§27. Study of Optimization of the ICRF Heating in Heliotron J

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Main purpose of this study is to optimize ICRF heating in a helical-axis heliotron device, Heliotron J on the basis of results of several helical devices. In the previous experiment, good confinement of fast minority ions and high-efficiency of ICRF heating for a high bumpiness have been achieved in the minority heating using hydrogen and deuterium as a minority and a majority, respectively. The bumpinesses (B_{04}/B_{00}, where B_{04} is the bumpy component and B_{00} is the averaged magnetic field strength) are chosen to be 0.15 (high) and 0.06 (medium, STD) at the normalized radius of 0.67 in this study. In STD configuration, the heating position effect has been observed as well by changing an ICRF frequency. In these experiments, the high energy ions are distributed asymmetrically against the magnetic axis chord in the vertical angle scan of the charge-exchange neutral particle energy analyzer (CX-NPA).

The magnetic field of Heliotron J is non-symmetric configuration. The profile measurement in the poloidal cross section seems to be important as well as the pitch angle distribution of the fast ions in the three-dimensional magnetic field of Heliotron J. The wide range observation (about 25% in the poloidal cross section) of fast ions is performed by changing the line of sight of the CX-NPA in two directions for three bumpinesses[1]. For the quantitative comparison of the fast ion tail, the effective temperature of fast minority ions is defined as the slope of the energy spectrum in the range of 1 keV to 7 keV. In this energy range, protons can follow a banana orbit although the collision effect is not negligible. The better performance of the high bumpiness is confirmed in this vertical angle scan of the CX-NPA at several horizontal angles as shown in Fig. 1 (a)-(c). The tail temperature is largest in the high bumpiness case and the difference of the energy spectra in the vertical scan within 0.4 in the normalized minor radius is very small for the on-axis heating condition. In addition to that, the scan experiment is performed for another resonance location in the medium bumpiness (See Fig. 1 (d)). The largest change in the vertical scan is found for the inner-side heating in the medium bumpiness at φ = 0° and 4°, whereas there is little change at 6°. Here, φ is the horizontal angle of the CX-NPA, φ = 0° corresponds the line of sight crossing the torus axis. In the upper part of the plasma, more fast ions are observed. There is no such profile change in the on-axis condition for three bumpinesses. The experimental condition is as follows: the magnetic field strength is 1.25 T, the line-averaged electron density is 0.4×10^{19} m^{-3} and the ICRF power of 0.25–0.30 MW is injected into a target plasma produced by a 70-GHz ECH. The ion and electron temperatures at the center of the ECH plasma are about 0.2 and 0.8 keV, respectively. The minority ratio is about 10%.

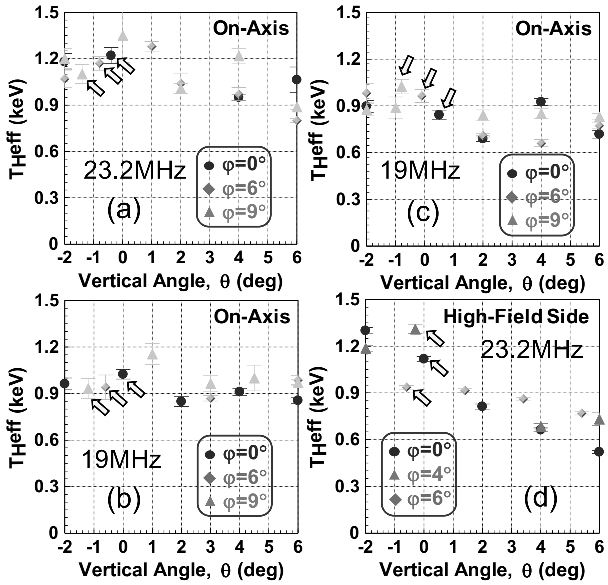

Fig. 1 The effective temperature profiles of fast minority ions at horizontal angle, φ, in (a) the high bumpiness, (b) the medium bumpiness, and (c) the low bumpiness. The high field side heating case in the medium bumpiness is (d). The line of sight crossing the magnetic axis is indicated by the arrows.

The area of the CX-NPA measurement is limited due to the observation port size. For the comprehension of the fast ion confinement, however, the fast ion information in all area of the plasma volume is required. For this purpose, a Monte-Carlo simulation has been developed. Using this code, the toroidal angle distributions of fast minority ions for one toroidal period are calculated for four cases of Fig. 1. The number of fast ions is summed up for each poloidal cross section within 10° in toroidal angle. From the result, it is found that the fast ions in the high bumpiness are largest at every angle. It is also found that the number of fast ions is larger in the corner section for the high-field side heating case and the fast ions in the on-axis heating cases are almost uniformly distributed in toroidal direction. For the resonance layer change experiment in STD configuration, the increase of the fast ions in the high-field side heating case is found near the corner section. The total number of the fast ions is also larger in the high-field side heating case. It is possible that the bulk heating by generated fast ions is larger in this case. This result agrees with the experimental result in the heating position change experiment.

1) H. Okada, T. Mutoh, et al., "Characteristics of ICRF Minority Heating for the Bumpiness and the Resonance Position in the Magnetic Field of Heliotron J", Proc. 18th ISHW, Jan. 29-Feb. 3 Canberra, Australia (2012) P3.14