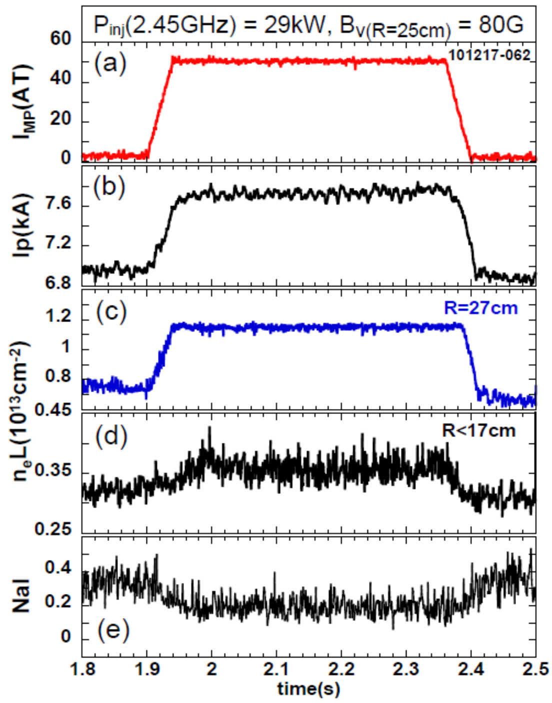

Figure 3 Time traces of ECH/ECCD plasmas with the n = 1 MP field (I_{MP} = 50AT), where B_t = 480G, $B_{v(R=25cm)}$ = 80G and P_{inj} = 29kW.

Figure 4 shows the HX energy spectra with and without the applied n = 1 MP field measured by the vertical pulse height analysis system (R = 0.355m). The HX energy spectrum emission comes from high-energy trapped electrons located on the low field side outside the last closed flux surface [7]. The photon count is decreased especially in the high energy range by applying the n = 1 MP field. As the bulk electron density is increased by the applied MP field (Figs. 3(c) and 3(d)), it is inferred that the density and the energy of high-energy electrons along R = 0.355m are decreased. In addition, as shown in Fig. 3(e), reduction of the HX emission measured by a NaI scintillator in the MP phase is also observed. These results suggest that the application of the n = 1 MP field may induce the loss of high-energy trapped particles located on the low field side and

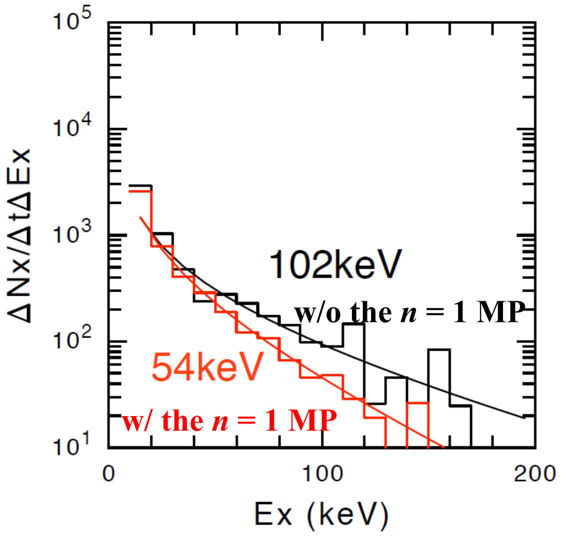

Figure 4 Hard X-ray energy spectra with and without the applied n = 1 MP field at R = 0.355m.

prevent the production of high-energy trapped electrons by ECH.

Figures 5(a)-(c) show the radial profiles of plasma pressures mainly due to the high energy components which is estimated by a magnetic analysis method using data from seventeen flux loops [6]. Here, $P_{||}$ and $P_{\perp}$ indicate the pressures of parallel and perpendicular components to the toroidal magnetic field, respectively. The perpendicular pressure profile outside the last closed flux surface (LCFS) on the low filed side with the applied n = 1 MP field is clearly reduced compared with the parallel one. Therefore, this suggests that the applied n = 1 MP field leads to the enhanced loss of the trapped electrons rather than the passing electrons. Furthermore, expanding of the LCFS is estimated by the calculation. As a consequence, the n = 1 MP field have a positive effects on an ECH/ECCD plasma under the high B_v configuration, i.e. increase in Ip and improvement of the bulk plasma performance. The detail transport physics are not clear yet. However, these results suggest a possibility of selective controlling the pitch angle of high-energy electrons by the application of the MP field which mainly has the non-resonant RMP components.

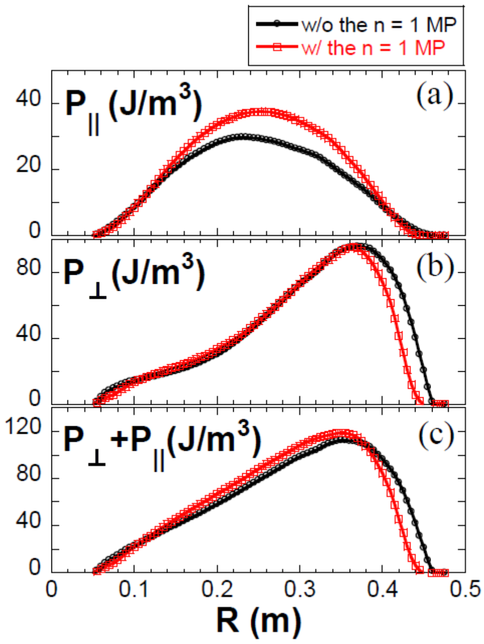

Figure 5 Radial pressure profiles estimated by a magnetic analysis method with and without the applied n = 1 MP field on the horizontal cross-section. (a)parallel pressure, (b) perpendicular pressure and (c) sum of the pressures for the discharge as in Fig.3 (t = 1.86s and 2.33s).

Acknowledgements

This work was supported by a Grant-in-Aid for Japan Society for the Promotion of Science Fellows (No. 215858).

References

[1] T. Evans *et al.*, Phys. Rev. Lett. **92**, 235003 (2004)
[2] Y. Liang *et al.*, Phys. Rev. Lett. **98**, 265004 (2007)
[3] H. Kawashima *et al.*, J. Plasma Fusion Res. **70**, 868 (1994)
[4] K.H. Finken *et al.*, Nucl. Fusion **47**, 91 (2007)
[5] T. Yoshinaga *et al.*, Phys. Rev. Lett. **96**, 125005 (2006)
[6] M. Uchida *et al.*, Phys. Rev. Lett. **104**, 065001 (2010)
[7] H. Tanaka *et al.*, Proc. 19th Topical Conf. on Radio Frequency Power in Plasmas (Newport Rhode Island, 2011)