§1. Control of Rotational Transform by Electron Cyclotron Current Drive in Helical Systems

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Non-inductive current has an important role on realization of high performance plasmas and sustainment of steady state in toroidal fusion devices. ECCD is expected as an effective current drive scheme to suppress the non-inductive current and to tailor the rotational transform profile in stellarator/heliotron (S/H) devices. The physics study in previous experiments of Heliotron J (the major radius, R = 1.2 m, the minor radius, a = 0.17-0.2 m, the magnetic field, B < 1.5 T) showed that the EC driven current can be controlled by $N_{\|}$, and that the ECCD is determined by the balance between the Fisch-Boozer effect and the Ohkawa effect [1-3]. The EC driven current experimentally estimated quantitatively agrees with theoretical results calculated by a ray tracing code, TRAVIS, in which the 3-D magnetic structure and the parallel momentum conservation are taken into account [4].

EC driven current of a few kA is enough to modify the rotational transform profile in Heliotron J if it flows at the central region. Although the total amount of EC driven current is rather smaller than that in tokamaks, it is comparable to other non-inductive current such as bootstrap current and NB current. The effect of EC driven current on rotational transform is calculated. The rotational transform in vacuum is assumed $\iota/2\pi = 0.525$, and the EC driven current profile is calculated by the TRAVIS code. The magnetic field strength is 1.25 T so that the EC current is driven around magnetic axis. The calculation shows that the counter-ECCD of a few kA reduces the central rotational transform, making a high magnetic shear.

Effect on MHD modes has been experimentally studied by a second harmonic 70 GHz ECCD. Figure 1 shows the time evolution of ECH+NBI plasmas. The magnetic configuration of $\iota/2\pi$ = 0.525 and the magnetic field strength of B=1.25T are chosen, and the balanced NB power is injected. The positive sign of toroidal current is defined as the direction to decrease the rotational transform. For $N_{\|}$=0.0, non-inductive current of -0.5 kA flows, consisting of bootstrap current and NB current. FFT analysis of Mirnov coil signals shows that a coherent mode of m/n=4/2 is excited at f = 80 kHz, and density fluctuation measurement using a multi-channel beam emission spectroscopy indicates that the mode is localized around r/a ~ 0.6, suggesting that the observed mode is energetic particle mode (EPM). This mode has been successfully suppressed for $N_{\|}$ = -0.3, where the calculated EC current of 2.4 kA flows in the direction to decrease the rotational transform. No clear change in global confinement has been observed in this experiment. The stabilizing mechanism may be that the magnetic shear is stronger, and/or the population of high-energy ions is reduced due to the outward shift of excitation position. Such a stabilization has been also observed in the other configurations, $\iota/2\pi$ = 0.512 and 0.56.

The effect of magnetic shear on MHD modes is investigated by scanning the EC driven current. The magnetic configuration is the same as in Fig. 1. The magnetic shear is estimated at r/a = 0.6 where the mode is excited. The calculated EC driven current monotonically increases from -0.3 kA to 2.4 kA in the range of -0.3< $N_{\|}$ <0.0. For the EC driven current more than 2.0 kA, the mode amplitude is completely suppressed to the level of ECH-only phase. This result indicates that there is a threshold in magnetic shear to stabilize the EPM.

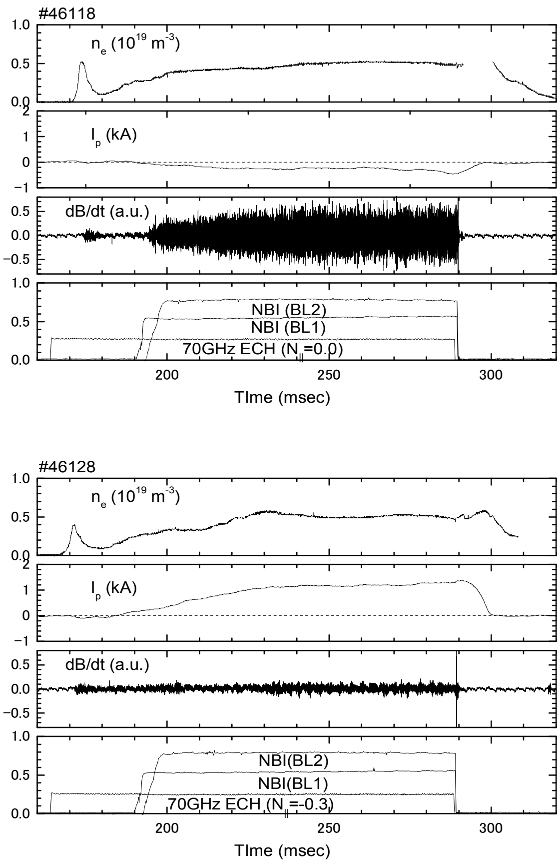

Fig. 1 Time evolution of ECH+NBI plasmas (a) without ECCD and (b) with ECCD. The ECH power is 0.3MW, and the co- and counter-NBI powers are 0.8 MW and 0.6 MW, respectively.

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