§11. Evaluation of ICRF Heating Characteristics in the LHD

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In order to heat plasma by ion cyclotron range of frequencies (ICRF) efficiently, minority ion heating is used in Large Helical Device (LHD) experiments. Minority ion heating was adopted in helium majority and hydrogen minority in the LHD. In the ICRF minority ion heating, the efficiency strongly depends on the minority ion ratio. The heating efficiency also depends upon the resonance layer, plasma loading, plasma parameter, and antenna shape such as with/without faraday shield (FS) because these parameters change the fast ion tail, the absorption layer and/or heating power to peripheral region. The investigation of the efficiency of the ICRF heating is important to achieve the generation and to sustain higher performance plasma. However, the actual relation of the high energy tail generation and bulk relaxation rate during the ICRF power injection remains unclear. In this study, the ICRF heating efficiency was investigated by the ICRF power modulation experiments. The accelerated high energy tail count N_t is detected by the silicon-diode-based fast neutral analyzer (Si-FNA). The sight line of the Si-FNA is perpendicular to the magnetic field line, and particles more than 20 keV are integrated. Plasma stored energy W_d is measured by diamagnetic loops. W_d represents the sum of the stored energy of the bulk plasma and fast ions. Figure 1 shows the modulated ICRF power P_{ICH}, the count of the detected fast ions N_t, and stored energy W_d. In the ICRF minority heating, RF power is absorbed by minority ions and transferred to bulk ions by collision. As shown in Fig. 1, we obtained the information of the delay of glows of the fast ion counts and delay of the measured stored energy W_d, which represent the fast ion confinement time τ_{tail}, the energy relaxation tail to bulk time $\tau_{t\text{-}b}$, and the energy confinement time τ_E. W_d contains both the stored energy of the fast ions and the bulk ions, however, significant difference of the delays was observed. This means the energy relaxation time $\tau_{t\text{-}b}$ is shorter than the modulation frequency 4 Hz. The heating efficiency η and energy confinement time τ_E can be calculated by the modulation amplitude and phase delay in the condition of ignorable small tail energy[1)]. However, recent ICRF experiments cannot ignore the tail energy by the recent upgraded ICRF heating power. We obtained the heating characteristics of three types of antenna as shown in Fig. 2. The amplitude of the count of the detected fast ions N_t and stored energy W_d were proportional to the modulation amplitude P_{ICH} with different tendencies by the three antennae. However, the rate of generation of the tail and energy relaxation time were the same by the different antennae.

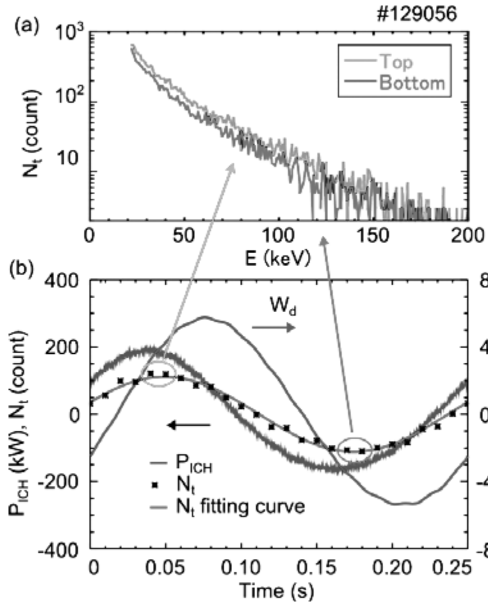

Fig. 1. Sinusoidal modulation experiment for investigating the heating characteristics of various antennae. By modulating the ICRF power, the modulation signals of high energy count N_t and plasma stored energy W_d were observed. (a) The effective temperature T_{eff} were almost the same at the top and the bottom of the sine curve.

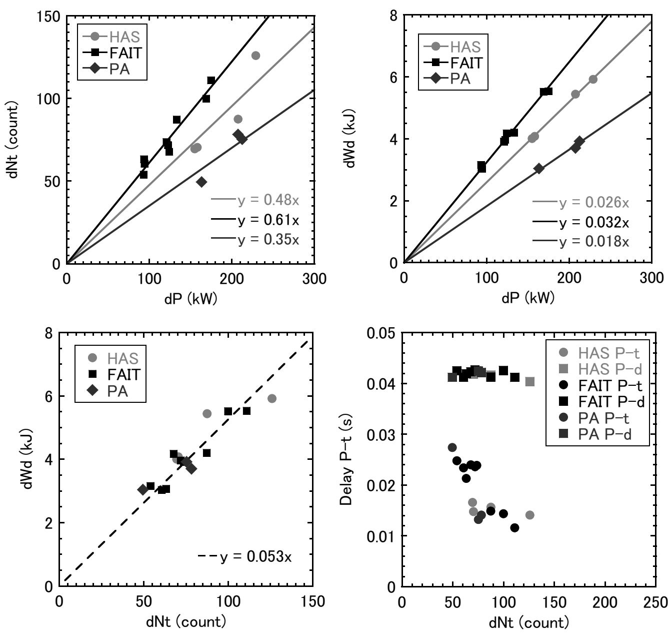

Fig. 2. Modulation amplitude of the N_t and W_d differed by the antenna type during the changing of the ICRF power P_{ICH}. On the other hand, the rate of generation of the tail and energy relaxation time were the same by the different antennae.

1) Torii, Y., et al.: Plasma Physics and Controlled Fusion 43 (2001) 1191-1210