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Analysis of Fast Ion Distribution Generated by ICRF Heating in Heliotron J
ヘリオトロンJにおけるICRF加熱で生成された高速イオン分布の解析

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In Heliotron J, the ICRF minority heating has been performed for the investigation of the fast ion confinement and bulk ion heating. The effectiveness of the toroidal ripple is confirmed in the measurement of the accelerated fast ions and positional dependense of the fast ions is oberved. The Monte-Carlo simulation is performed to understand fast minority ion behavior in Heliotron J plasmas. In this paper, the velocity distribution for three different configurations and the poloidal and toroidal dependense of fast ions is discussed.

1. Introduction

Main purpose of this study is to optimize fast ion confinement by using ICRF heating in a helical-axis heliotron device, Heliotron J (R_0 = 1.2 m, a = 0.1-0.2 m, $B_0 \leq$ 1.5 T) [1, 2, 3]. Fast ion confinement is one of the most important issues for helical devices where the field ripple is ordinary large. The magnetic field of Heliotron J is non-symmetric and characterized as the relatively large toroidal ripple.

The fast-ion velocity distribution has been investigated using fast protons generated by ion cyclotron range of frequencies (ICRF) proton-minority heating in Heliotron J with a special emphasis on the effect of the toroidal ripple (bumpiness) [4, 5] and the heating position [6]. The majority ion is deuteron in this study. From the fast protons and the bulk ion temperature measured by the charge-exchange neutral particle energy analyzer (CX-NPA), the high bumpiness is the best among the three bumpinesses, which are 0.15 (high), 0.06 (medium, STD) and 0.01 (low) at the normalized radius of 0.67 (B_{04}/B_{00}, where B_{04} is the bumpy component and B_{00} is the averaged magnetic field strength). From the line-of-sight scan measurement of the CX-NPA, the distribution of the fast ions has strong toroidal angle dependence in the high bumpiness configuration.

Initial results for Monte-Carlo simulations of fast ions (protons) has been obtained and the effects of the configuration were discussed, where the calculation was performed for the energy spectra in the region (< 20 keV) [5]. For the calculation of the pitch angle dependence up to 20 keV, the huge number of test ions is required. In this paper, the ions are summed up after the averaged energy for fast ions is saturated. It makes the number of test ions smaller to get the results since the calculation time step is very short comparing with the average energy saturation time. Then, the data of the huge number time steps can be utilized to reduce statistical error for the calculation results.

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2. Velocity Distribution Calculated by Using Monte-Carlo Code

Velocity distribution of the fast ions for the three bumpinsesses is calculated. After 1.5 ms, the averaged fast ion energy is almost saturated, then, the position and velocity for the fast ion is accumulated for 0.5 ms in the condition of the calculation time-step is 0.1 μs.

From calculated velocity and pitch angle, fast proton velocity distribution is estimated for the three bumpinesses. Figure 1 shows the contour plots of (a) for the high bumpiness, (b) for the medium bumpiness and (c) for the low bumpiness. Fast ion generation in the high bumpiness is the largest. This tendency is caused from the effectiveness of the bumpiness for the fast ion confinement in Helitoron J configuration. The pitch angle for the largest ion tail in each plot is not π/2 in all bumpinesses whereas the acceleration direction via ICRF heating is perpendicular. The reason for this result is there is relatively large loss region along perpendicular direction in low β condition of Heliotron J plasma. From this reason, the largest fast ions is seen at the pitch angle of 120° as the experimental observation [5].

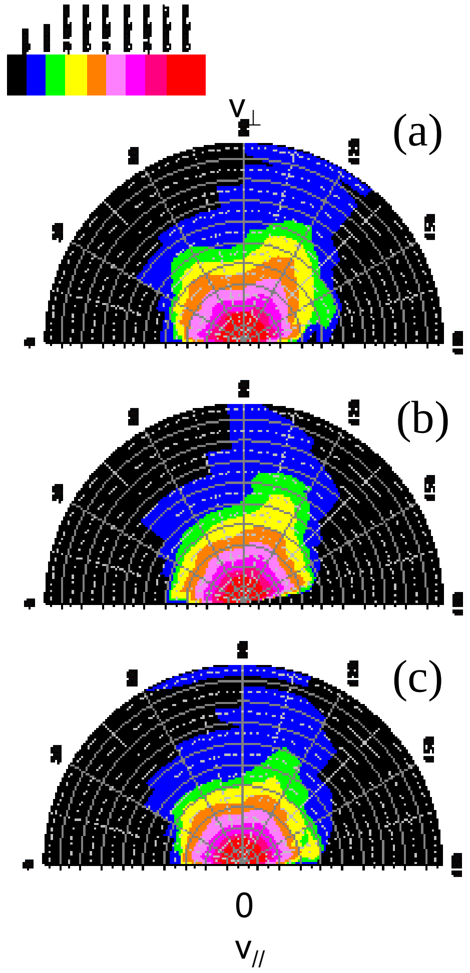

Fig.1. The contour plots of fast ion velocity distribution up to 20 keV for the three bumpinesses: (a) the high bumpiness, (b) the medium bumpiness and (c) the low bumpiness. Color map is made from the logarithm of the particle number.

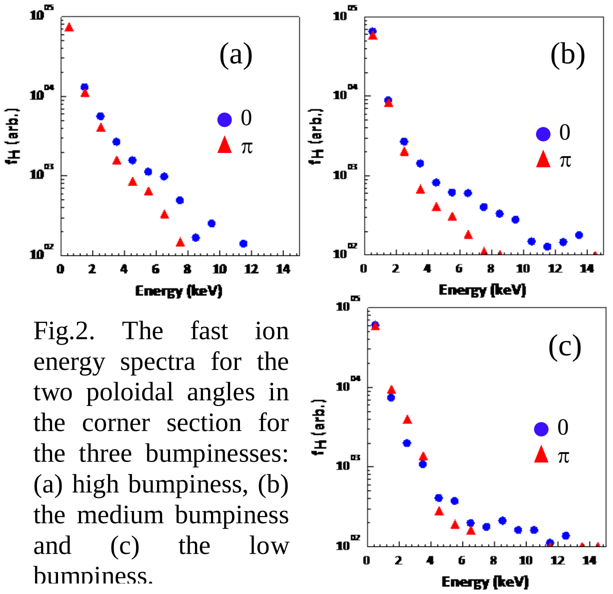

Fig.2. The fast ion energy spectra for the two poloidal angles in the corner section for the three bumpinesses: (a) high bumpiness, (b) the medium bumpiness and (c) the low bumpiness.

In Fig.2, the fast ion energy spectra at the poloidal angles of 0 and π in the corner section [5] are illustrated. The outer torus area corresponds to 0 in the poloidal angle. For all bumpinesses, more fast ions are confined in the outer region than in the inner region for the corner section. The difference of the fast ions between the two angles is large in the high and medium bumpinesses.

For the toroidal distribution of fast ions, the dependence is not so large since the mirror ratio is small. However, in the high bumpiness, the largest fast ions are observed in the corner section and the fast ions become smaller towards the straight section. There is little change in the toroidal direction for the medium and low bumpinesses. The large fast ion flux is observed in the experiment that the line-of –sight of the CX-NPA is directed to the corner section in the high bumpiness as the calculation result.

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References

[1] H. Sano, et al.: J. Plasma and Fusion Res. SERIES **3** (2000) 26.
[2] T. Obiki, et al.: Nucl. Fusion **41** (2001) 833.
[3] M. Wakatani, et al.: Nucl. Fusion 40 (2000) 569.
[4] H. Okada, et al.: Nucl. Fusion 47 (2007) 1346.
[5] H.Okada, et al.: PFR **6** (2011) 2402063.
[6] H.Okada, et al.: 19th ISHW2013, Padova, Italy.