§35. Study of Field Optimization of Fast Ion Confinement by Using ICRF Heating in Heliotron J

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Main purpose of this study is to optimize fast ion confinement by using ICRF heating in a helical-axis heliotron device, Heliotron J on the basis of results of several helical devices. 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 charge-exchange neutral particle energy analyzer (CX-NPA) in two directions. The experiment was performed in the minority heating using hydrogen and deuterium as a minority and a majority, respectively. The minority ratio is about 10%.

In Heliotron J, fast ion velocity distribution in the low density region has been investigated using fast protons generated by ICRF minority heating with special emphasis on the effect of the toroidal ripple of magnetic field strength (bumpiness) and heating position. The bumpinesses (B_{04}/B_{00}, where B_{04} is the bumpy component and B_{00} is the averaged magnetic field strength) are selected to be 0.15 (high) and 0.06 (medium, STD) at the normalized radius of 0.67 in this study. The high bumpiness among three bumpiness configurations was found to be preferable for the fast ion confinement in the low density experiment and two dimensional dependence of fast ion distribution was experimentally investigated. The result of fast ion observation should be analyzed including such effects and the configuration dependence of fast ion confinement and heating efficiency should be clarified.

Using Monte-Carlo method, the toroidal and poloidal dependence of the velocity distribution of minority hydrogen is calculated to comprehend the experimental results[1)]. The results of velocity distribution for three bumpiness configurations are shown in Fig. 1. The maximum velocity for each case corresponds to 20 keV in energy. In the toroidal dependence for the high bumpiness configuration, the high energy tail in the straight section is formed at 120° and 60° in pitch angle, however, only the tail at 120° is observed in the corner section. There is loss region near 90° in pitch angle for all configurations although the area differs for different cases. Therefore, the high energy tail is decreased at 90° for all cases. For the medium bumpiness, the toroidal dependence is very weak and the tail at 120° is dominant in every toroidal angle. For the low bumpiness configuration, the high-energy tail is smallest among three configurations and both peaks at 60° and 120° are observed. The high energy tail is larger in the outside area in the torus for every case. However, the change of energy spectra for various toroidal sections is little in each case.

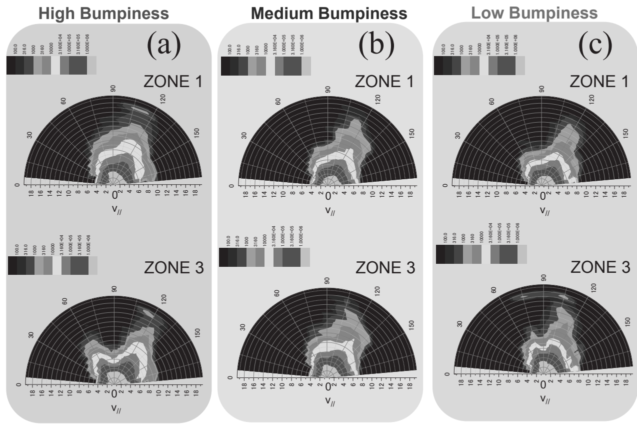

Fig.1. Velocity distribution for protons with the maximum energy of 20 keV. Zone 1 corresponds to the corner section and Zone 3 to the straight section for three bumpiness configurations; (a) high bumpiness, (b) medium bumpiness and (c) low bumpiness, respectively.

To extend energy range of fast ions, target plasmas are produced by EC + NBI heating with 1×10^{19} m^{-3} in the line-averaged density. The injected hydrogen energy E_0 of NB is 24 keV. The experiment is performed in the high bumpiness and low-ε_t configurations. In the measured energy spectrum of hydrogen without ICRF pulse, E_0, $E_0/2$ and $E_0/3$ peaks are observed. In this case, the line-of-sight of the CX-NPA is near the injection line of NB. The ion temperature of target plasmas is in the range from 0.1 keV to 0.2 keV. When ICRF pulse is imposed, the tail is substantially increased, then, E_0, $E_0/2$ peaks are covered by the enhanced fast ion flux. Two configurations, the high bumpiness and the low-ε_t, are investigated. In low-ε_t configuration, enhancement of high energy tail is larger than that in the high bumpiness configuration. The energy of detected high-energy hydrogen by the CX-NPA exceeds 50 keV near the injection pitch angle of NB in the low-ε_t configuration only. This configuration is considered to be most effective among the configurations examined for the ICRF minority heating in Heliotron J device. Wave propagation in Heliotron J plasmas is also in progress using TASK/WM code[2)].

1) H. Okada, et al., “Analysis of fast ion distribution generated by ICRF heating in Heliotron J”, Plasma Conference 2014, Nov.18-21, 2014, Toki Messe, Niigata, 21PA-016.

2) S. Murakami, et al., “Wave propagation analysis of ion cyclotron range of frequency heating in Heliotron J”, Plasma Conference 2014, Nov.18-21, 2014, Toki Messe, Niigata, 19PA-041.