§11. Experimental and Ray-Tracing Study of the Third Harmonic ECH

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The 3rd harmonic electron cyclotron heating by the extraordinary mode injection (X3 heating) can enlarge a possible heating region up to the higher density region. Up to now, we successfully performed X3 EC heating experiment at 168 GHz, 84 GHz [1)] and 77 GHz frequency region [2)].

The objective of the 3rd harmonic heating experiment in this experimental campaign is to obtain a data set of the target plasma with wide plasma density and antenna forcal position, because the absorption position and efficiency of the harmonic heating is strongly affected by the refraction around the ECR due to the finite temperature dispersion. The X3 heating experiment was conducted using three 77 GHz gyrotrons. The cut-off density is $5 \times 10^{19}\mathrm{m}^{-3}$. 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 co-injected NBI and sustained. The millimeter-wave power of 77 GHz was injected from 2O antenna (t =3.7 s - 3.9 s), 9.5U antenna (t =4.1 s - 4.3 s) and 5.5U antenna (t =4.5 s - 4.7 s). A time evolution of the core electron temperature ($r_{eff} \sim 0$ m) measured by Thomson scattering is shown together with the ECH pulse, the plasma stored energy and the line-averaged density in Fig.1. The core electron temperature increases with the ECH power injection except the non-optimized 2O antenna injection. The line-averaged density was changed from 0.7 to $2.2\times10^{19}\mathrm{m}^{-3}$. The central electron temperature was about 1.2 keV.

The absorption rate of the ECH power for each antenna was estimated by the calculation of an increment of $\mathrm{d}W_p/\mathrm{d}t$ just before and after the turn-on timing of each ECH pulse. Focal position dependences of the absorption rate were investigated for 9.5U-in antenna (Fig. 2) and 5.5U-out antenna (Fig.3) in two density groups, such as around 0.7 and $2.1\times10^{19}\mathrm{m}^{-3}$. The dashed lines show the calculation results by TRAVIS ray-tracing code. On the whole, the experimentally estimated absorption rates are almost a half of the calculated ones. For both cases, the focal positions giving the maximum absorption move to the higher field side of the ECR (smaller R_f) with density. In the high density cases of the experiment, the absorption was still observed for the injection beyond ECR position ($R_f > 3.7$m), while no absorption occurred in the calculation. This suggests that the multi-reflection effect becomes stronger in the high density cases.

We deeply acknowledge Drs. N. B. Marushchenko and Y. Turkin for using TRAVIS ray-tracing code.

1) T Shimozuma, *et al.*, PFR, (2008) Vol.3, S1080-1 – S1080-5.
2) T Shimozuma, *et al.*, to be published in PFR.

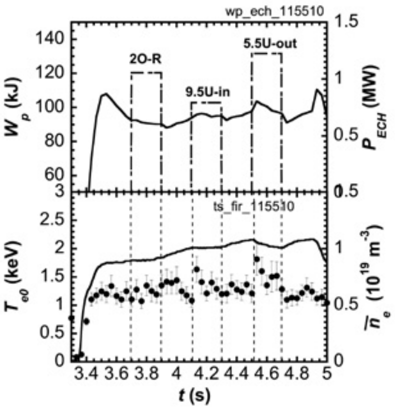

Fig. 1: A time evolution of plasma stored energy, line-averaged electron density , electron temperature with ECH injection timing and power.

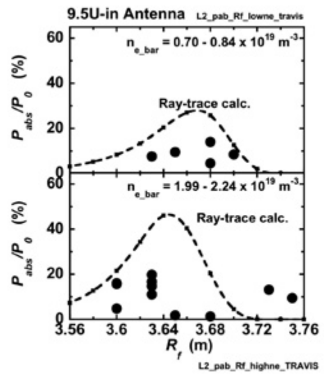

Fig. 2: The focal position dependences of the absorption rate (9.5U-in antenna) in two density cases. Filled circles are experimentally obtained, and dashed lines show the TRAVIS results.

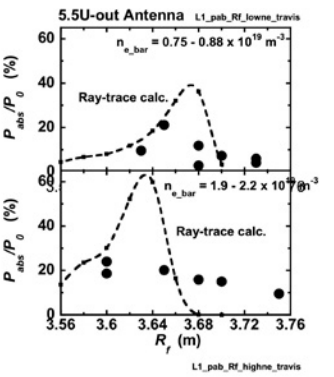

Fig. 3: The focal position dependences of the absorption rate (5.5U-out antenna) in two density cases. Filled circles are experimentally obtained, and dashed lines show the TRAVIS results.