§9. Physics of ECCD and Control of Rotational Transform

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Plasma current is not required to sustain plasma equilibrium state in stellarator/heliotron devices. However, non-inductive current such as bootstrap current which is driven by finite plasma pressure inevitably flows in the toroidal direction, affecting plasma equilibrium and stability through modification of rotational transform profile. Even a small amount of plasma current should be controlled to keep high-performance state and to avoid MHD instabilities. Electron cyclotron current drive is a useful scheme to control plasma current externally. Recent studies in the Heliotron J device has revealed that ECCD strongly depends on the magnetic configuration and the current drive position [1]. The EC driven current is determined by the Fisch-Boozer effect and the Ohkawa effect, and the current direction is reversed depending on the EC deposition position, indicating that the trapped particle has an important role to determine the EC driven current. Experiments in the Heliotron J also showed that an energetic-ion-driven instability could be stabilized by ECCD due to formation of magnetic shear [2]. In this report, we study the ECCD physics and application of ECCD to MHD stabilization in the LHD device.

In the experiment, an EC power of second harmonic 77 GHz X-mode has been applied to an NBI plasma with R_{ax}=3.6m where interchange modes and/or Alfven Eigenmodes are excited. The electron density is 0.5-1.0×10^{19} m^{-3}, much lower than the cut-off density. In the discharge, the plasma is sustained by a counter-NB (NBI#2) power, and then by co-NB (NBI#1). The electron density and stored energy are almost the same both in co-ECCD and counter-ECC, while the plasma current has a difference of 13 kA, indicating that EC current is driven.

A coherent mode of 1 kHz frequency has been observed in the counter NBI plasmas with no ECCD. The poloidal mode number is m=2 identified from an SX array measurement, and toroidal mode number is n=1 from magnetic probes. The mode excitation location estimated from the SX array measurement coincides with iota=0.5 rational surface. These results conclude that the observed mode is an interchange mode excited at the core region. Figure 1 shows that the time evolution of magnetic fluctuation of n=1 mode. The interchange mode has been suppressed by counter ECCD or ECH. It appears that the behavior of AEs are also affected by ECCD. We have observed internal transport barrier (ITB) in the core electron temperature, depending on combination of NBI and ECCD. ITB is formed in the co-NBI+co-ECCD or counter-NBI+counter-ECCD, suggesting that modification of rotational transform profile and/or the change in radial electric field is related to the ITB formation.

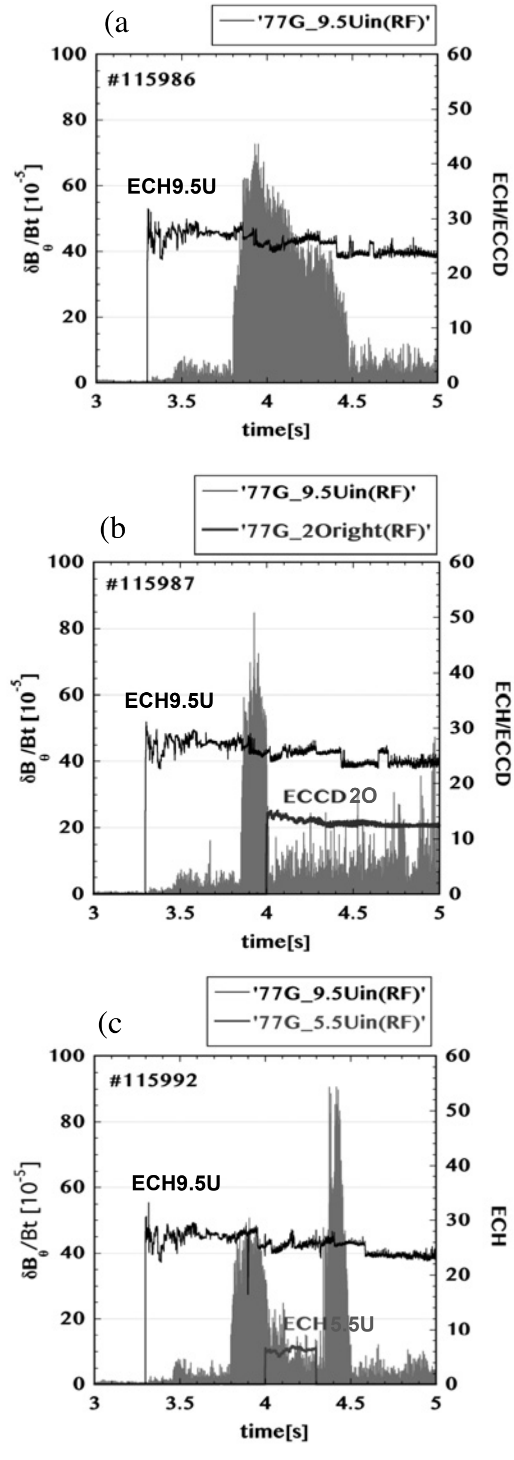

Fig. 1. Time evolution of n=1 magnetic fluctuation amplitude, (a) without additional ECH/ECCD, (b) with counter-ECCD (2O) and (c) with ECH (5.5U).

1) Nagasaki, K., et al., Nucl. Fusion **51** (2011) 103035.
2) Nagasaki, K., et al., 24th IAEA Fusion Energy Conference, San Diego, USA, Oct. 8-13, 2012, EX/P8–10.