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Modeling of the electron cyclotron wave propagation in the boundary region of the high dense plasma

高密度プラズマの周辺部領域における電子サイクロトロン波帯の波動伝播モデリング

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With expanding the calculation region for the electron cyclotron wave propagation analysis outward the given last close flux surface (LCFS), the effect of the refraction on the shift of the O-X mode conversion window is investigated. If the ray-tracing calculation starts distant from the LCFS, influence of the wave refraction is enhanced even if the density is very low in the boundary region. This result suggests the importance to take into account the density profile in the weak confinement region in the plasma boundary.

1. Introduction

The ray-tracing calculation is widely used to investigate the characteristics of the electron cyclotron (EC) wave propagation and absorption in magnetic confined plasmas. In most cases, the initial values of the calculation are given where the line of site of the incident wave crosses the last closed flux surface (LCFS) based on the Snell's low on the assumption that the electron density is almost zero outside the LCFS that is given by the equilibrium analysis and rapidly increases inside the LCFS. However, practically the density is not necessarily zero at the LCFS and the plasma can spreads over the weak confinement region outside the LCFS. In the large helical device (LHD), the electron density at the artificially defined LCFS can be more than 80 % of the cutoff density of the EC wave for electron cyclotron resonance heating (ECRH) in high density operations. In such cases, to give the initial values at the LCFS may not adequate any more. We expand the calculation region for the ray-tracing outside the artificially defined LCFS and investigate the influence of the electron density profile in the plasma edge region on the wave propagation by giving various artificially density profiles.

In this paper, the influence of the edge density profile on the shift of the ordinary – extraordinary (O-X) mode conversion window is mainly introduced.

2. Shift of the O-X mode conversion window

In high density operations where the electron density at the electron cyclotron resonance (ECR) layer is more than the cutoff density of the electromagnetic mode, ECRH can be performed by the electron Bernstein wave (EBW) that can be excited by the injection of the electromagnetic wave via the mode conversion process. For the wave injection from the lower magnetic field side, the ordinary (O) mode is injected toward the point where the plasma cutoff and the left-hand cutoff are located close to each other so that the O-X mode conversion occurs. In the linear theory, the generated X-mode is fully mode

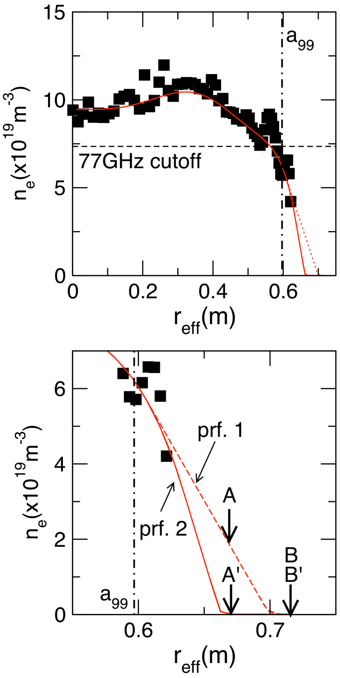

Fig. 1 : Measured electron density profile (square), density profiles used in the calculation (solid ant dashed lines). The ray-tracing calculation starts at the points A(A') and B(B').

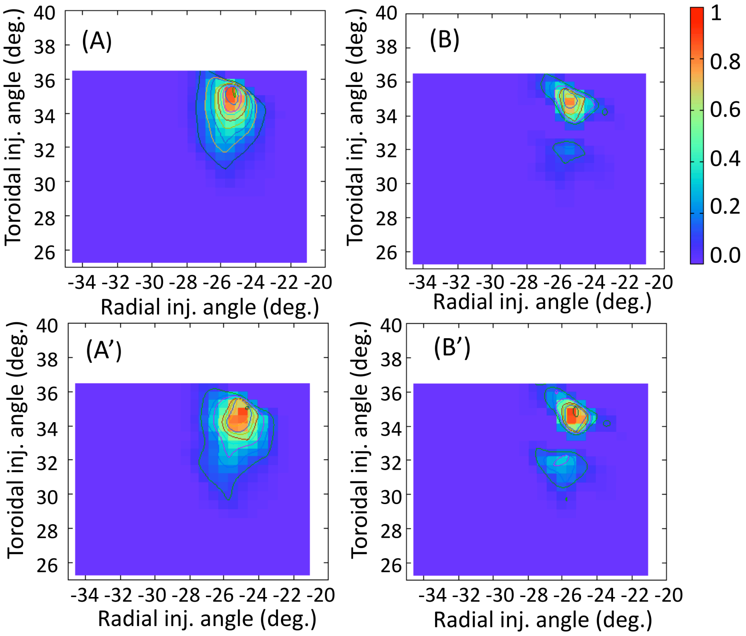

Fig. 2: Contour plots of the O-X mode conversion rate. (Upper) Plots for prf.1 for different calculation start points A and B. (Lower) Plots for prf.2 for different calculation start points A' and B'.

converted to the EBW (O-X-B mode conversion) if the density gradient at the mode conversion region is gentle enough. We call the range of the injection angle as the "O-X mode conversion window", with that high O-X mode conversion rate can be obtained.

Fig.1 shows the electron density profile given by the Thomson scattering measurement and profiles of the edge region given for the calculation. The plasma cutoff of the 77GHz EC wave is located near the a_{99} surface inside which 99 % of the electron kinetic energy is included. Outside the a_{99} surface, we adopt two types of the density profiles prf.1 and prf.2, and calculate the O-X mode conversion rate for various injection angles with taking into account to the wave refraction in the plasma with use of the ray-tracing calculation. For each profile, two calculation start points "A(A')" at r_{eff}=0.670m and "B(B')" at r_{eff}=0.716m are adopted as shown in the lower column in Fig. 1.

In Fig.2 the contour plots of the O-X mode conversion rate are shown as functions of the radial and toroidal injection angles for each profile and start point shown in Fig. 1. For the cases of the same calculation start point, the difference of the density profile does not affect the position of the O-X mode conversion (MC) window very much. Instead, the difference of the calculation start point affects the position of the O-X mode conversion window more. Influence of the wave refraction seems to be enhanced for the case of long distance propagation. This result means that even the density is low, the influence of the refraction cannot be ignored in the boundary region.

In addition to the influence of the refraction, the O-X mode coupling in the low density region caused by the existence of the magnetic shear may not be ignored. Even in the lower density discharges where the central electron density is about $1 \times 10^{19} m^{-3}$, the experimental results suggests that injected right-handed 2nd harmonic circularly polarized wave cannot couple to the X-mode well although the propagation angle to the magnetic field is large enough.

In the LHD, the stochastic layer where the plasma is confined weakly spreads for wide region. We cannot study the propagation of the EC wave over the stochastic region at present. With combination with 3D transport code in the scrape off layer, the calculation region can be expanded outward more.

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