Integrability of electrostatic lower-hybrid ray trajectories in rippled cylindrical plasmas and the spectral gap of lower-hybrid current drive

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It has recently been shown [J. P. Bizarro *et al.*, Phys. Rev. Lett. **75**, 1308 (1995)], that the magnetic ripple caused by the discrete nature of the toroidal-field coils in a tokamak can have a significant effect on lower-hybrid (LH) wave propagation and, consequently, on LH current drive. Indeed, magnetic ripple may induce Hamiltonian chaos in the ray motion and thus lead to strong variations in the component of the wave vector parallel to the equilibrium magnetic field. Therefore, magnetic ripple can be effective in bridging the spectral gap typical of LH current drive and can greatly affect the LH wave accessibility to the plasma center. Such work has taken into account the electromagnetic effects in the LH dispersion relation.

In this communication, the frequencies of the unperturbed ray motion are obtained analytically to show that electrostatic LH ray trajectories are integrable in cylindrical plasmas with magnetic ripple for parameters typical of LH current drive. The analytical predictions, which are the first quantitative analytical results ever obtained concerning the nonlinear dynamics of LH rays, are confirmed by numerical calculations. Electromagnetic effects have thus to be retained in order to have ripple-induced ray stochasticity, which is linked to the existence of a separatrix for the ray motion defined by the accessibilty condition. As a consequence of this study one concludes that, for electrostatic LH propagation in weakly toroidal plasmas, where the poloidal mode number remains essentially zero, the spectral gap characteristic of LH current drive cannot be bridged by Hamiltonian ray stochasticity, an important result that is confronted with experimental data. In particular, the capability of ray tracing to provide a universal mechanism to fill the gap is seriously questioned.