§61. Second Harmonic Ordinary Mode EC Heating Experiment by 77GHz High Power Injection

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High-harmonic electron cyclotron heating is an effective method to heat high density and high beta plasmas. In place of the fundamental ordinary (O1) mode and the second harmonic extraordinary (X2) mode heating, a sufficient heating efficiency will be expected using the second ordinary (O2) mode and the third extraordinary (X3) mode heating scenario, when the temperature and density of a target plasma is sufficiently high[1)]. For example, a cut-off density of the O2 mode wave propagation is double of X2 mode cut-off density. The objective of this research is to confirm the effectiveness of O2 mode heating experimentally.

A target plasma was sustained by NBI, and its density was ramped-up from 2 to 6 $\times 10^{19}\mathrm{m}^{-3}$ over the X2 cut-off density ($3.7 \times 10^{19}\mathrm{m}^{-3}$) in the discharge time of 2 sec. An O- and X- mode polarized wave were injected from the O-port antenna that was installed in the horizontally elongated cross section. In this configuration, the wave could be injected almost perpendicularly to the electron cyclotron resonance layer, and the inflection effect of the wave was expected to be small. The magnetic strength at the magnetic axis of 3.6 m was 1.43 T. Five ECH pulses with 200 ms pulse width and 1 MW power were injected every 300 ms. The time trace of the ECH and NBI pulses, line-averagd electron density (n_{e_bar}) and stored energy(W_p) for the O mode injection are show in Fig. 1. During the shot, the central electron temperature decreased from 1.5 keV to 1 keV with the increase of the electron density. The absorption rate of the O2 and X2 mode power for each pulse could be estimated by the calculation of an increment of $\mathrm{d}W_p/\mathrm{d}t$ just before and after the turn-on and turn-off timing of each ECH pulse. A density dependence of the absorption rate is plotted in Fig. 2. The vertical dashed line corresponds to the cut-off density of X2 mode ($3.7 \times 10^{19}\mathrm{m}^{-3}$). In X2 mode case, the maximum absorption rate reaches 80 %, whereas it is 50 % for O2 mode. Over the cut-off density of X2 mode, however, the absorption rate of O2 mode overcomes that of X2 mode. This means effective heating of O2 mode over the cut-off density of X2 mode. Leakage RF signals detected by a sniffer probe, which is installed in the same port as the antenna installed, are also plotted in the figure. The leakage RF signal, which reflects a non-absorbed RF power in a single pass, gradually increases with density and continues to increase over the cut-off density for X2 mode injection. On the contrary, the leakage RF signal for O2 mode injection does not change so much over the wide density range. The behavior of the sniffer probe signals explains that O2 mode absorption is not affected by X2 cut-off and even density, though its absorption is determined mainly by low electron temperature.

Ray-traving calculations using TRAVIS code [2)] were also performed in the same magnetic and injection conditions. The results shows a hundred percent absorption of X2 mode below the X2 mode cut-off denity and sharp decrease of the absorption to zero just above the cut-off. On the contrary, the absorption of O2 mode is increasing gradually with the density and reaches the maximum of about 40 % around $4.5 \times 10^{19}\mathrm{m}^{-3}$. These behaviors are qualitatively agreed with experimental results. However, a multi-reflection effect should be considered to explain the difference in the absolute values of the absorption.

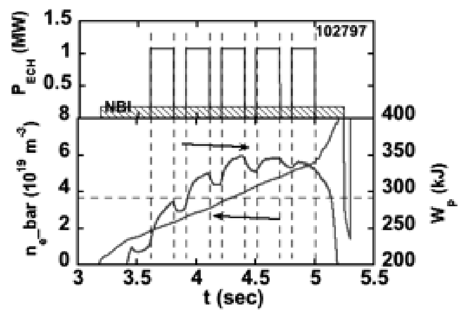

Fig. 1: The time trace of the ECH and NBI pulses, line-averagd electron density (n_{e_bar}) and stored energy(W_p) for the O mode injection.

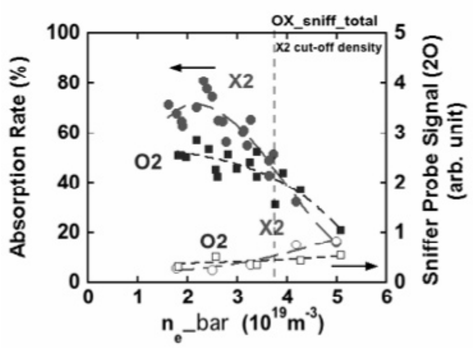

Fig. 2: The dependences of power absorption on the line-averaged density are plotted fro O2-mode (closed squares) and X2 mode (closed circles) injection. The sniffer probe signals are also shown for O2 (open squares) and X2 (open circles) modes.

1) T Shimozuma, *et al.*, PFR, (2008) Vol.3, S1080.

2) N.B. Marushchenko *et al.*, PFR, (2007) Vol.2, S1129.