Full wave modeling of off-axis LHCD using the LHEAF code on Alcator C-Mod

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Abstract
We will present LHEAF full wave simulation results of Alcator C-Mod LHCD experiments. LHEAF is a full wave simulation code for LHCD based on the finite element method, which allows simulations of the hot core plasma, the SOL plasma, and the launcher in a seamless manner. The LHEAF Fokker-Planck module has been upgraded to a 3D Fokker-Planck code to compare code results with Alcator C-Mod experiments. Simulation results of stable LHCD discharges show good agreement with the current profile obtained by an equilibrium reconstruction. We will also discuss interesting wave spectrum broadening observed in code simulations in the multi-pass regime, which may be difficult to reproduce using a traditional ray-tracing technique.

Motivation
Full wave effects, such as diffraction, have been considered to affect wave propagation and absorption of the LH waves. In the previous literature, 1, 2, 3 we have reported results showing full wave LHEAF simulation and ray-tracing agrees well. These simulations have been done in the strong single absorption case, such as ITER simulation shown below.

Many present-day LHCD experiments including Alcator C-Mod are in the multi-pass regime, in which the full wave effects is expected to be more prominent.

The LHEAF code
• A efficient full wave simulation based on FEM
  - Based on single mode analysis
  - SOL/launcher can be included seamlessly
  - can handle very high poloidal mode number
  - COMSOL + MATLAB:
    - Solves Maxwell equation
    - MATLAB:
      - Hot plasma effects
      - Fokker-Planck calculation (1D-3D)
      - Off-site calculation

A LHCD discharge without any instability.

Target discharge
Fig. 2 (a) Plasma current and LH power, (b) line integrated density, (c) loop voltage and (d) non-thermal ECE emission at the frequency outside of plasma

Simulation results
• Log (|E||+1) shows the most of waves are absorbed on the second pass after bouncing off the low density cut-off layer, and the LHEAF prediction of the driven current profiles shows good agreement with experiment.

The standard ray-tracing/Fokker-planck code (GENRAY/CQL3D) shows good prediction of the driven current profiles shows good agreement with experiment. But, LHEAF code better agrees in terms of the position of peak driven current, and the spread of driven current close to the plasma edge.

Summary
LHEAF is now coupled to 3D Fokker-Planck code and is capable of simulating hard X-ray emission profile. The codes were applied to Alcator C-Mod, low density good LHCD discharges

Comparing the wave spectrum between LHEAF and ray-tracing, an extra spreading of spectrum due to full wave effects is suggested. Presently, it is not clear which full wave effects contribute to this and we are investigating this in detail

Appendix
3D Fokker-Planck calculation in LHEAF
• Evaluating parallel diffusion from transit time acceleration

HXR diagnostics on C-Mod

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