§8. Preliminary Experimental Results of High Density Plasma Heating by Use of 154 GHz Gyrotron

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As a result of NIFS collaboration research program with University of Tsukuba, a new high power and higher frequency 154 GHz gyrotron to perform plasma heating at high density region up to 14.7×10^{19} m^{-3} (right-hand cutoff density of 154 GHz waves at 2.75 T magnetic field) was fabricated and delivered to NIFS in 2012. The 154 GHz EC-waves from the gyrotron were applied to LHD experiment for the first time in the 16th experimental campaign. The transmission line for the new gyrotron was connected to the antenna called "2-O left" installed in the 2-O horizontal port.

A series of discharges with wide range of electron density was performed to confirm the capability of high density plasma heating by 154 GHz waves. The sub-cool magnetic field configuration of R_{ax} = 3.6 m with B = 2.85 T was selected so that second harmonic electron cyclotron resonance layer existed at the equatorial plane in the horizontally elongated poloidal cross section. The target plasmas were sustained with NBI#2 and #5. Plasma density was controlled by additional gas-puffing and/or SSGP. The aiming direction of EC-wave beams was set obliquely with the setting parameters (R_f, T_f, Z_f) = (3.9 m, 0.2 m, 0 m) so that the beam aimed at a position 0.2 m apart from the 2-O cross section to 1-O side, with radial position of ~3.9m.

Figure 1 plots the waveforms of plasma stored energy W_p, line average electron density n_{e_ave} and EC-wave pulses in one of the discharges. The 154 GHz EC-waves of 0.95 MW were injected in X-mode polarization with 25 Hz power modulation. At the density region fairly lower than the right-hand cutoff density, the responses of W_p are quite clear to each EC-wave pulse. Heating efficiency evaluated from the changes in W_p is higher than 90 %. Electron temperature profiles at the start timing of EC-wave injection (5.2 s) and the stop timing (5.1 s) of different pulses, to match with the measuring timings of Thomson scattering diagnostics, were compared in Fig. 2. Increase in the profile at the stop timing corroborates the increases in W_p.

Figure 3 summarizes the heating efficiencies experimentally obtained and calculated by use of TRAVIS code, as functions of n_{e_ave}. Unfortunately, appropriate high density plasma with n_{e_ave} higher than the plasma cutoff density of 77 GHz waves, 7.4×10^{19} m^{-3}, was sustained in only one discharge, but this result provides a clear indication of the advantage of applying 154 GHz EC-waves in LHD for high density plasma heating.

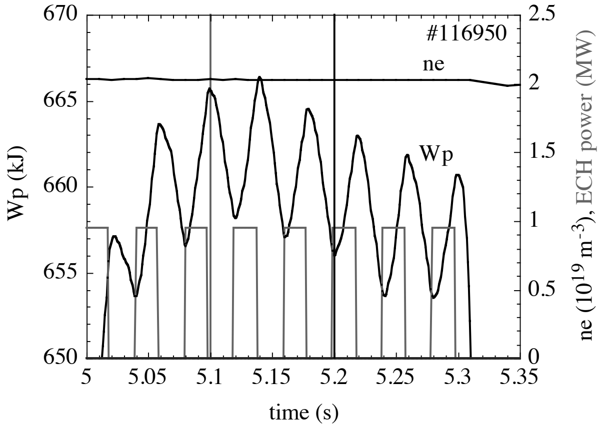

Fig. 1. Waveforms of plasma stored energy, line average electron density and 154 GHz EC-wave pulses in the discharge #116950.

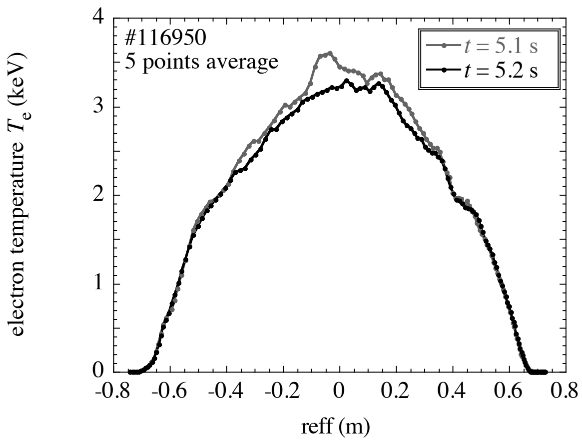

Fig. 2. Electron temperature profiles at the timings of 5.1 s (red, end of ECH pulse) and 5.2 s (black, start of ECH pulse), indicated by vertical lines in Fig. 1. Each data point shows averaged value of neighboring 5 original points to suppress meaningless fluctuations.

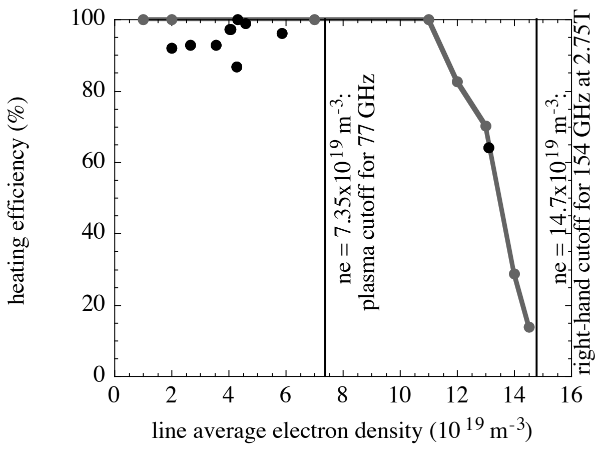

Fig. 3. Heating efficiencies (black circles: experiment, red circles connected with lines: calculation by TRAVIS code) are plotted as functions of line average electron density.