§47. Effect of Magnetic Shear on Propagation and Absorption of EC Waves

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Electron cyclotron waves propagate in plasmas below cut-off density, which are ordinary (O) and eXtraordinary (X)-modes in cold plasma approximation. While these two modes propagate independently in uniform magnetic field due to the difference in refractive index, they are coupled in the field with magnetic shear through the non-uniformity, resulting that the mode power fraction changes along the propagation path. This phenomenon was experimentally observed at 106.4 GHz 2nd harmonic X-mode heating experiments in the Heliotron E device, and the results are in good agreement with simulation results using electric field equations with magnetic shear [1]. Since the LHD device has a strong magnetic shear as well as the Heliotron E device, it is expected that the O- and X-modes are coupled in particular at plasma edge region where the change in poloidal magnetic field changes much in the radial direction. The purpose of this study is to clarify the physical mechanism of the mode coupling and to optimize the ECH heating efficiency in LHD.

Figure 1 shows an example of mode coupling using a vector equation with Stokes parameter in the LHD configuration. The vector equation is given as [2]

$$\frac{d\mathbf{s}}{dz} = \mathbf{\Omega}(z) \times \mathbf{s}(z)$$

$$\mathbf{\Omega} = \begin{pmatrix} \Omega_1 \\ \Omega_2 \\ \Omega_3 \end{pmatrix} = \frac{\omega_{pe}^2 \omega_{ce}^2}{(N_X + N_O) c\omega^3 D} \begin{pmatrix} \dfrac{B_{xp}^2 - B_{yp}^2}{B^2(1-\omega_{pe}^2/\omega^2)} \\ \dfrac{B_x B_y}{B^2(1-\omega_{pe}^2/\omega^2)} \\ \dfrac{2\omega B_z}{\omega_{ce} B} \end{pmatrix}$$

$$\mathbf{s} = \begin{pmatrix} \cos 2\chi \cos 2\psi \\ \cos 2\chi \sin 2\psi \\ \sin 2\chi \end{pmatrix},$$

$$D = 1 - \frac{\omega_{ce}^2}{\omega^2} \frac{B_x^2 + B_y^2 + (1-\omega_{pe}^2/\omega^2) B_z^2}{\left(1-\omega_{pe}^2/\omega^2\right) B^2}$$

We assume the electron density profile observed in the plasma experiment. It can be seen that the injection wave mode is strongly affected by a plasma outside last closed flux surface and that the X-mode ratio oscillates with the period larger than the wavelength along the propagation path. In this case, the X-mode rate is 96 % at the resonance layer. It is possible to reach nearly 100 % by adjusting the polarization condition of injection waves. Figure 2 shows comparison of 77 GHz ECH absorption rate between the LHD experimental results and the simulation results. The simulation predicts that the absorption is nearly 100 % for circular polarization, while it is low ~80 %. We may need to include the experimental conditions such as magnetic field configuration and injection angle more accurately. Comparison with results from a full wave equation will be performed in the future.

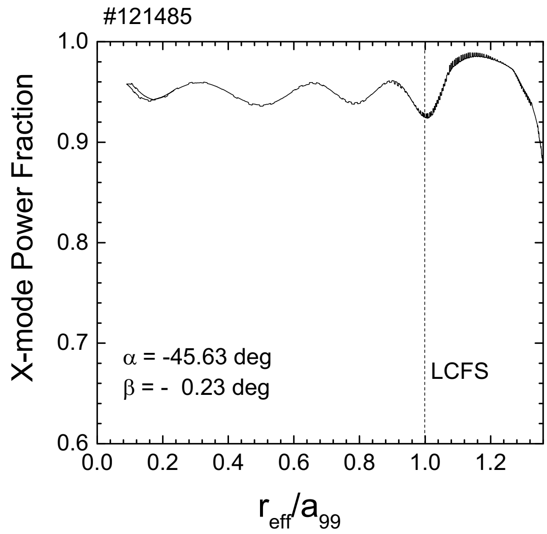

Fig. 1 X-mode ratio along propagation path in LHD

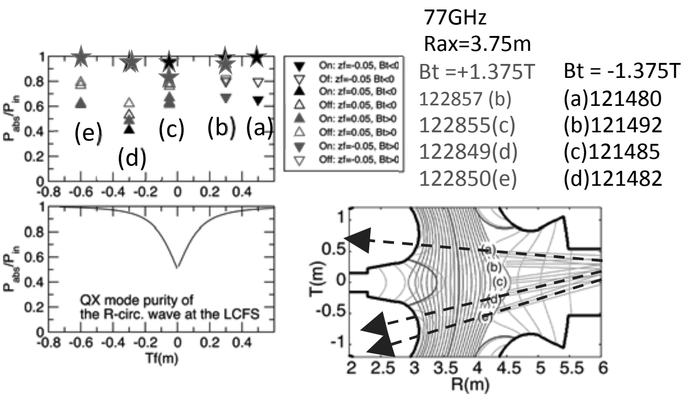

Fig. 2 Comparison of 77GHz ECH power absorption rate between experiment and simulation

1) K. Nagasaki, et al., Phys. Plasmas 6 (1999) 556
2) K. Nagasaki, et al., 20th Int. Stellarator-Heliotron Workshop, 5-9 October 2015, Greifswald, P2S1-13 (Poster)