Physics of Off-Axis Electron Cyclotron Current Drive*

R. Prater,[1] R.W. Harvey,[2] Y.-R. Lin-Liu,[3] J.M. Lohr,[1] T.C. Luce,[1] M. Murakami,[4] C.C. Petty[1] and R.A. Ellis III[5]

[1]*General Atomics, P.O. Box 85608, San Diego, California 92186-5608 USA*
[2]*CompX, P.O. Box 2672, Del Mar, California 92014-5672 USA*
[3]*Department of Physics, National Dong Hwa University, Hualien, Taiwan*
[4]*Oak Ridge National Laboratory, P.O. Box 2008, Oak Ridge, Tennessee 37831 USA*
[5]*Princeton Plasma Physics Laboratory, P.O. Box 451, Princeton, New Jersey 08543 USA*

Electron cyclotron current drive is a key option for driving current off-axis in a tokamak, as needed for example for current profile control or for suppression of neoclassical tearing modes. Experiments in DIII-D at low beta have shown that the partial cancellation of the Fisch-Boozer co-current by the Ohkawa counter-current can cause strong deterioration of the current drive efficiency at larger minor radius. However, more recent experiments at higher power have shown that the loss in efficiency can be mostly recovered if the target plasma has higher electron beta, β_e. The improvement in efficiency with beta can be understood from a theoretical standpoint by applying the Fokker-Planck code. The separation in frequency between the cold cyclotron resonance and the location of peak absorption is a critical parameter which determines—and is determined by—how far into the bulk of the electron distribution the resonance extends. The effect of increasing the absorption is to shift the resonance toward larger $v_{||}$, away from the trapped-passing boundary in velocity space. At the same time, increasing the electron temperature causes the resonance to curve away from the trapped particle region of velocity space due to relativistic effects, for outside launch. These effects combine to shift the region of velocity space which is affected by the waves away from the trapping boundary. This reduces the flux of particles across the trapping boundary, thereby reducing the Ohkawa counter-current and increasing the net efficiency. The particle flux in velocity space driven by the EC power represents the source term in the Fokker-Planck equation, and in steady state a pattern of collisional return flux is generated. This flux can extend well beyond the region where the source is large, so interaction with the trapping boundary may still take place. Comparison of theory, as embodied in the Fokker-Planck code, and experiment shows excellent agreement over a wide range of parameters, including β_e, $n_{||}$, and the magnetic well depth, validating the code as an effective means of predicting the ECCD. Computer modeling shows that the ECCD efficiency predicted by the code is adequate for supporting Advanced Tokamak scenarios in DIII-D.

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