Electron Cyclotron Counter Current Drive Experiments in Bi-directional Lower Hybrid Current Drive Plasma in TRIAM-1M

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In order to investigate the controllability for the current profile by means of counter current drive in full current drive plasma, experiments by combination of backward propagating LHW and ECW have been performed in full current drive plasma sustained by forward propagating LHW. Three ctr-cd aspects have been investigated with respect to the power ratio of backward (P_{BW}) to forward (P_{FW}) LHWs; 1) a clear reduction of driven current for bi-directional current drive for $P_{BW}/P_{FW} < 0.8$, 2) a rapid transition to enhanced forward current for $P_{BW}/P_{FW} > 0.8$ [1] and 3) positive change in current by ctr ECW into FW LHCD plasma and further changes to negative value depend on P_{BW}/P_{FW} of LHW.

Two kinds of bi-directional propagating LHWs with $N_{||}$~±1.8 at 8.2 GHz and ECW with $N_{||}$~-0.33 in the fundamental X-mode at 170 GHz are used. The experimental conditions are as follows; B=5.6-7 T, P_{FW}-P_{BW}=20-80 kW, P_{EC}~100 kW, electron density $n_e \sim 0.6 \times 10^{19}$ m^{-3} and I_{cd}~25-40 kA. A target plasma is sustained by FW-LHW under the fixed condition. Typical scheme is as follows. BW-LHW is injected at the flat top of the current for 1 s and P_{BW}/P_{FW} is varied up to 2. The combined $P_{BW}+P_{FW}$ state is sustained for 5 s which is at least > 20 times longer than the current skin time. During the flat top phase BW-ECW is injected for 0.5 s. ECW is launched through the remote steering antenna and the elliptical polarization for the oblique injection is optimized by adjusting two grooved mirror polarizers located in the transmission line [2]. The magnetic filed is varied as the relativistic resonance condition $f = f_{ce}/\gamma + k_{||}v_{||}$ [3] are fulfilled for R-a<R<R_{max}, i.e. at R~R_0(B=6.0T), R<R_0(B=5.6T) and R>R_0(B=6.4T). Here f_{ce}, R_0, a, R_{max}, γ , $k_{||}$(<0), and $v_{||}$(<0) are cyclotron frequency, major and minor radii, relativistic factor, parallel wave number of ECW and parallel velocity of counter streaming energetic electrons, respectively. The width of the resonance window between the cutoff layer and R_{max} from which the resonance condition can be fulfilled is ~ a few cm. Under the fixed power of ECW at 100 kW and $N_{||}$ of -0.3, P_{BW}/P_{FW} is varied from 0 to 1.4.

First, for BW-LHW injection with $P_{BW}/P_{FW} < 0.8$ a reduction (~15%) in current driven by FW-LHW is accompanied with peaking of j(r). A large Shafranov shift with $\Delta r/a$ of ~ 0.3 is observed in hard X-ray radial profile, which suggests that a high poloidal beta plasma is achieved via the contribution of tail electrons $\beta_p^{tail} \sim I_A/I_{CD}$[4,5]. Second, the rapid increment in current and broadening of j(r) are observed for $P_{BW}/P_{FW} > 0.8$. Even when $P_{BW}/P_{FW} > 1$ FW current is still sustained and the broad HX profile is established. The details of this transition have been investigated. Third, though the backward streaming energetic electrons are confirmed by the first experiment and further reduction in I_{CD} is expected by BW-ECWs coupling to them, the large increment in I_{CD} of ~ 40% is observed for injection into FW-LHCD plasma. However, ΔI_{CD} is reduced and finally small negative when P_{BW}/P_{FW} is increased. Three Ctr-ECCD results at different resonance spatial windows show that the current reduction becomes significant when it moves from the outboard side to the inboard side through the axis.

References

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