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

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Main purpose of this study is to optimize ICRF heating position and heating mode in a helical-axis heliotron device, Heliotron J experimentally. Monte-Carlo simulation is also performed to clarify the heating and confinement mechanism, then, the establishment of the optimization technique is aimed. 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 high energy tail component in the standard configuration (STD) was not same at the upside and downside of the magnetic axis when the heating position was located on the inner side of torus. The high energy hydrogen flux is measured by the charge-exchange neutral particle energy analyzer (CX-NPA). In the on-axis case, no such tendency was observed. The distribution of high energy ions for the three bumpipnesses is measured by the CX-NPA in this study. 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.

The two dimensional CX-NPA scan for the line of sight is performed for the three bumpiness configurations in on-axis heating condition[1,2]. The scan region is from -2° to 12° for the horizontal angle and from -2° to 6° for the vertical angle. The toroidal position of the line of sight is changed in the horizontal angle scan as well as the pitch angle of the observed fast ions. The position of the line of sight in the oblique cross section is changed in the vertical angle scan. The experimental conditions are as follow: the magnetic field strength is 1.3 T, the line-averaged electron density is 0.4×10^{19} m^{-3} and the ICRF power of 0.25 MW is injected into a target plasma produced by a 70-GHz ECH of about 250 kW. The ion temperature at the center of the ECH plasma is about 0.2 keV. The minority ratio is about 10%. The frequency of the ICRF heating is 19 MHz for the medium and low bumpinesses and 23.2 MHz for the high bumpiness. The effective temperature of the minority high energy tail is estimated in the energy range from 1 keV to 6 keV.

The energy spectra measured by the CX-NPA at 0° in the horizontal angle are shown in Fig. 1. The vertical scan from -2° to 6° is performed. The angle of 6° corresponds to 0.4 in the normalized minor radius. The slope of the high energy tail of the minority hydrogen is small in the high bumpiness case. The slope is smallest at the vertical angle of 2°. That means the largest fast ions are observed in this location. In Fig. 1(a), the slope varies with the observed vertical angle. Such vertical angle dependence does not appear in Fig. 1 (b) and (c). In the low bumpiness in Fig. 1 (c), the slope is steep and there is little high energy component through all vertical angles.

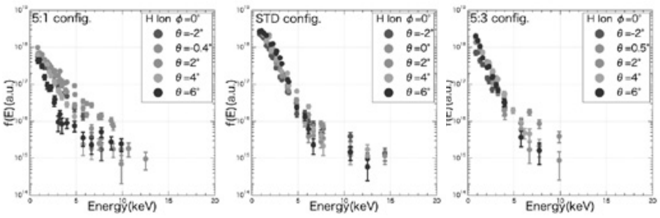

Fig.1 The vertical angle dependence of the energy spectra at 0° of the horizontal angle: (a) for the high bumpiness, (b) for the medium bumpiness and (c) for the low bumpiness.

The effective temperature of the fast minority hydrogen is shown in Fig. 2 for vertical angles and horizontal angles in the three bumpinesses. The line of sight passes the magnetic axis is positioned at about 0° in the vertical angle. For the most angles, the effective temperature of fast minority ions and the bulk ion temperature in the high bumpiness are highest among three configurations. In the high bumpiness case only, the minority effective temperature profile is asymmetrical against the magnetic axis at -2° and 3° of horizontal angle. The maximum effective temperature is 2 keV at -2° in the horizontal angle.

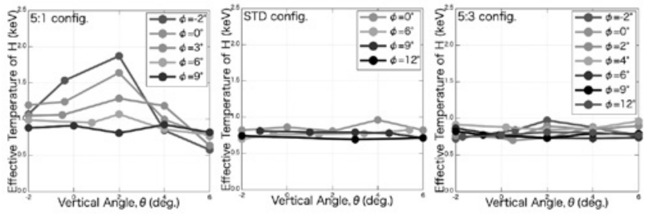

Fig. 2 The horizontal (ϕ) and vertical (θ) angle dependence of the effective temperature of the minority hydrogen: (a) for the high bumpiness, (b) for the medium bumpiness and (c) for the low bumpiness.

In the larger horizontal angle, the profile is symmetrical against the magnetic axis as in other two bumpinesses. Such profile is not observed in the medium and low bumpinesses. For the bulk ion temperature profile, no asymmetry is observed in all bumpinesses. In the Monte-Carlo simulation, the generation of fast ions in the high bumpiness configuration is largest among three configurations. Calculated pitch angle dependence agrees with the experimental result. The non-uniformity in the toroidal distribution is found only in the high bumpiness case. The analysis of the spatial distribution of the fast ions is in progress by comparing experimental data with simulation results.

1) H. Okada, T. Mutoh, et al., "Analysis of fast ions generated by the ICRF heating in Helitoron J", 29th JSPF Meeting Nov. 28-Nov. 30, Kasuga, (2012) 30E10P.
2) H. Watada, H. Okada, et al., "Spatial and Configuration Dependence of Fast-Ion Energy Spectrum by ICRF Heating in Helitoron J", 29th JSPF Meeting Nov. 28-Nov. 30, Kasuga, (2012) 30E22P.