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Wave Propagation Analysis of Ion Cyclotron Range of Frequency heating in Heliotron J

ヘリオトロンJにおけるイオンサイクロトロン周波数帯加熱の波動伝播解析

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In Heliotron J, ion cyclotron range of frequency (ICRF) heating has been performed to study fast ion generation and confinement. Understanding the property of wave propagation is necessary to realize high efficiency heating using ICRF waves. The dependence of the density, minority ion ratio and magnetic configuration on the wave propagation is investigated using three-dimensional wave analysis code TASK/WM. It is found that the radial wave length decrease as the minority ion ratio increases for f_{RF} = 19.0 MHz. For f_{RF} = 23.2 MHz, the wave length does not change, as the minority ion ratio increases. The wave propagation is calculated in the fully three-dimensional magnetic field of Heliotron J by using TASK/WM code for heating analysis.

1. Introduction

Ion cyclotron range of frequency (ICRF) heating is one of the major heating methods in nuclear fusion. In Heliotron J, ICRF heating experiments have been conducted to study fast ion generation and confinement, using minority ion heating scheme where the main ion is deuterium and the minority ion is hydrogen. Understanding the property of wave propagation and wave absorption is necessary to realize high efficiency heating by ICRF heating. The main purpose of this study is to clarify the dependence of density, minority ion ratio and magnetic configuration on the wave propagation and the wave absorption in ICRF heating. Three-dimensional wave analysis code TASK/WM is used to calculate and analyze radio frequency wave in Heliotron J plasmas, which are produced in the fully three dimensional magnetic field. Other study that uses TASK/WM code is the simulation study of ICRF wave propagation in JT60U plasma and LHD plasma [1].

2. Three-dimensional Wave Analysis Code TASK/WM

TASK/WM code solves Maxwell's equation for the electric field $\boldsymbol{E}$ in nonorthogonal coordinates.

$$\nabla \times \nabla \times \boldsymbol{E} = \frac{\omega^2}{c^2} \overleftrightarrow{\varepsilon} \cdot \boldsymbol{E} + i\omega\mu_0 \boldsymbol{j}_{ext} \qquad (1)$$

In Eq(1), $\overleftrightarrow{\varepsilon}$ is the dielectric tensor in nonorthogonal coordinates and $\boldsymbol{j}_{ext}$ is the surface current density on the antenna surface [1,2]. Figure1 shows the ReE_+ (the real part of left-circularly polarized component of electric field) in the Heliotron J plasma, which is calculated using TASK/WM. The input parameters are f_{RF} = 19.0 MHz, $\boldsymbol{j}_{ext}$ = 1.0 Am^{-1}, antenna minor radius R_{ANT} = 0.20 m, plasma major radius R_0 = 1.2 m , plasma minor radius a = 0.18 m , the magnetic field at magnetic axis B_0 = 1.25 T, the density at magnetic axis n_0 = 1.0×10^{-19} m^{-3}, and the minority ion ratio r_{min} = 10%. For the calculation, the cold plasma model is applied. The input frequency f_{in} was assumed as Eq (2) to include the damping.

$$f_{in} = (1 + i0.03) f_{RF} \qquad (2)$$

The black line outside the plasma in Fig.1 illustrates the vacuum chamber wall. The boundary conditions are as follows: the antenna current is three-dimensional current sheet, the wall is assumed to be perfect conductor and the wall position is defined from the extrapolation of the Fourier components of the outermost magnetic surface.

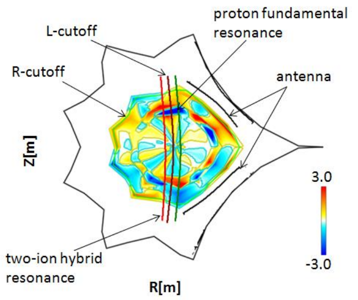

Fig.1. ReE_+ (the real part of left-circularly polarized component of electric field) of Heliotron J plasma

3. Wave Propagation Analysis for f_{RF} = 19.0 MHz and 23.2 MHz

The radio frequency of 19.0 MHz is applied for the on-axis heating and 23.2 MHz is used for the inner-side heating. Previous study shows that the effective temperature of the minority fast ion by the on-axis heating is higher than by the inner-side heating, and the deuterium temperature increase in the inner-side heating is higher than in the on-axis heating [3].

The minority ion ratio and the plasma density dependence on the wave propagation in Heliotron J plasma was investigated on the standard configuration for 19.0 MHz and 23.2 MHz.

First, the results for f_{RF} = 19.0MHz are shown in Fig.2 and Fig.3. Figure 2 shows the minority ion ratio dependence on ReE_+. In this case, the radial wave length decrease as the minority ion ratio increases. Figure 3 shows the plasma density dependence on ReE_+. In this case, the amplitude of the standing waves decrease as the plasma density increases, and increase as the density further increase again. This result can be caused that the increase in ReE_+ by the toroidal resonance of waves is observed.

Next, the results for f_{RF} = 23.2 MHz are shown in Fig.4 and Fig.5. Figure 4 shows the minority ion ratio dependence on ReE_+. In this case, the wave length does not change, as the minority ion ratio increases. Figure 5 shows the plasma density dependence of ReE_+. In this case, the radial and poloidal wave lengths increase as the plasma density increases.

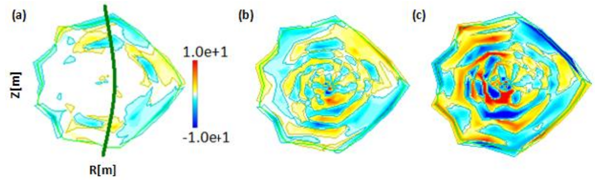

Fig.2. Minority ion ratio dependence on ReE_+ for f_{RF} = 19.0MHz: minority ion ratio (a) 5%, (b) 15% and (c) 20%.The fundamental cyclotron resonance layer for proton is also illustrated in the left figure.

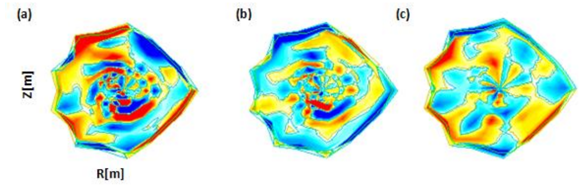

Fig.3. Plasma density dependence on ReE_+ for f_{RF} = 19.0MHz: (a) $n_e(0) = 2.0\times10^{-19}$ m^{-3}, (b) $n_e(0) = 3.0\times10^{-19}$ m^{-3} and (c) $n_e(0) = 5.0\times10^{-19}$ m^{-3}

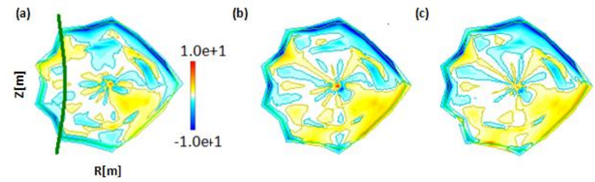

Fig.4. Minority ion ratio dependence of ReE_+ for f_{RF} = 23.2MHz: minority ion ratio (a) 5%, (b) 15% and (c) 20%

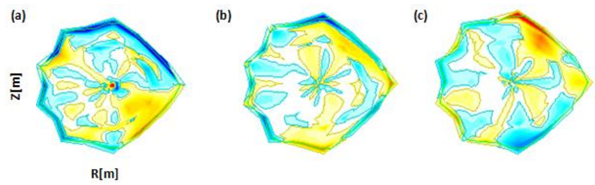

Fig.5. Plasma density dependence of ReE_+ for f_{RF} = 23.2MHz: (a) $n_e(0) = 1.0\times10^{-19}$ m^{-3}, (b) $n_e(0) = 2.0\times10^{-19}$ m^{-3} and (c) $n_e(0) = 5.0\times10^{-19}$ m^{-3}

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