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

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In toroidal plasmas, control of non-inductive current is an important task to realize high performance operation and maintain steady state. In Stellarator/Heliotron (S/H) systems, since external coils produce the confinement magnetic field, we do not need Ohmic current for plasma equilibrium. However, bootstrap current, which is driven by pressure gradient, flows in the plasma, resulting that the change in rotational transform affects the equilibrium and stability. Use of electron cyclotron current drive (ECCD) is proposed for control of rotational transform profile in order to prevent magnetic island from forming in the core region and to suppress interchange MHD instabilities [1]. From diagnostic point of view, on the other hand, the S/H systems have advantage of accurate measurement of low current less than 1 kA. Furthermore, comparison of the experimental results between S/H systems and tokamaks brings us deeper understanding of ECCD physics in toroidal devices. In this study, we have conducted 2nd harmonic X-mode ECCD experiments in Heliotron J to optimize non-inductive current for suppressing magnetic island and stabilizing MHD instabilities [2]. The maximum EC power is 440 kW, and the maximum pulse length is 160 msec. The parallel refractive index is fixed as $N_{\|}$=0.44. The non-focused EC power is injected from the straight section where the B contour is saddle-shaped.

Figure 1 shows the dependence of the EC driven current on the magnetic ripple at low density, n_e=0.5×10^{19}m^{-3}. Here the rotational transform and the plasma volume are kept almost constant. The magnetic field ripple, defined by the ratio of magnetic field at the straight section to that at the corner section, h=B$_{str}$/B$_{cor}$ ranges from 0.78 to 1.06. The positive sign corresponds to the Fisch-Boozer effect, while the negative one corresponds to the Ohkawa effect. When the EC power is deposited at the ripple top, the EC driven current flows in the Fisch-Boozer direction, and the EC driven current approaches zero and its flow direction is reversed with a decrease of ripple ratio. This experimental result implies that the ECCD is strongly affected by the population of trapped electrons generated by the magnetic ripple.

The ECE intensity is a function of the magnetic field strength as shown in Fig. 2. The ECE intensity is measured with a 16-channel radiometer. Since the magnetic field gradient is large at the ECE measurement port, the shift of resonance layer is small, Δρ<0.05 in the range of $0.48<\omega_0/\omega<0.50$. The optical thickness is grey, τ~1, at n_e=0.5×10^{19} m^{-3}, T_e=500 eV, meaning that ECE signal reflects the contribution of both thermal electrons and high energy electrons. For the ripple top heating, the ECE intensity drastically increases at on-axis heating, and it is sensitive to electron density at low density regime. On the other hand, the ECE intensity increases little for the ripple bottom heating, and it is weakly dependent on electron density.

A launching system with a focusing mirror and a steerable flat mirror is being installed in order to localize the EC power and to control the power deposition position. The low power test results show that the available parallel refractive index is from -0.1 to 0.6, and the 1/e^2 beam radius at magnetic axis is 30 mm. We will perform the ECCD experiment using this launching system in the next experimental campaign.

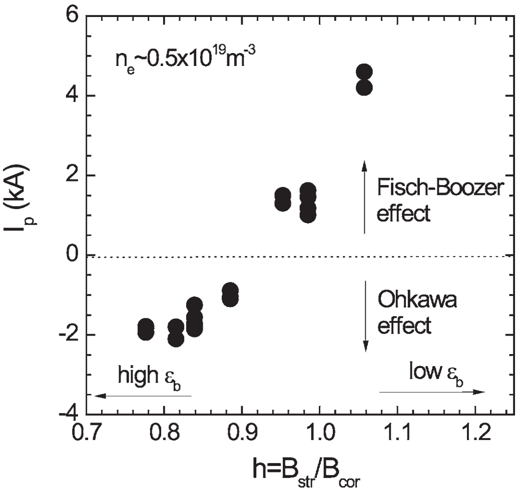

Fig. 1. Dependence of EC driven current on magnetic ripple.

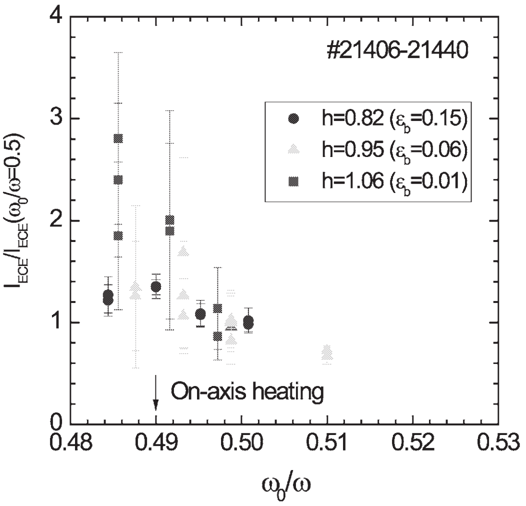

Fig. 2. Dependence of ECE intensities on magnetic field strength.

1) Nagasaki, K., et al.: Plasma Fus. Res. **3** (2008) S1008
2) Nagasaki, K. et al., 22nd IAEA Fusion Energy Conference, 2008, EX/P6-15