§62. Electron Cyclotron Current Drive by Use of 77 GHz EC-Waves

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To investigate the possibility of electron cyclotron current drive (ECCD) in LHD and the usage of ECCD for plasma stabilization, a high-power, long-pulse 77 GHz ECH system with a focused EC-wave beam injection antenna with wide range of beam injection angle is a very effective tool. So far, ECCD experiments in LHD have been performed with 84 GHz ECH systems (400 kW/0.6 s or 100 kW/CW). With the 100 kW/8 s pulses injected from a lower port (1.5-L port) generated EC-driven current up to 10 kA for the line-average electron density $n_e \sim 0.1 \times 10^{19}$ m^{-3}. Using 775 kW, 8 s 77 GHz EC-waves injected from a horizontal port (2-O port), a series of ECCD discharges was performed in which the beam direction (defined by $N_{//}$ at magnetic axis as a cosine of the angle between the original beam direction and the tangent of magnetic field line) was scanned. The magnetic axis position R_{ax} of 3.75 m was adopted due to its low magnetic ripples around the magnetic axis. After the plasma generation with the support of other ECH power, the 77 GHz waves for ECCD sustained the plasmas of $n_e \sim 0.3 \times 10^{19}$ m^{-3}, changing $N_{//}$ in a shot-by-shot basis. In spite of the changes in $N_{//}$, n_e and the plasma stored energy W_p were kept nearly the same values for the discharges. On the other hand, as Fig. 1 shows, large variations in plasma current I_p according to the $N_{//}$ change, from positive to negative direction in accordance with the Fisch-Boozer theory, was demonstrated. The highest driven current was obtained with $N_{//} = -0.38$ and I_p reached -42 kA. The profile of electron temperature T_e in the case of $N_{//} = 0$ (Fig. 2 left) is peaked at the plasma center, suggesting effective on-axis heating. T_e profile in the case of $N_{//} = -0.38$ (Fig. 2 right) is flattened, suggesting an off-axis power deposition due to Doppler-shift by oblique injection.

The dependence of I_p measured at 9 s on $N_{//}$ is plotted in Fig. 3. An optimum value of $N_{//}$ to maximize EC-driven current in the negative direction can be recognized as $N_{//} \sim -0.3$. The reason of the degradation in ECCD efficiency at $N_{//} < -0.4$ is considered as: with large $|N_{//}|$ the power deposition profile shifts from the magnetic axis to outward region further, where the magnetic ripple is larger. Due to the dumping effect by the magnetic ripples, the driven current is reduced.

The large-current ECCD would be an effective tool for an improvement in plasma performance through a modification of plasma current profile and/or rotational transform profile, especially by removing the rational surface of 0.5 from the plasma core region with effective co-ECCD.

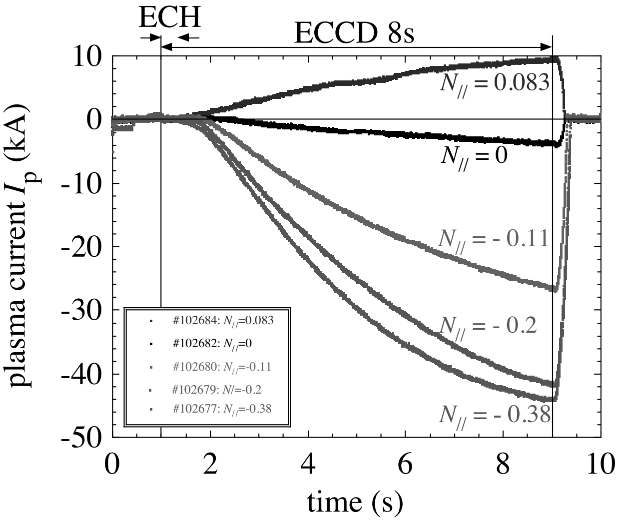

Fig. 1 Variation in the plasma current I_p against EC-wave beam direction $N_{//}$.

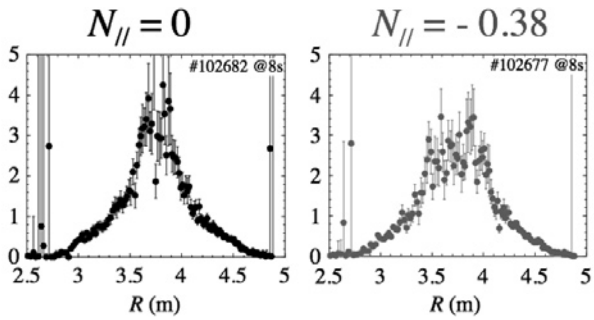

Fig. 2 Electron temperature profiles measured at 8 s for $N_{//} = 0$ (left) and $N_{//} = -0.38$ (right).

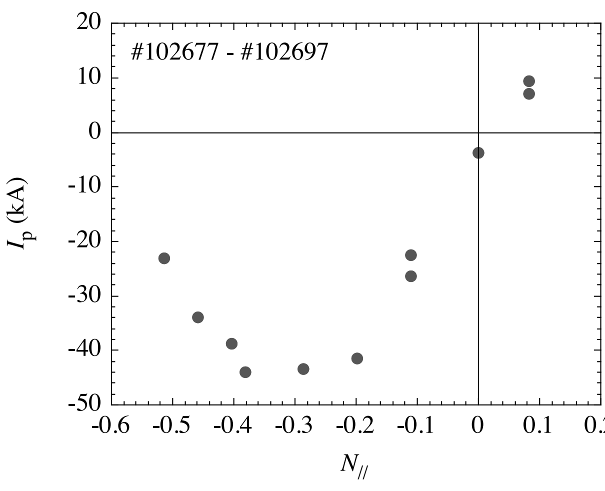

Fig. 3 Dependence of the plasma current I_p against the EC-wave beam direction $N_{//}$.