§8. 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. Finite plasma pressure drives bootstrap current, and tangential neutral beam injection (NBI) generates a so-called Ohkawa current, both of which modify the rotational transform profile in Stellarator/Heliotron (S/H) systems, thereby affecting equilibrium and stability. Electron cyclotron current drive (ECCD) is recognized as a useful scheme for stabilizing magnetohydrodynamic (MHD) instabilities and analyzing heat and particle transport. In S/H systems, ECCD is expected as an effective current drive scheme to suppress the non-inductive current and to tailor the rotational transform profile, particularly in low-shear devices. The ECCD experiment in Heliotron J showed that the EC driven current strongly depended on the magnetic field configuration, suggesting that the ECCD is determined by the balance between the Fisch-Boozer effect and the Ohkawa effect [1]. Comparative studies have been performed among Heliotron J, TJ-II, CHS and LHD, and common phenomena connected with injection angle dependence and ECCD efficiency has been observed [2].

We so far launched a non-focused Gaussian beam of 70GHz second harmonic X-mode with fixed angle in Heliotron J. We have recently installed an upgraded EC launching system in order to extend the controllability of EC driven current [3]. The injected power is up to 270 kW, and the maximum pulse length is 140 msec in the experiment reported here. The upgraded 70GHz launching system consists of an ellipsoidal mirror and a steerable flat mirror. A low power test using a Gunn Oscillator shows that the beam radius of $1/e^2$ power is 3 cm at the magnetic axis, smaller than the minor radius, a~17 cm, and the available $N_{||}$ ranges from -0.05 to 0.6. The new EC launcher is positioned between the straight and corner sections, while it was positioned at the straight section for the previous experiment, meaning that the power is deposited at the different ripple position.

Figure 1 shows the $N_{||}$ dependence of the measured toroidal current for two magnetic field configurations. For $N_{||}$=0.0, it is bootstrap current that mainly contributes to the total current. The dependence of the bootstrap current on the magnetic field configuration agrees with neoclassical theory. Separation of the bootstrap current from the total current at finite $N_{||}$ will be done in the next experimental campaign by reversing the magnetic field direction. The EC driven current flows in the Fisch-Boozer direction, and it can be controlled by $N_{||}$, which is maximal around 2 kA around $N_{||}$=0.4 for the configuration of B_{st}/B_{cor}=1.06. Here B_{st} and B_{cor} is the magnetic field strength at the straight and corner sections, respectively. The experiments at two magnetic field configurations show that the EC current is more driven when the power is deposited at the high field position in magnetic ripple structure. However, this amount of EC driven current is reduced by half compared with a ripple top heating under the same magnetic field configuration. With larger $N_{||}$, the resonance shift to the edge region makes the single-pass absorption rate lower or the absorption profile broad, giving rise to the reduction in the EC driven current. Figure 2 shows the relationship between the ECE signal and the toroidal current. Enhancement of ECE signals by a factor of 3 and high correlation between the toroidal current and the ECE intensity have been observed. Since the optical thickness is gray, τ~1, at this low density, the ECE signal reflects not only bulk T_e but also high-energy tail. This suggests that the high-energy electrons may contribute to the ECCD driven by the Fisch-Boozer effect.

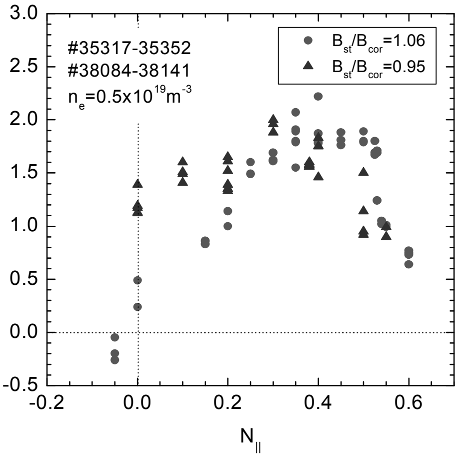

Fig. 1. Dependence of measured toroidal current on parallel refractive index.

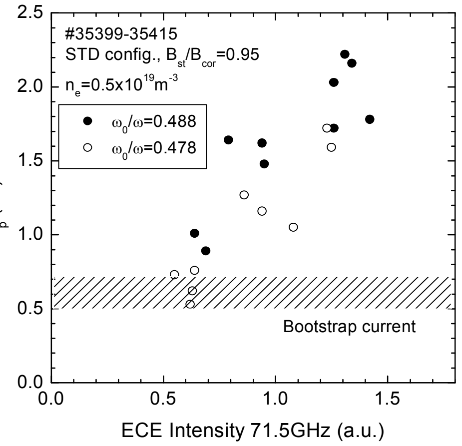

Fig. 2. Relationship between ECE intensity and toroidal current.

1. K. Nagasaki, et al., Nucl. Fusion **50** 025003 (2010).
2. K. Nagasaki, et al., Plasma and Fusion Res., **3** S1008 (2008).
3. K. Nagasaki, et al., to be published in Contribution to Plasma Physics.