§61. Study on Physical Process of Electron Cyclotron Current Drive

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In stellarator/heliotron (S/H) systems, few attentions have been paid to toroidal current, since it is not required for plasma equilibrium. However, recent experimental results show that bootstrap current is driven by pressure gradient, and so-called Ohkawa current flows for tangential NBI, affecting the plasma equilibrium and stability. It is recognized that even small current of a few kA should be controlled particularly for low shear S/H systems. Electron cyclotron current drive (ECCD) is an external current drive scheme to control the non-inductive current. We have performed international collaboration research on ECCD in Heliotron J (Kyoto Univ.), CHS (NIFS) and TJ-II (CIEMAT) [1], and it was found that the EC driven current is at the order of 1 kA in three devices and the normalized current drive efficiency is almost the same within the factor of two. The final target of this study is to clarify the physical process of ECCD commonly observed in S/H systems by comparing the experimental results with theory.

ECCD experiments have been conducted using the upgraded launching system in Heliotron J [2]. Figure 1 shows an example of the time evolution of ECH plasmas. The standard configuration is chosen, and the EC power is injected with $N_{\parallel}$ of 0.38. The resistive diffusion time estimated by L_p/R_p is 100–200 msec for the Heliotron J plasma parameters, where L_p and R_p are the plasma inductance and resistance. The measured current is constant at the latter half of discharge. The positive sign of I_p corresponds to the Fisch-Boozer direction. We have scanned the magnetic field strength at low density, n_e=0.5×10^{19}m^{-3} for standard configuration as shown in Fig. 2. It is noted that the resonance moves to the high field side (the inside of the torus) as B (that is, ω_0/ω) decreases. For $N_{\parallel}$=0.0, it is bootstrap current that mainly contributes to the measured current. The bootstrap current is 0.9 kA at on-axis and high field side heating, and it decreases as the resonance moves to the low field side. For $N_{\parallel}$=0.38, the net current largely increases as the resonance moves to the high field side. The EC driven current, which is estimated by substituting the total current at $N_{\parallel}$=0.38 from that for $N_{\parallel}$=0.0, is maximal around 1 kA at ω_0/ω=0.48, and it flows in the Fisch-Boozer direction. Here the bootstrap current is assumed to be constant since the pressure profile measurement is not available yet. This maximum value of EC driven current is almost the same as that in the previous straight section injection for standard configuration [3]. It is not clear yet why the EC current is weak at on-axis heating. One possible reason is that the ECCD is determined not only by the local magnetic field but also by the 3D magnetic field structure. Further experiments are required to clarify the dependence on the magnetic field structure.

The poloidal field generated by localized EC driven current modifies the rotational transform. A simple calculation assuming Gaussian EC current profiles for standard configuration shows that co-ECCD of 5 kA increases the central rotational transform from 0.57 to over unity, forming a negative magnetic shear. Although the poloidal magnetic field generated by ECCD is much lower than the toroidal field at the central region, even small current strongly affect the rotational transform. On the other hand, the ctr-ECCD decreases the central rotational transform to zero, forming a positive magnetic shear. These situations should occur in experiment, since this order of EC driven current has been observed in the Heliotron J experiment. The localized ECCD can be a candidate to control the rotational transform profile for the improvement of confinement and transport.

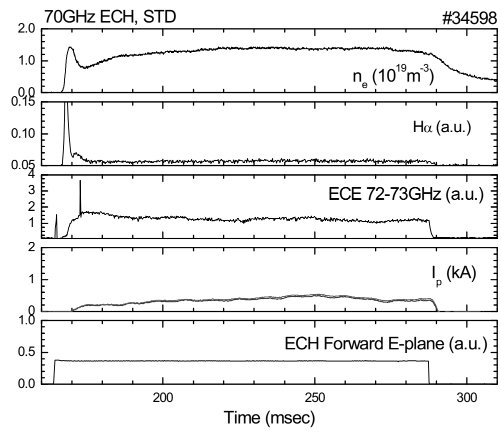

Fig. 1 Example of time evolution of EC plasma at standard configuration. The EC driven current is constant at the latter half of discharge.

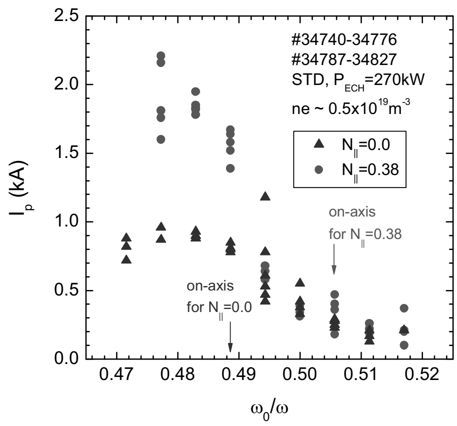

Fig. 2 Measured current as a function of the magnetic field strength at $N_{\parallel}$=0 and $N_{\parallel}$=0.38.

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