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Study of Fast Wave Heating in LHD by Code Calculation

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Abstract

Ion cyclotron range of frequency (ICRF) heating is one of additional heating tools for LHD. Fast wave heating is main heating method in ICRF heating. We calculated the deposition profiles and electric fields using the two-dimensional helically symmetric global wave code for LHD plasma. By changing the minority fraction, the wave number parallel to magnetic field and the wave frequency, the cases that electron heating or ion heating is dominant are found out.

Keywords:

helical system, fast wave heating, full wave code, electron heating, ion heating

1. Introduction

Ion cyclotron range of frequency (ICRF) heating is planned as one of the additional heating for LHD and the whole ICRF system for steady state operation have been developed. The wave frequency is changeable from 25 MHz to 100 MHz and output power of 3 MW for steady state and 12 MW for pulse operation is expected. At the beginning, we will install two types of antenna; conventional loop antenna[1] and folded waveguide antenna (FWGA)[2]. The FWGA will generate the ion Bernstein wave and be used for plasma production in various magnetic field strength. The loop antenna will launch the fast wave and the main purpose is plasma heating.

In helical system, confinement of high energy ion is poor and the high energy ions produced by fast wave heating will escape from the plasma. Then, it is very difficult to get the good heating result in fast wave heating in helical plasma. It is important to prepare many heating scenarios and understand the wave behavior in helical plasma. In this paper, the fast wave heating is studied by code calculation.

2. ORION Code

We used ORION code to analyze the fast wave heating in helical system. This code was developed by Jaeger in Oak Ridge National Laboratory[3,4] and introduced to NIFS by US-Japan collaboration activity. This global wave code solves reduced-order-wave equations in two-dimensional helically symmetric magnetic field configuration. The upshift of wave number parallel to the line of magnetic force and heating by mode-converted ion Bernstein wave are neglected. This code has been used to analyze the experiment of ATF and Alcator C-mod, and so on. Figure 1 shows the position of cyclotron resonance layer for hydrogen in different wave frequencies. Amplitude of magnetic field is 3 tesla. Fast wave is launched from the high field side antenna drawn at the right side in the vacuum vessel.

3. Calculation Results

3.1 Large minority fraction case

Figure 2 shows the dependence of power absorption on rf frequency. Plasma density is 1×10^{20} m^{-3} and the temperature is 2.5 keV. Deuterium plasma includ-

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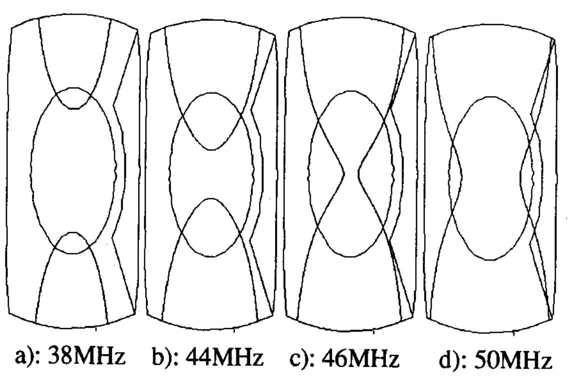

Fig. 1 Position of cyclotron resonance layer of minority ion.

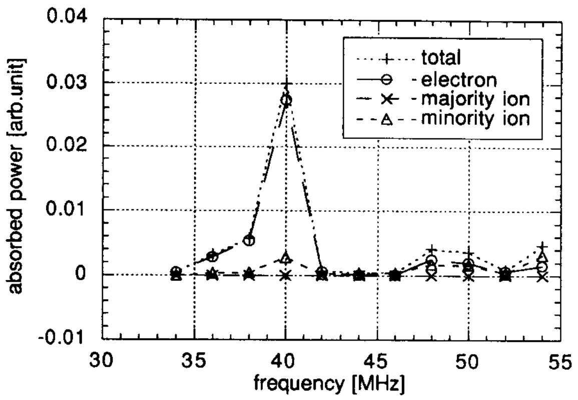

Fig. 2 Power deposition dependence on rf frequency in large minority fraction case.

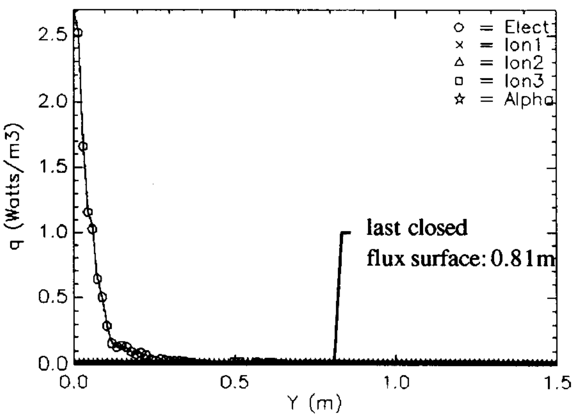

Fig. 3 Power deposition profile on flux surface in large minority fraction case. (40 MHz) Ion 1,2,3 indicate majority, minority, impurity (no impurity in this calculation), respectively.

ing 30 % hydrogen ion is assumed. Electron heating is dominant in a frequency lower than 43 MHz and higher than 47 MHz, where the cyclotron layer is located on the outside from a half of the plasma radius. The region in which electron heating is dominant moves inside of plasma as the fraction of minority ion increases. Figure 3 shows the power deposition profile on flux surface in 40 MHz case. The main electron absorption occurs at the plasma center through Landau damping / transit time magnetic pumping. In other frequency, electron absorption also occurs at the two-ion hybrid resonance, which is located on slightly high field side of the cyclotron resonance. In this case, the deposition profile in electrons becomes peaked at the off-center position. Since ion and electron absorption mechanisms are competitive, ion heating becomes predominant when the cyclotron resonance layer goes into plasma center region even in this electron heating dominant scheme. In helical devices, the high energy ions produced by fast wave heating escape from plasma[5]. To obtain the good heating efficiency by fast wave in LHD, the strong electron heating may have to be accomplished.

3.2 Small minority fraction case

Figure 4 shows the dependence of power absorption on rf frequency in small minority fraction case. All plasma parameters except minority fraction are the same as in the large minority fraction case. Fraction of minority ion is 3 % in this calculation. Power absorption by minority ion becomes strong as the cyclotron layer moves into the plasma core region. Figure 5 shows the deposition profile on flux surface at the frequency of 44 MHz. Dotted line shows the normalized

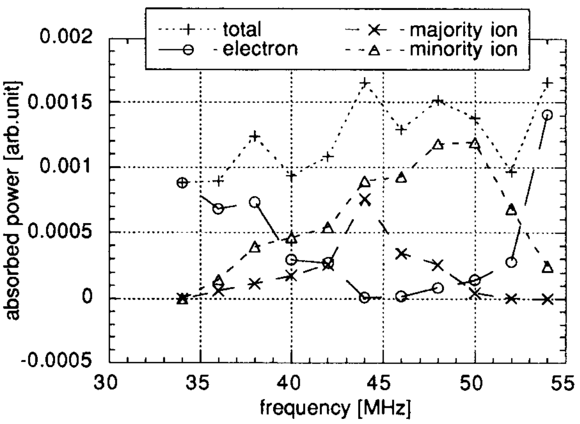

Fig. 4 Power deposition dependence on rf frequency in small minority fraction case.

total absorption. In this case, the cyclotron layer is located near the plasma core and ion heating concentrates on plasma center region. At the frequency of 46 MHz, one cyclotron layer is situated in front of the antenna (Fig.1c). Ion heating is stronger in this resonance layer than the other one. The peak of deposition profile moves to off-center position accompanied with the change of position of the resonance layer. Increase of minority absorption at the higher frequency side in Fig.4 attributes to the cyclotron layer which exists in front of antenna. Ion heating scheme interests to study the high energy ion loss in helical system. However, the existing helical devices meet a difficulty to reduce the ion concentration below 10 %.

3.3 Small $k_{\parallel}$ case

Smaller parallel wave number case is calculated in the same parameters as the case of large minority fraction. In this calculation, the parallel wave number is reduced to 2.4 from 8 in former calculations. Figure 6 shows the dependence of power absorption on rf frequency. The ion heating is dominant in almost all frequency region especially when the cyclotron layer is located in plasma center region. In 44 MHz case, the ion absorption occurs only at the cyclotron layer. Then, the deposition profile on flux surface at the frequency of 44 MHz shown in Fig.7 has a peak at off-center position. This result is different from the small minority fraction case in 44 MHz, where the ion absorption region moves to the plasma core. By changing the parallel wave number, the ion and electron heating is switched. However, at the start phase of LHD ICRF experiment only one set of loop antenna will be installed in the vacuum vessel and the parallel wave number is out of control.

4. Summary

Using the global wave code, ORION, the calculation about fast wave heating in LHD has been carried out. Ion and electron heatings are found out from survey of the plasma parameters. Electron heating is dominant when the fraction of minority ion is relatively high and ion cyclotron resonance layer is located on plasma peripheral region. Ion heating is dominant when the minority ion concentration is small and ion cyclotron resonance layer is located on the plasma core region.

Ion heating is also possible when the parallel wave number is small. In this calculation, the magnetic field configuration is different from actual one because of the two-dimensional calculation. It is very important to develop the three-dimensional calculation code to study the fast wave heating in helical system more precisely.

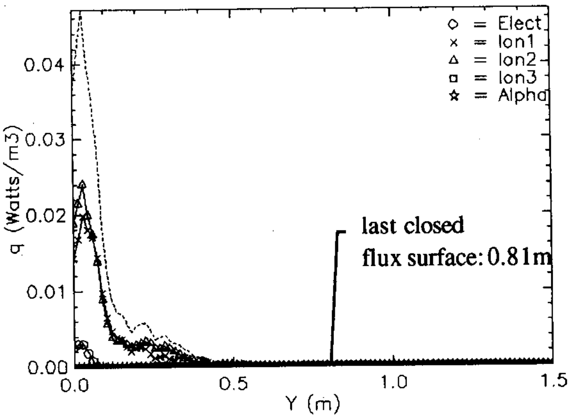

Fig. 5 Power deposition profile on flux surface in small minority fraction case. (44 MHz) Symbols are the same in Fig. 3.

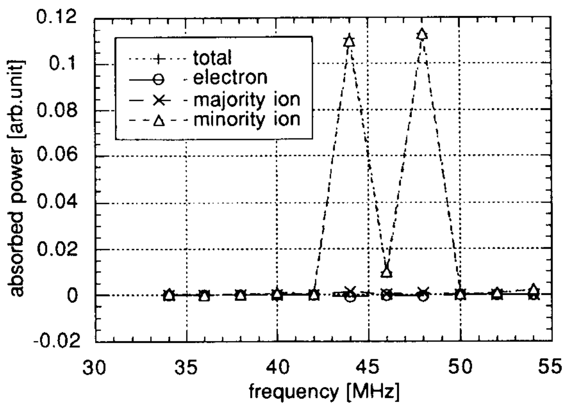

Fig. 6 Power deposition dependence on rf frequency in small parallel wave number case.

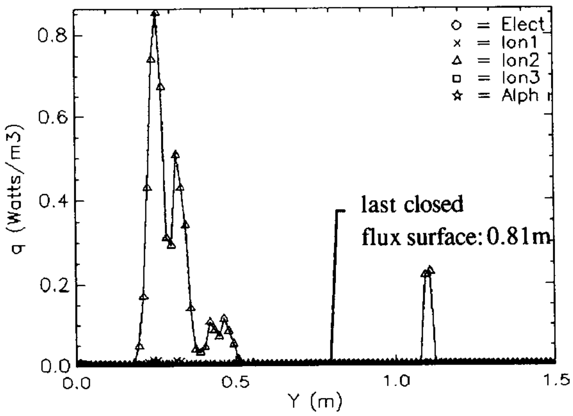

Fig. 7 Power deposition profile on flux surface in small parallel wave number case. (44 MHz) Symbols are the same in Fig. 3.

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