Quasilinear Analysis of Lower Hybrid Current Drive in ITER and DEMO

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The active control of the radial current density profile is one of the major issues of thermonuclear fusion energy research based on magnetic confinement. Lower hybrid (LH) waves at several GHz could in principle be efficiently used, but the fact that electron temperature at reactor pedestal is too high for allowing efficient penetration of the coupled RF power due to the strong linear Landau damping, could prevent the current profile control over the desirable radial domain. On the other hand, the high density of thermonuclear plasma requires the grill to launch LH waves with parallel wavenumber greater then the critical one, in order to satisfy the accessibility condition.

In this work, we present new analytical and numerical results, based on the quasilinear theory, demonstrating that lower hybrid waves at several GHz can efficiently drive current in the outer radial half of a reactor plasma by using suitable power spectra, which could be easily launched by waveguide antennas. This analysis has been carried out by means of the code "Ray^{star}", a numerical tool that includes and integrates several modules: i) "LHPI", for parametric decay instability analysis at the plasma edge, ii) "Grill3D" for establishing the coupled spectrum, iii) "RayLH", to account for the evolution of wave trajectory and the calculation of the quasilinear diffusion coefficient, iv) "FokPla" to determine the 2D (in velocity space) equilibrium electron distribution function in presence of the LH waves, including electron trapping. The results of this analysis, performed for the expected plasma parameters of ITER (Scenario 2 and 4) and DEMO (Pulsed and Steady State), demonstrate the key role of the $n_{||}$ antenna spectrum as well as the antenna location (e.g., in the high field side) in determining the LH power penetration to the core of thermonuclear plasmas. An antenna spectrum with sufficiently narrow principal peak at the minimum accessible n|| moderates the strong absorption expected in a high temperature plasma (which however remains single-pass), and allows the wave to reach inner layers. PAM (passive-active multi-junction) antennas realistically designed for ITER and DEMO have been considered; the peak of the power spectrum and the spectral width can consistently be obtained by suitably feeding and phasing the waveguide of the PAM antenna in order to get a fine control of the radial deposition profile.

Wave propagation and quasilinear damping of LH waves have also been studied analytically, supporting the above numerical approach. The combined analytical solution of ray tracing, amplitude transport equations and time dependent 1D Fokker Planck equation, in fact, illuminates and explains features of the quasilinear approach and the key role of the wave spectrum for the LH power deposition profiles.