§65. ECRH by Oblique Launching of the Fundamental X-mode in Relatively High Electron Density Plasma

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In LHD, the fundamental X-mode can access the ECR layer from the high field side by oblique upward launching from the L-port antenna in the following way. The launched wave first encounters the right-handed (R-) cutoff in the foreground of the ECR layer outside the last closed flux surface (LCFS). If the width of the evanescent region between the R-cutoff and the upper hybrid resonance (UHR) layer is thin enough outside LCFS, the launched X-mode may pass through the region and may reach the ECR layer. If the absorption in the ECR layer outside LCFS is weak, the X-mode can enter inside the LCFS from the high field side without damped out. The X-mode approaches the ECR layer again from the high field side inside the LCFS. If the parallel component of the refractive index $N_{//}$ has a finite value, the X-mode is strongly absorbed there and if $N_{//}$ is close to be zero, the X-mode can leave the ECR layer without being damped out then approaches the UHR layer. In the UHR layer, the X-mode is mode converted to the electron Bernstein wave (EBW) fully and is also absorbed by cyclotron damping in the ECR layer. Therefore almost complete power absorption as the X-mode or EBW is expected by obliquely launching of the fundamental X-mode.

In the previous study of the oblique launching in LHD, the X-mode was launched in discharges of relatively low electron density where $n_{e0} \leq 1\text{x}\ 10^{19}\text{m}^{-3}$. Power absorptions were observed in the region from ρ~0.3 to ρ~0.7 for various experimental conditions. The analyses with the ray-tracing calculation have suggested power absorption as the X-mode is dominant in such low density plasmas. They also suggest that if n_{e0} is higher than $2\text{x}\ 10^{19}\text{m}^{-3}$and if the X-mode is launched so that $N_{//}$ becomes nearly zero near the ECR layer[1)]. Note that $N_{//}$ can change along the orbit because of the inhomogeneity of the magnetic field therefore $N_{//}$ can become zero although it is not zero at first.

In the last 13th experimental campaign, 84GHz millimeter wave was launched to couple with the X-mode in discharges of n_{e0}~$2\text{x}\ 10^{19}\text{m}^{-3}$ and n_{e0}~$5\text{x}\ 10^{19}\text{m}^{-3}$. The magnetic configuration was (R_{ax}, B_t, γ, B_q)=(3.7m, 2.675T, 1.254, 100%). Fig. 1 shows discharge waveforms where n_{e0}~$5\text{x}\ 10^{19}\text{m}^{-3}$. Temperature rise was observed by ECE in the region ρ=0.46~0.88. Changes of the gradient of the stored energy were observed in both moments when the ECRH power was turn-on and turn-off. Fig.2 shows the results of ray-tracing calculation in which the electron density profile $n_e(\rho)=4.7*(1-(\rho/1.25)^8)^2$ and the electron temperature profile $T_e(\rho)=1.95*(1-(\rho/1.25)^2)^2$ are adopted to fit the profile obtained by Abel transformation of the line integrated electron density profile measured by the FIR interferometer and the electron temperature profile obtained by Thomson scattering measurement. For 181 rays, ray-tracing calculations have been done. In the experiment, the aiming point of the launched wave was set as (R_f, T_f, Z_f)=(3.26m, -0.55m, 0.0m), where R_f, is the radial distance from the center of the torus, T_f, is the distance from the vertically long cross section and Z_f is the vertical distance from the mid-plane. In that case of launching, as shown Fig.2 (a-1) and (a-2), about 10 % of the launched power is absorbed as EBW. Inside LCFS the power absorption occurs around ρ =0.8 that is included in the region where the power temperature rise was observed in the experiment. Minor deviation of the alignment of the launched beam may more power absorption. About 25% of the launched power is absorbed as EBW inside LCFS as shown Fig.2 (b-1) and (b-2). Power absorption as the X-mode occurs before the X-mode enter inside LCFS and also occurs after the wave travels through the central region of the plasma then get out of LCFS. Because the twisted helical coils are located near the entrance and the exit of the wave and the resonance condition is fulfilled in both cases. The orbit and the power absorption efficiency of the X-mode is strongly affected by the electron density and temperature profiles outside LCFS. However it is difficult to know the profile correctly since they might be no more functions of the extrapolated normalized minor radius outside LCFS. Ray-tracing with various types of the peripheral temperature density profiles are required for the affirmation.

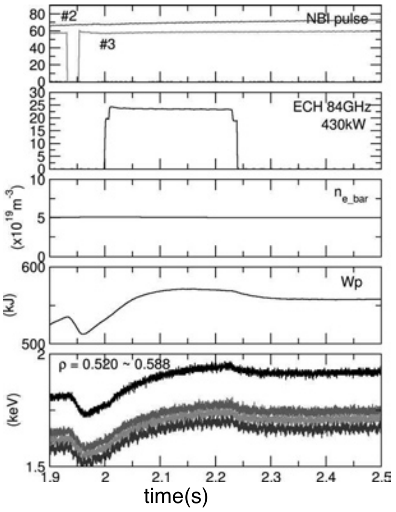

Fig. 1: Discharge waveforms. 84GHz, 430kW millimeter waves were launched into the NBI heated plasma. The electron temperature changes are shown in the bottom column.

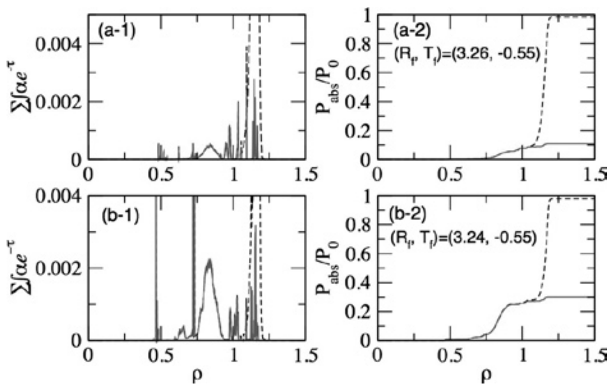

Fig.2 : Profiles of local absorbed power and summed absorbed power integrated along the normalized minor radius ρ.

1) Igami, H.,et al. : Nuclear Fusion **49** (2009) 115005