Contributions of Electron Cyclotron Waves to Performance in Advanced Regimes on DIII-D*

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High-power electron cyclotron (EC) heating and current drive is an important and versatile tool for tailoring the current density and plasma pressure profiles on DIII-D. While many different topical areas utilize EC waves in experiments, the high power gyrotron program on DIII-D plays a critical role in Advanced Tokamak (AT) regimes where there is a simultaneous need for high non-inductive current and high beta. Three AT scenarios that have used EC waves to increase performance are the Quiescent High-confinement mode (QH-mode), the low q_{min} hybrid scenario, and the large bootstrap current fraction "high q_{min}" scenario.

The EC current drive profile in QH-mode has been found directly from the periodic response of the motional Stark effect (MSE) signals to a slow modulation of the EC power. The electron temperature is kept nearly fixed by adopting a "push/pull" setup where co- and counter-injecting gyrotrons at the same deposition location alternate during each cycle so that the total heating power remains constant with time. Fourier analysis of the poloidal flux diffusion equation yields a local measurement of the EC current source in analogy to measuring the EC power deposition profile from the oscillations in the electron temperature profile.

Strong core current drive from EC waves and neutral beams has increased the non-inductive current fraction in the hybrid scenario to ≈100%. The EC driven current is calculated to be 0.17 MA, out of a total current of 1.1 MA, for 3.0 MW of absorbed power by the CQL3D quasi-linear Fokker-Planck code. Despite the strong core current drive, the safety factor remains above unity owing to the poloidal magnetic flux pumping effect in hybrids with a m/n=3/2 tearing mode. While the low value of q_{min} (≈1.05) results in a modest bootstrap current fraction (50%) even at high beta, the high current drive efficiency on-axis fully makes up for this deficiency allowing approximately full non-inductive operation to be achieved. In addition, good alignment between the current drive profile and the desired plasma current profile is not necessary in this scenario as the poloidal magnetic flux pumping in hybrids self-organizes the current density profile.

In the "high q_{min}" AT scenario, experiments have been performed to optimize the safety factor profile and EC current profile for stable operation with high bootstrap current fraction. EC current drive has been used to provide part of the off-axis non-inductive current, and to produce a tearing stable equilibrium. It was found that a broad ECCD deposition at rho~0.3-0.55 yields a current density profile that is more stable to tearing modes, and is compatible with the need of off-axis non-inductive current. However, there was variability in the results since the tearing stability depends sensitively on conditions when the plasma is close to the ideal beta limit.

Finally, electron heat transport and turbulence has been studied in low-collisionality QH-mode with strong core EC heating. There is evidence of a transition to a trapped electron mode (TEM) dominated regime with higher T_e/T_i (≥1 in the core), and a substantial increase in electron temperature fluctuations is measured by correlation ECE. Changes in the electron and ion heat transport during central EC heating in QH-mode are being modeled using the Trapped Gyro-Landau Fluid (TGLF) code.

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