§25. Numerical Study of Wave Propagation Near the OX Mode Conversion Region

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With the use of the plasma parameters around the O-X mode conversion region in the LHD, characteristics of the wave propagation were examined for 77GHz waves by full wave calculations by the TASK/WF2D code and compared with trajectories obtained by multi ray tracing calculations. The TASK/WF2D code solves the Maxwell's equation by finite elements method (FEM) in two dimensional (2D) space with use of the dielectric tensor of the cold plasma. We adopted a simple linear electron density profile that changes only along the x direction with $L_n/\lambda_0 = 53$ and a uniform magnetic field to be $\Omega_{ce}/\omega = 0.615$ parallel to the z direction, where L_n is the density scale length, λ_0 is the vacuum wavelength, Ω_{ce} is the electron cyclotron angular frequency, and ω is the wave angular frequency. The electric field as the boundary value is given based on the electric field at the aperture plane of a rectangular waveguide whose inner side a = 0.1 m. Fig. 1 shows wave patterns as contour maps of the x, y, z components of the electric field strength and contours of the absorbed power by collisional damping when the O-mode dominant electromagnetic (EM) waves are injected with the injection angle $\theta_{inj} = \theta_{opt} = arccos(N_{//opt})$ from the lower right side, where $N_{//opt} = \sqrt{\Omega_{ce}/(\omega + \Omega_{ce})}$. A part of the injected EM waves reaches the high density side of the evanescent region between the plasma cutoff (PC) and the left handed cutoff (LC) then propagates backward toward the upper hybrid resonance (UHR). The distribution of the absorbed power suggests this backward wave is fully absorbed by collisional damping near the UHR. Although the launching angle θ_{inj}, is set to be θ_{opt}, split wave patterns that might express the waves reflected near the PC as the O-mode are shown. Since the radiation pattern of the waves launched from the waveguide aperture is not strictly the same as that of the plane waves, the broadening of the launched wave might cause the deviation of $N_{//}$ from $N_{//opt}$ and reflection. Trajectories of the reflected O-mode obtained by multi ray-tracing calculations with taking into account the broadening explain this split wave pattern well. The wave pattern and the multi ray trajectories correspond with each other for the X-mode reflected at the right-handed cutoff (RC) also. However, the multi ray trajectories do not fully cover the wave patterns of the backward waves after the O-X mode conversion. For the cases of $N_{//} = N_{//opt} + 0.02$ and $N_{//} = N_{//opt} + 0.1$, the full wave and the multi ray tracing calculations were also performed in the same manner. As shown in Fig. 2, the deviation of $N_{//}$ from $N_{//opt}$ by 0.02 allows efficient O-X mode conversion but the deviation of $N_{//}$ from $N_{//opt}$ by 0.1 allows a very poor O-X mode conversion rate as shown in Fig. 3. In both cases multi ray trajectories do not fully cover the wave patterns of the backward waves after the O-X mode conversion also.

In the ray-tracing calculations, we determine the reference point where the perpendicular component of the refractive index $N_\perp$ becomes the minimum at the low density side of the evanescent region. The wave vector at the reference point, $\boldsymbol{k}_s$ is taken as a conserved value and the point where $\boldsymbol{k}_s$ is the solution of the dispersion equation is looked for in the high density side along the direction of the density gradient. From the comparison between the full wave calculations and the multi ray tracing calculations, it has been suggested that it might be better to place the restart point with taking into account the propagation perpendicular to the direction of the density gradient.

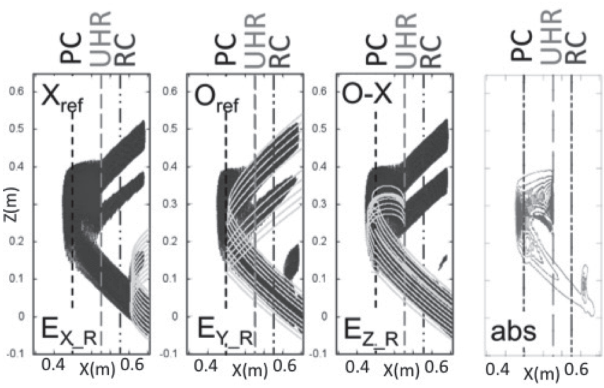

Fig. 1: Contours of the real components of the electric field (x, y, z from the left) and absorbed power obtained by full wave calculations when the injection angle set to be θ_{opt}. Multi ray trajectories of the (from the left) reflected X-mode, the reflected O-mode, and the X-mode converted from the O-mode are drawn over. $\theta_{inj} = \theta_{opt}$ at the beam center and $\theta_{inj} = \theta_{opt} \pm 1.5$ at each edge of the beam.

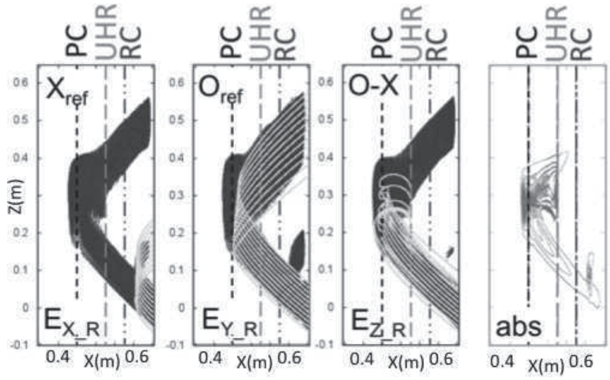

Fig. 2: Similar plots to Fig. 1 when $\theta_{inj} = arccos(N_{//opt}+0.02)$.

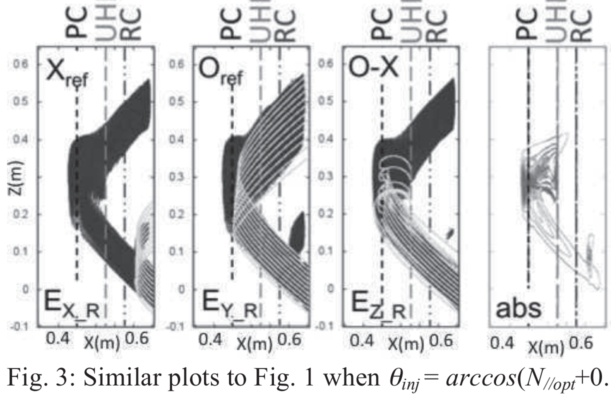

Fig. 3: Similar plots to Fig. 1 when $\theta_{inj} = arccos(N_{//opt}+0.1)$.