§16. Extension of Plasma Density Region Heated by Third Harmonic ECRH and Optimization of Antenna Focal Position

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We have been continuing the study of the high harmonic electron cyclotron resonance heating (HH-ECRH) to extend the heating region of higher density and higher beta plasmas. The 3rd harmonic electron cyclotron heating by the extraordinary mode injection (X3 heating) can enlarge a possible heating region up to the higher density and higher beta region than the 2nd harmonic X mode heating when the same frequensy gyrotrons are used. So far we successfully performed O2 and X3 EC heating experiment at 77 GHz frequency region [1, 2].

The objective of the 3rd harmonic heating experiment in this experimental campaign is to extend the density region of the target plasma heated at the 3rd harmonic resonance, because the absorption efficiency of the harmonic heating strongly depends on the plasma density. The X3 heating experiment was conducted by the ECRH power injection from 5.5U antenna using one of a MegaWatt 77 GHz gyrotron. We selected the magnetic field strength of 0.95 T so that the position of the magnetic axis coincided with ECR, when the Shafranov shift was taken into account. A target plasma was produced by a tangentially injected NBI with negative ion sources (N-NBI, Energy$\simeq$180 keV) and it was sustained by a perpendicularly injected NBI with positive ion sources (P-NBI,Energy$\simeq$40 keV) without plasma current. The plasma density was ramped up to 3×10^{19} m^{-3}. The millimeter-wave power of 77 GHz was injected from the 5.5U-out antenna. The absorption rates and the electron temperature values at the ECRH turn-on and -off timings are plotted for the 5.5U-out antenna case as a function of the line-averaged electron density in Fig. 1. The maximum absorption rate of about 40 % was obtained around the density of 1.5×10^{19} m^{-3} with $T_e \sim 1.2$ keV at the ECRH off timing.

During the above experiments, we also obtained the antenna focal position dependence of the absorption rate using the pulse train injection of gyrotron power during the plasma density ramp-up. The obtained results are summarized in Fig. 2 a). The absorption rate for the fixed antenna focal position on the equatorial plane is plotted as a function of the line-averaged electron density. In the low density region ($1.5 - 2.0 \times 10^{19}$ m^{-3}), the outer focal position such as R_f=3.63 - 3.65 m is better than the inner focal position as R_f=3.61 - 3.59 m. In the higher density (2.5×10^{19} m^{-3}), the absorption becomes better for the inner focal position. When R_f=3.67 m, a part of the injected millimeter-wave beam cannot pass through the resonance and the absorption rate totally decreases. The example of the ray-trace calculation is shown in Fig. 2 b). The optimized focal position is the envelope of the maximum absorption lines shown by dashed line. A real-time control of the antenna focal position is required to realize this operation.

1) T Shimozuma, et al., Plasma and Fusion Research, 8 (2013) 2402073-1 – 2402073-5.

2) T Shimozuma, et al., Proceedings of 25th IAEA Fusion Energy Conference, St. Petersburg, Russia (Park Inn Pribaltiyskaya), 13–18 October 2014, EX/P6-34. to be published in Nucl. Fusion.

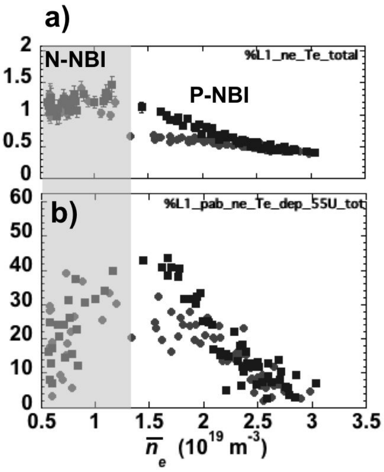

Fig. 1: Dependence of X3 (5.5U-out antenna) absorption rate estimated at ECRH turn-on timing (circles) and -off timing (squares) on the line-averaged density in b). Density dependence of electron temperature at the center is also plotted in a). In the low density region (the hatched region), the target plasma was sustained by the negative ion source NBI(N-NBI). The higher density plasma, on the other hand, was sustained by the P-NBI.

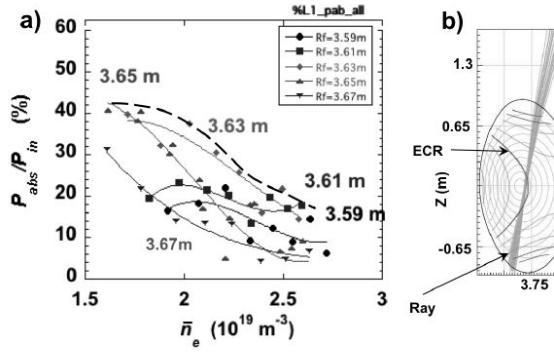

Fig. 2: a) The absorption rate is plotted as a function of the line-averaged density for several fixed antenna focal position indicated in the figure. The example of the ray-tracing calculation result with the injection configuration is shown in b).