Self-consistent full-wave / Fokker- Planck calculations for ion cyclotron heating in non-Maxwellian plasmas

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An important problem in radio frequency (RF) heating of fusion plasmas is the absorption of power by non-Maxwellian components such as ion cyclotron heated species, fusion-born alpha particles, and fast ions associated with neutral beam injection[1-3]. Heating of these energetic components can occur at high harmonics of the ion cyclotron frequency where conventional 2-D full-wave models for RF heating are not valid. In this work, the 2-D all-orders full-wave solver, AORSA[4], is extended to treat non-Maxwellian velocity distributions. Quasilinear diffusion coefficients are derived directly from the full-wave RF electric fields and used to calculate self-consistent distribution functions with the CQL3D Fokker-Planck code.[5]

The RF power absorption is quadratic in the wave electric field and involves a double summation over the Fourier wave numbers ($\mathbf{k}_1$ and $\mathbf{k}_2$) for each electric field component.[6] This sum can be extremely costly to evaluate. In 2-D, four nested loops are required for each cyclotron harmonic. Even for Maxwellian distributions, calculating these sums can take orders of magnitude more computation time than the wave solution itself. For non-Maxwellians, the time is totally prohibitive. A more efficient way of calculating the power absorption results when the velocity space integrals are brought outside of the sums over $\mathbf{k}_1$ and $\mathbf{k}_2$. In this case, the nested sums are replaced by a product of sums that is much easier to evaluate. Although the perpendicular velocity integral must be done numerically, there is still an enormous saving in computation time, and the power absorbed by non-Maxwellian components can be evaluated in approximately the same time as required to evaluate the plasma current.

To solve the Fokker-Planck equation self-consistently with the wave solution, the quasilinear operator[7] must be derived directly from the full-wave RF electric fields. The quasilinear diffusion coefficients are closely related to the power absorption, and can be deduced by writing the RF power absorbed in terms of the quasilinear coefficients. These coefficients are then bounce-averaged and used directly in iterative calculations with the CQL3D Fokker-Planck code. Examples of self-consistent iterative solutions obtained with AORSA and CQL3D include neutral beam ions heated by high harmonic fast waves in the National Spherical Tokamak

Experiment (NSTX), and tritium ions heated at the second harmonic resonance in the ITER burning plasma experiment.

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