2nd Asia-Pacific Conference on Plasma Physics, 12-17,11.2018, Kanazawa, Japan

Integro-differential full wave analysis of electron cyclotron resonance interactions in a tokamak plasma

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Externally launched radio-frequency waves in the electron cyclotron (EC) range of frequencies and their harmonics have strong resonance interaction with the plasma electrons in a toroidal device [1]. Together with the space-dependent magnetic field in a tokamak, they lead to highly localized resonance absorption and effective non-inductive current drive. Analysis of electron cyclotron heating (ECH) and current drive (ECCD) follow directly from the propagation and absorption characteristic of EC waves [1-2]. Most of previous analyses of propagation and absorption of EC waves in an inhomogeneous plasma are based on the wave number which is well-defined in a uniform plasma and has an essential role in describing the physics of plasma-wave interactions [3]. The dielectric tensor in a hot plasma has been usually expressed as a function of wave number. In order to describe the response of plasma without wave number, it is appropriate to use an integral form of dielectric tensor derived by integrating along an unperturbed particle orbit [4]. Maxwell's equation with the integral form of dielectric tensor is numerically solved as a boundary-value problem by means of the finite element method (FEM). Numerical analysis with FEM may have higher performance with parallel processing owing to sparse coefficient matrix. Though the integration is localized in an element in usual FEM for differential equations, coupling between elements in a localized region occurs in the FEM for integro-differential equations. In a magnetized plasma, guiding centre motion along an inhomogeneous magnetic field and cyclotron motion perpendicular to the magnetic field are considered for deriving the dielectric tensor as an integral operator. This scheme was applied to EC waves.

In this work, in the first case, one-dimensional analysis of cyclotron damping in the presence of magnetic field inhomogeneous along the field line is carried out by integral operator scheme [5] to obtain the power deposition profile in magnetic beach heating.

In the second case, the O-X-B mode conversion in spherical tokamaks [6] is studied. Mode conversion to the electron Bernstein wave and strong absorption at the cyclotron resonance are described. It is shown that the mode conversion efficiency is consistent with analytical estimates. The extension to two-dimensional analyses in an equatorial plane and a poloidal cross section of tokamak plasmas is also discussed and preliminary results are presented.

References

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