The wave-mode purity in ECRH: advanced 3D ray-tracing modeling

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For an effective electron cyclotron resonance heating (ECRH) of plasma, a precise matching of the RF beam polarization to the vacuum/plasma boundary is required. However, even in the case of a pure wave-mode launched into the plasma, the propagation of the RF beam in tokamak and stellarator plasmas is always associated with the evolution of a wave polarization. As a consequence, initially pure wave-mode (say, X-mode) becomes a combination of the initial mode and the spurious one (O-mode). Thus, because the parasitic wave-mode is less absorbed than the main one, an unwanted and considerable stray-radiation may appear.

To calculate the wave-mode conversion rate along the ray propagating in 3D plasmas, the model based on the coupled equations has been developed. An accounted wave structure (WS) corresponds to the geometrical optics approach (GO): the wave-front is plane, and WS slowly varies on the wavelength scale. To avoid a significant increase of the computational times compared to the ray-tracing calculations, we consider at the moment only a 1D model coupled with the reference ray. Thus, the evolution of the polarization vectors is given by the solution of coupled 1D wave equations based on the ray-tracing with integration performed only in the direction of the ray. Finally, the effects related to the geometry, i.e. deviation of the ray from the straight-line, are taken into account as the wave-vector change and the ray’s metrical features. To utilize the coupled equations formalism for general geometry, we apply the numerical diagonalisation of the evolution matrix at every integration point along the ray. After this, the diagonalization matrix is calibrated to vary smoothly along integration curve. Based on this we solve final conversion equations.

To define an initial wave-mode purity at the entrance in plasmas, the module with routines for matching of the RF-beam polarization to the vacuum-plasma boundary has been developed and added to the TRAVIS code. It provides a more precise information for the ECRH scenarios as well as the ECE diagnostics and/or the final mode purity based on polarization parameters of the wave in the vacuum. This also includes the impact of re-entrances of the ray after reflections at mirrors/walls and the further wave-mode conversion inside the plasma. Calculations based on the developed method are implemented and integrated into the TRAVIS ray tracing code. Altogether, it allows us to make a further improvement of the model for simulations of the ECRH scenarios as well as the ECE diagnostics for the W7-X Stellarator.