23P026-P

Dependence of the ICRF Heating Efficiency on the Resonance Position in Heliotron J

ヘリオトロンJにおけるICRF加熱の共鳴位置による加熱特性の変化

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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. In the standard configuration, the fast minority ion was increased and the bulk ion temperature was decreased in the on-axis heating compeparing with inner-side heating case. This is not consistent with the scheme of the minority heating. The Monte-Carlo simulation is performed for the fast minority ions. The number of fast ions in the inner-side heating is larger in the relatively low energy region comparing with the on-axis heating case. The higher ion temperature is possibly caused from this condition.

1. Introduction

Fast ion confinement is a critical issue for helical devices, since magnetic field ripple is ordinarily large. 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) [1, 2, 3]. Fast ion velocity distribution in the low density region has been investigated using fast protons generated by ICRF minority heating in Heliotron J with special emphasis on the effect of the toroidal ripple of magnetic field strength and heating position. 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 as shown in Fig. 1 (a). From the measurement, the pitch angle dependence of the energy spectra for three bumpy configurations and the heating position dependence by changing rf frequency were reported [4, 5]. The high bumpiness was preferable for the fast ion confinement as expected. In medium bumpiness, the two conditions of cyclotron resonance layer location were performed. The positions of the resonance layers are shown in Fig.1 (b). The effective temperature of the minority proton in on-axis heating was higher than in the inner-side

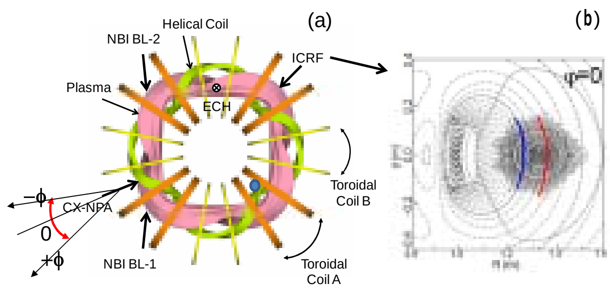

Fig. 1. (a) The arrangement of the heating systems and the CX-NPA. The horizontal angle of the CX-NPA is also illustrated. (b) The two positions of the fundamental resonance layer for minority protons in the ICRF antenna cross section. Red and blue lines indicate the on-axis heating case and inner-side heating, respectively.

heating; however, the bulk deuteron temperature was lower. It is not consistent with the minority heating scheme since most rf input power is absorbed by minority ions. In this report, the energy spectra in the function of pitch angle in the CX-NPA measurement and the Monte-Carlo simulation results will be discussed.

2. Energy Spectra of Generated Fast Ions and the Results of the Monte-Carlo Simulation

The rf frequency of 19 MHz is used for the on-axis heating and 23.2 MHz is for the inner-side off-axis heating. Target plasmas are generated by a 70-GHz ECH with about 300 kW of the injection power. An ICRF pulse is superposed during an ECH pulse. The ICRF power is about 280 kW and minority ratio is 0.1. Figure 2 (a) and (b) show the hydrogen energy spectra for the on-axis case and the inner-side case, respectively. In each figure, pitch angle dependence of the energy spectrum is indicated. The observed pitch angle is changed by

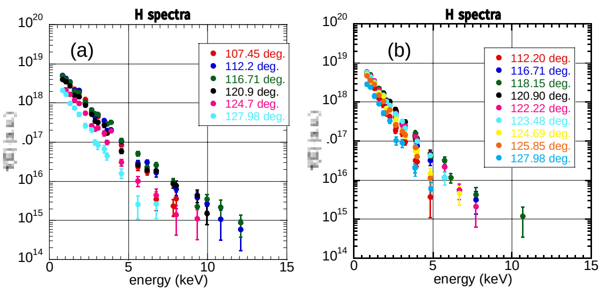

Fig. 2 Energy spectra measured by the CX-NPA in the function of pitch angle; (a) for the on-axis heating and (b) for high field side heating.

varying the toroidal angle, ϕ of the CX-NPA illustrated in Fig. 1 (a), keeping the condition that the line of sight crosses the plasma center. In the higher energy region more than 5 keV, the hydrogen flux in the on-axis heating case is larger than in the inner-side heating case for the wide range of pitch angle. The slope of the energy spectrum is steeper in the inner-side heating case than in the on-axis heating case even for the low energy portion.

To interpret the experimental results and to determine the fast-ion distribution in a plasma volume, Monte-Carlo simulations were performed. The numerical model includes orbit tracing, Coulomb collisions, and acceleration by ICRF heating. Minority protons are used as test particles and heating is simulated by the velocity kick in the perpendicular direction in velocity space when ions cross the cyclotron layer. In this calculation, the acceleration term for ICRF heating is proportional to the ICRF electric field amplitude, which is an input parameter. The electric field amplitude is determined from the input power for ICRF heating. The plasma parameters are $T_e(0)$ = 0.7 keV, $T_i(0)$ = 0.3 keV, $n_e(0) = 0.5 \times 10^{19}$ m^{-3}, and Z_{eff} = 3.0. The input rf field is adjusted so that the input power is about 100 kW in each case.

The energy spectra for the on-axis heating case are shown in Fig. 3 (a) and for the inner-side

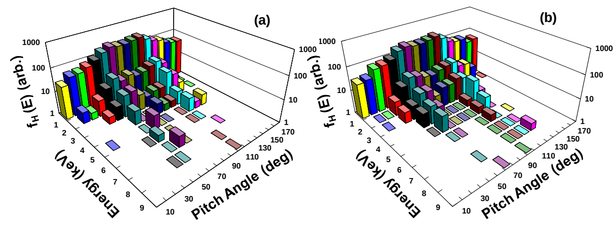

Fig. 3 The energy spectra in the function of pitch angle calculated using the Monte-Carlo code; (a) for the on-axis heating and (b) for high field side heating.

heating, in Fig. 3 (b). The difference of two cases is not so clear since the calculated energy range is not so large, neither. The minority ions at 3 keV in Fig 3 (b) is larger than that in Fig 3 (a). The minority ions are rapidly decreased above 3 keV in energy near 90° in pitch angle. This decrease is likely caused by the increase of loss region in velocity space because of the power absorption in the outer area in the plasma minor radius. The number of ions in the low energy is larger for the case of (b) than that for (a). It is possible that the ratio of the absorbed energy in ions to that in electron is larger in the case of (b). This is one candidate for the reason that the bulk ion temperature decreased instead of the increase of fast minority ions whereas the increase of the bulk ion temperature is caused mainly by the Coulomb collision between fast minority ions and bulk ions. The larger energy range simulation is under progress for further discussion.

Acknowledgments

This work is performed with the support and under the auspices of the Collaboration Program of the Laboratory for Complex Energy Processes, Institute of Advanced Energy, Kyoto University, the National Institute for Fusion Science (NIFS) Collaborative Research Program (NIFS04KUHL030 and NIFS04KUHL041), and JSPS KAKENHI 22560819.

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