§14. ICRF Heating Experiment in Heliotron J

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Main purpose of this study is to understand the heating mechanism of ICRF heating in the Heliotron J magnetic field and improvement of the heating efficiency. For the minority heating scheme, the fast ion generation and its confinement are key issues because the RF energy is absorbed mainly by the minority ions. The bulk heating is performed via Coulomb collisions with the fast-minority ions.

Fast ion velocity distribution is investigated using fast protons generated by ICRF minority heating in Heliotron J, a low-shear helical-axis heliotron ($R_0 = 1.2$ m, a = 0.1-0.2 m, $B_0 \leq 1.5$ T), with special emphasis on the effect of the toroidal ripple of magnetic field strength. The configurations used in this study are as follows; the bumpiness (B_{04}/B_{00}, where B_{04} is the bumpy component and B_{00} is the averaged magnetic field strength) are 0.15 (high) and 0.06 (medium) at the normalized radius of 0.67. The configuration of $B_{04}/B_{00} = 0.06$ corresponds to the standard configuration in Heliotron J. The bumpy field component is controlled mainly by changing the current ratio of toroidal coil A to toroidal coil B. The fast ions are measured by a charge-exchange neutral particle energy analyzer (CX-NPA) installed at the opposite position in the toroidal angle to the ICRF antennas. From the measurement, the pitch angle dependence of the energy spectra for three bumpy configurations is observed. The majority species of plasma is deuteron and the minor is proton. The minority ratio is about 10%.

The ICRF wave of the frequency of 23.2 MHz for the high bumpy case and 19 MHz for the medium and low bumpy cases is injected into ECH plasmas[1), 2)]. The frequency is selected so that the ECH resonance is positioned at the axis of the plasma. The magnetic field is 1.25T at the plasma axis in the ECH injection section. The line-averaged and ICRF injection power are 0.4 x 10^{19} m^{-3} and about 0.3 MW, respectively. The energy spectra obtained in three bumpy configurations are shown in Fig. 1 for various pitch angles by changing toroidal angle of the CX-NPA. The high energy component is observed near the pitch angle of 120 deg in the range of observation from 111 deg to 128 deg in the high bumpy case. The tail component extended to about 30 keV is observed only in the high bumpy case. The variation for the pitch angle is very small for the medium bumpy case. However, the amount of the high energy flux is largest near 120 deg as the high bumpy case. In the low bumpy case, the pitch angle dependence is different from the other two cases. The slope of the energy spectra is gradually decreased from 127 deg to 108 deg. There is not high energy flux beyond 15 keV in the medium and low bumpy cases. The good confinement of the fast ions in the high bumpy configuration has been expected from the loss region in velocity space calculated by the orbit tracing without collisions.

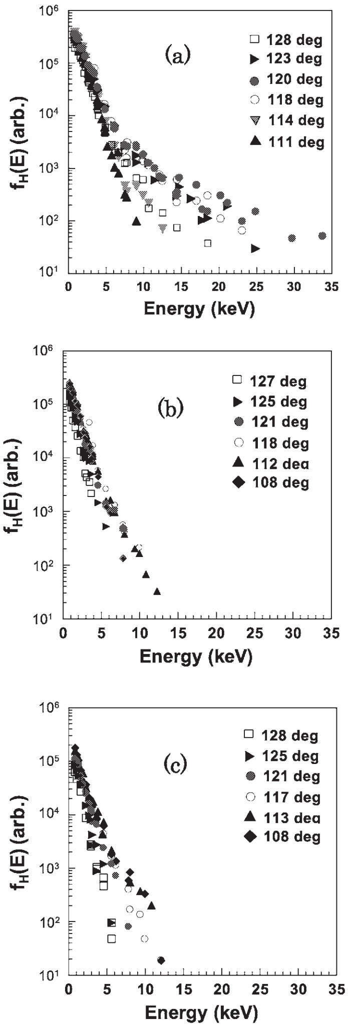

Fig. 1 The energy spectra of minority protons for various pitch angles in the tree bumpy configurations.

In the experiment, the sampling volume of the CX-NPA in real and velocity space is restricted; the energy spectra are calculated using a Monte-Carlo code with collision effects and ICRF acceleration term to understand experimental results. Minority protons are considered to be test particles, then, the bulk plasma parameters are constant in time. The initial velocity distribution of protons is assumed to be a Maxwellian corresponding to the bulk ion temperature. The density and temperature profiles are assumed to be uniform in the toroidal and poloidal directions and parabolic in the minor-radius direction. The energy spectra in these conditions are saturated within 1 ms after the initial timing, then estimated for every 10 deg of pitch angle. The high energy ions are generated near 60 deg and 120 deg in pitch angle and largest in the high bumpy case as the experimental result. The energy spectra in the medium and low bumpy cases have peak near 90 deg. In the low bumpy case, the amount of high energy ions is smallest among three bumpy cases. The asymmetry of the energy spectra on the both side of 90 deg is observed in the calculated spectra. For the next step, the energy spectra on the opposite side will be investigated experimentally and the ICRF field calculation will be included in the calculation model.

1) H. Okada, et al., "Velocity Distribution of Fast Ions Generated by ICRF Heating in Heliotron J", Proc. 22nd IAEA Fusion Energy Conference (2008) EX/P6-28.
2) H. Okada, et al., "Configuration Control Experiment in Heliotron J", Proc. 18th International Toki Conference (2008) I-03.