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Electron Cyclotron Current Drive Efficiency in the STEP Device

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The UK's Spherical Tokamak for Energy Production (STEP) design program aims at demonstrating the ability to achieve a net electrical gain from fusion reactions in a magnetically confined plasma under reactor relevant conditions. A key aspect for a successful design of a Tokamak reactor is the minimization of the recirculating power needed to maintain plasma operation, dominated by the power required for the auxiliary Heating and Current Drive (H&CD) systems.
After considering all viable H&CD concepts, and assessing multiple aspects like physics applications, technology maturity, ease of maintenance, cost, and grid to plasma efficiency, the STEP program has recently decided to rely uniquely on mm-wave H&CD actuators, namely Electron Cyclotron (EC) and Electron Bernstein Waves (EBW).
This work outlines the studies done so far to assess the H&CD capabilities of EC waves in the burning plasma of different STEP prototype reactor concepts. The modelling of the EC beam propagation, absorption and current drive in the plasma has been performed with the GRAY beam-tracing code [1]. ECCD efficiency has been evaluated in each prototype with extensive scans of the launcher position, toroidal and poloidal launch angles, wave polarization and frequency. The parametric scan allowed to identify the optimal EC beam injection conditions which maximize the CD efficiency, and to verify its robustness against changes of the plasma parameters and its sensitivity to changes of the launch angles.
The normalized CD efficiency ζ_{CD} [2] for the best performing launch conditions at normalized minor radii $\rho < 0.6$ is typically found in the range $0.25 < \zeta_{CD} < 0.4$, with O-mode absorption at the first or second cyclotron harmonic resonance. Far off-axis, at $\rho > 0.8$, a larger efficiency $\zeta_{CD} > 0.5$ can be achieved via X-mode absorption at the down-shifted first harmonic resonance and Ohkawa current drive. The ECCD performance during other phases of the plasma discharge, and the trade-off between maximum performance and reliable operation, need careful evaluation before a final choice is made for the optimal EC launch configuration.

[1] D. FARINA, Fusion Sci. Technol. **52**, 154-160 (2007)

[2] T.C. LUCE, *et al.*, Phys. Rev. Lett. **83**, 4550 (1999)

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