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ヘリオトロンJにおけるO-X-Bモード変換を介した電子バーンシュタイン波加熱のレイトレーシングシミュレーション

Ray tracing simulation of electron Bernstein wave heating via O-X-B mode conversion in Heliotron J

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In previous research, numerical analysis of electron Bernstein wave (EBW) heating via slow X - EBW (X-B) mode conversion was studied in Heliotron J by using a ray-tracing code with 3D MHD-equilibrium calculation code (VMEC). It showed that the X-B heating was effective, and the power was absorbed on the resonance layer. However, EBW excitation via X-B mode conversion is limited by engineering constraint, that is, the slow X mode must be excited from the high magnetic field side.

EBW heating experiment and electron Bernstein emission (EBE) measurement at 35GHz is planned in Heliotron J. In this case, the O-mode is injected from the low magnetic field side to easily access the EBW. For this reason, it is useful to analyze EBW heating via O-X-B mode conversion. We have been developing a ray-tracing code in order to enable a simulation of EBW heating via O-X-B mode conversion and to obtain analytical insight before the experiments. We have searched the optimal injection angle, estimated the conversion efficiency and the power-absorption distribution of EBW heating via O-X-B mode conversion.

The O-X conversion efficiency is a function of the injection angle and the electron density profile. The O-X conversion efficiency η is calculated by the following formula.

$$\eta = \exp\left[-\pi k_0 L \sqrt{\frac{\beta}{2}}\left\{(1+\beta)\left(N_{||}-N_{opt}\right)^2 + {N_\perp}^2\right\}\right]$$

Here k_0 is the wavenumber in vacuum, $L = n_e/|dn_e/d\boldsymbol{r}|$ is density gradient length, $\beta = \omega_{ce}/\omega$, and $N_{opt} = \sqrt{\beta/(1+\beta)}$.

Figure.1 shows the contour plot of the mode conversion efficiency η at the electron density of plasma center, $n_{e0} = 2.0 \times 10^{19}\mathrm{m}^{-3}$. We assume that the injection point corresponds to a port #9.5 of Heliotron J ($r = 1.885$m, $\theta = 67.5$deg, $z = -0.11$m), which is located at intermediate between the straight section and the corner section. We define the direction to torus center as the origin of toroidal angle, and the horizontal direction as the origin of the vertical angle. Notable optimal angle range can be seen in the vicinity of (-20deg, 3deg), but it is unavailable because of engineering constraint. Instead we carried out the heating analysis with the other optimal injection angle in the vicinity of (-11.38deg, -13.245deg) which overcomes the engineering constraint. The conversion efficiency reaches approximately 100%.

Figure 2 shows a ray trajectory with this optimal angle injection. Figure 3 shows the refractive index against the normalized minor radius, ρ/a. The EBW power is absorbed at ρ/a ~0.5.

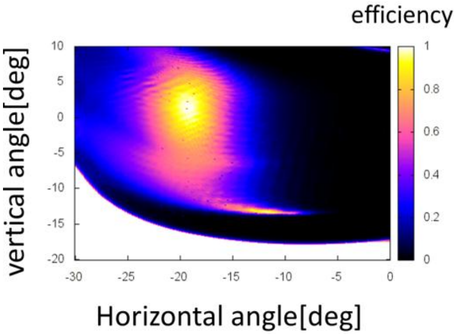

Fig. 1: Contour of
O-X conversion efficiency

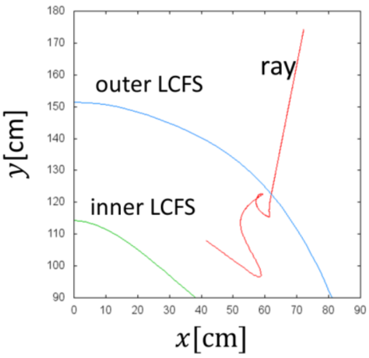

Fig. 2: Example of
ray trajectory

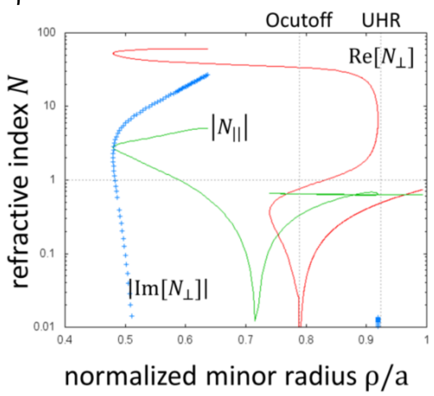

Fig. 1: Refractive index
as a function of **ρ/a**